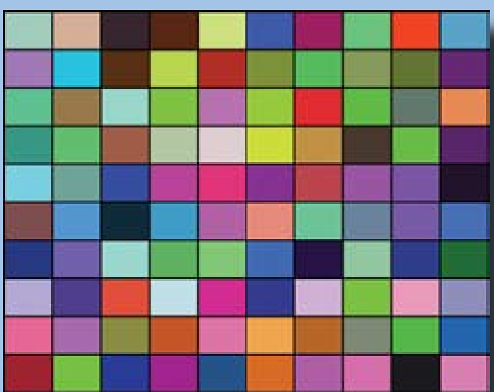
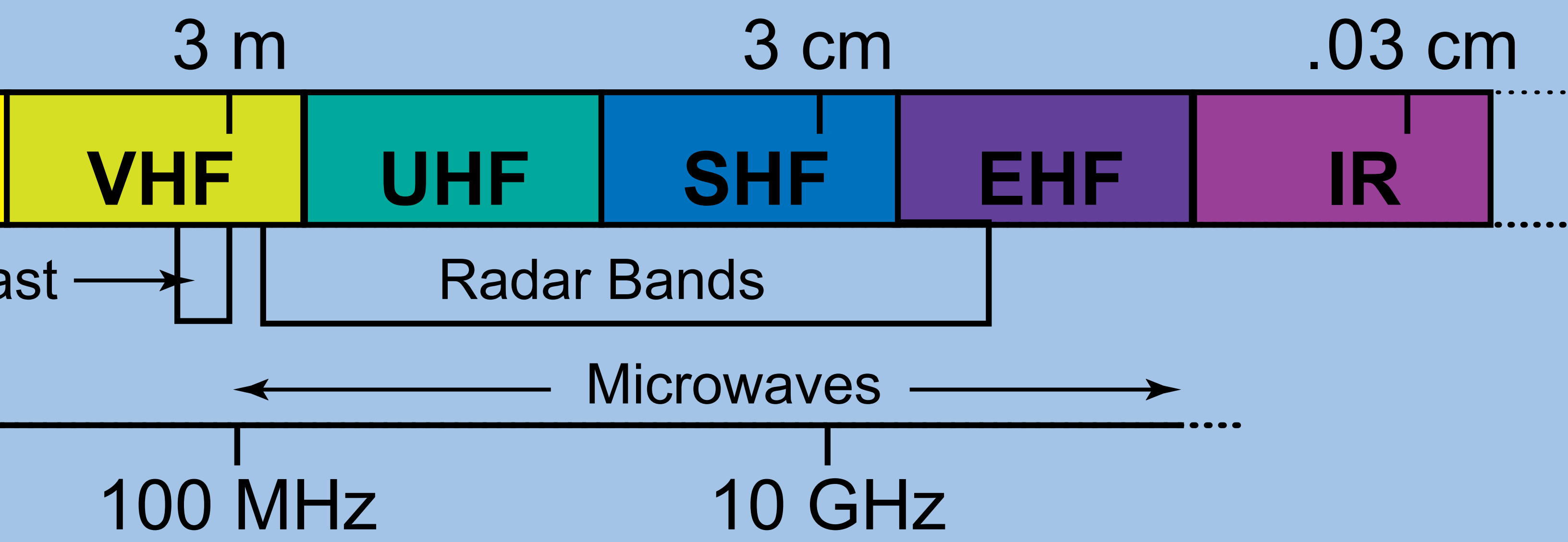
Institute for Telecommunication Sciences

2003

Technical Progress Report





Institute for Telecommunication Sciences

2003 Technical Progress Report

U.S. Department of Commerce
Donald L. Evans, Secretary

Michael D. Gallagher, Acting Assistant Secretary
for Communications and Information

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Contents

Summertime at the Department of Commerce Boulder Laboratories (photograph by F.H. Sanders).

The ITS Mission

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

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

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

ITS also maintains an Office of Research and Technology Applications (ORTA), established as a result of the 1980 Stevenson-Wydler Act. The ORTA assesses research and development projects for potential commercial applications, and makes information on Federal technologies available to State and local governments as well as private industry.

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.

ITS engineer installing an antenna at the Green Mountain Mesa field site (photograph by C. Redding).

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 2003 consisted of $6.0 million of direct funding from the Department of Commerce and approximately $4.7 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. CRPL moved to a new facility in Boulder, Colorado, in 1953.

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 within ESSA, 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; at the same time, ITS was transferred from ESSA to OT.

Finally, under the President's Reorganization Act #1 of 1977, OT and OTP merged to form NTIA. Since that time, 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.

Activities and Organization

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

- ***Spectrum and Propagation Measurements:*** ITS designs, develops, and operates state-of-the-art, automated spectrum measurement and propagation measurement systems; measures spectrum occupancy trends and patterns; measures emission characteristics of Federal transmitter systems; identifies and resolves radio frequency interference involving Federal systems; and performs radio propagation measurements for model development.
- ***Telecommunications and Information Technology Planning:*** ITS plans and analyzes existing, new, and proposed telecommunications and information technology systems and services, in order to improve the efficiency and enhance the technical performance and reliability of those resources.
- ***Telecommunications Engineering, Analysis, and Modeling:*** ITS evaluates and enhances the technical performance characteristics of existing, new, and proposed individual telecommunication systems, to improve their efficiency and enhance their technical performance.
- ***Telecommunications Theory:*** ITS develops and enhances innovative telecommunication technologies and engineering tools through the use of electromagnetic theory, digital signal processing techniques, models of human perception, propagation modeling, and noise analysis.

ITS's research and engineering work is supported by the ITS Director's Office, which promotes the laboratory's mission nationally and internationally. The Director's Office also provides general guidance and support to the program, budget, and administrative functions of the Institute. ITS also maintains an NTIA liaison function to provide advice and assistance to NTIA on preparation for and participation in national and international conferences and negotiations. In addition, the liaison coordinates technical research of the laboratory with other Federal agencies, e.g., the Department of Homeland Security's National Communications System.

Outputs

Major outputs of the Institute's research and engineering activities include:

- **Engineering Tools and Analyses:** Predictions of transmission media conditions and equipment performance; test design and data analysis of computer programs; and laboratory and field tests of experimental and operational equipment, systems, and networks.

- **Standards, Guidelines, and Procedures:** Contributions to and development of national and international standards in such areas as network interconnection and interoperation, performance evaluation, and information protection.

- **Research Results:** Mathematical models for electromagnetic wave propagation, noise, and interference characterization.

- **Expert Services:** Training courses and workshops to communicate technology advances and applications to industry and Government users.

Benefits

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

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

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

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

- **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.

- **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.

- **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.

- **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.

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. Agencies within the Department of Defense provide a significant portion of the Institute's other agency funding. Other major sponsors include the Department of Homeland Security, the Department of Transportation, the National Weather Service, the U.S. Coast Guard, and the National Institute of Standards and Technology.

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 is able to 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 2003 to both the public and private sectors.

An ITS technician preparing an antenna for the RSMS broadband over power line measurement task in a residential neighborhood (photograph by B. Bedford).

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 understanding 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 of radio signals to support research and engineering enabling more efficient and effective use of the spectrum. Major tools in this work 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, industry, and other Federal agencies.

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 develops RSMS-4 measurement hardware and software capabilities to provide RSMS-4 systems with greatly improved measurement and digital signal processing modes. 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 special 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 DTV measurements, background noise research, 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. Recently this work is 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 types of common shared radio systems. This work is funded by NTIA.

Ultrawideband Regulatory Support
The Institute continues measurements to characterize ultrawideband (UWB) devices and interference to conventional radio systems. Current work includes measurements of devices that mix UWB techniques with frequency-hopping or other modes and technical consultation on proposed regulatory changes. The project is funded by NTIA.

Radio Spectrum Measurement System (RSMS) Operations

Outputs

- Measurements to determine emission characteristics of a maritime surface search navigation radar.
- Measurements to determine emission characteristics of pulsed frequency hopping signals used in advanced designs of an automotive collision avoidance radar.
- Measurements to verify bandwidth correction factor equations applied to various ultrawideband signals.
- Measurements to determine emission levels of broadband signals transmitted over power lines.

The Radio Spectrum Measurement System (RSMS) and its associated measurement operations are the result of an ongoing commitment of the National Telecommunications and Information Administration (NTIA) to accomplishing four critical spectrum management missions:

1. Measure the extent, patterns, and amounts of radio spectrum usage in the United States (through specialized measurements of individual bands and through broadband spectrum surveys).
2. Measure the radio emission characteristics of individual transmitters to ensure compliance with existing regulations. These transmitters include — but are not limited to — radars, communication links, and navigation transmitters.
3. Measure the electromagnetic compatibility (EMC) characteristics of Government and non-Government transmitters and receivers. These characteristics are used by NTIA's Office of Spectrum Management (OSM) to design band allocation specifications that maximize benefits and minimize future interference problems.
4. Resolve interference problems in cases where a Government radio system may be involved as a victim or interferer.

ITS's RSMS Operations Project is expected to respond to requests for evaluation of these issues through engineering, measurements, and analyses.

In October 2002, ITS used its state-of-the-art spectrum measurement capabilities to measure the spectrum emissions of a maritime surface search navigation radar at the Table Mountain Field Site and Radio Quiet Zone facility north of Boulder, CO. The measurements were performed for two reasons: (1) to determine the rate at which unwanted emission levels varied as a function of measurement bandwidth; and (2) to determine the amount of change that occurred in the shape of the radar spectrum when measurements were performed within the near field limit of the radar antenna. The results were used by NTIA/OSM, presented at the 2003 International Symposium on Advanced Radio Technologies (ISART), presented to the ITU-R Working Party 8B Radar Correspondence Group in London, UK, in June 2003, and will appear in an upcoming NTIA Report on measurement of radar emissions for compliance with the Radar Spectrum Engineering Criteria (RSEC).

In February 2003, NTIA personnel from ITS and OSM worked jointly with the Federal Communications Commission (FCC) and a private sector company to perform measurements on emissions from an advanced design of an automotive collision avoidance radar at the FCC lab at Columbia, MD. The measurements were performed to characterize the radar's spectrum emissions in radio bands that are used by some remote sensing satellites. Results were used by multiple Government agencies to determine the impact that such radar operations might have on some remote sensing satellite operations.

In May 2003, personnel from ITS performed measurements on simulated pulsed frequency hopping signals to further characterize emissions of advanced automotive collision avoidance radars. Results of these measurements were used by NTIA to develop certification measurement procedures to determine compliance with the FCC's emission limits.

Also in May 2003, ITS personnel conducted measurements on various ultrawideband (UWB) modulated signals to verify bandwidth correction factor

RSMS-4 performing measurements of broadband over power line in a residential neighborhood in September 2003 (photograph by B. Bedford).

equations that were the outcome of earlier modeling. The results of these measurements were used by OSM in response to the FCC's requested comments regarding a further notice of proposed rulemaking on UWB.

In June 2003, ITS personnel transported a portable radar spectrum measurement system to a facility in the United Kingdom for a comparative set of measurements on radar spectrum emissions. The measurements, performed near Portsmouth, were made side-by-side with a UK system that had been designed from concepts originated by ITS engineers. The comparative measurements were performed to determine whether two independently designed and constructed measurement systems would show the same spectrum result for the same radar. The results from the two systems (US and UK) were comparable and within the experimental error bounds of the systems.

Starting in August 2003 and continuing into FY 2004, ITS personnel performed measurements to determine the radio emission levels from broadband over power lines (BPL). This is a new technology that transforms power lines into network cables that can deliver broadband content over unshielded wires. Two field measurements, each lasting approximately 2 weeks, were conducted at different sites (see figure above). The data from these measurements will be used by NTIA in developing a response to a notice of proposed rulemaking issued by the FCC.

In September 2003, ITS personnel performed antenna pattern measurements on a National Weather Service (NWS) radar. The measurements were performed to assist the US Administration with a technical Contribution to ITU-R Working Party 8B, which deals with maritime mobile, aeronautical mobile, and radiodetermination services.

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RSMS-4 Development

Outputs

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

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

The new RSMS 4th generation measurement vehicle (photograph by W.A. Kissick).

VEHICLE

A new measurement vehicle makes it possible to perform measurements efficiently and effectively. The vehicle 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 (where noise originating inside the vehicle could contaminate the measurements). Internet connections and routers are located throughout the enclosure, along with fiber optic control lines, multiple power outlets, and overhead cable racks. Three full-height instrument racks are available, with ample counter space, storage space, and head room. The racks can be moved forward for rear access, locked into place, or removed entirely.

The vehicle is powerful, easy-to-handle, and has sleeping space in the cab. A 20-kilowatt diesel generator provides for all electrical power demand, including full heating and air conditioning for extreme climates. Internet and shore power connections on the outside of the enclosure allow easy hook-up to local facilities. There are three 10-meter telescoping masts — two in the rear and one in the front. Extra brackets on the roof make it easy to mount antennas. All of this is accessible through a wide rear door and retractable staircase with handrails.

HARDWARE

Much new measurement equipment has been added, which provides substantial improvements to the already extensive inventory of measurement tools. The heart of the measurement system is four new spectrum analyzers that have excellent RF characteristics and powerful new digital signal processing capabilities. Two new vector signal analyzers (VSAs) allow 14-bit digitization in a 36-MHz IF bandwidth, backed up with an extensive software suite to perform complex signal analysis and demodulation. Two new, stand-alone, VXI-based channel analyzers allow surveying the radio environment, as well as digital acquisition when signals meet specified characteristics. They can also be used to trigger analysis by the VSAs. Also included are high speed digital signal processing chips that can be programmed for advanced detection criteria using open-architecture software.

Two new quad-input digital oscilloscopes with a front-end bandwidth of 500 MHz and maximum sampling rate of 8 GS/s have special smart-triggering capabilities and segmented memory. The latter allows efficient acquisition of pulsed signals with small duty cycles. Another new digital oscilloscope with a front-end bandwidth of 1 GHz and maximum sampling rate of 5 GS/s has specialized peak and sample detection capabilities, making it suitable for wide bandwidth acquisition and analysis — including pulsed signals. Finally, two new preselectors have been designed and tested and are currently under construction. They will filter and amplify, improving system sensitivity and allowing operation in large-signal environments.

SOFTWARE

The RSMS-4G software has an open-ended architecture that allows nearly unlimited expansion in many possible directions. Integral to this flexible architecture are instrument and measurement dynamic link libraries (DLLs). DLLs have been developed for several key pieces of measurement equipment (including spectrum analyzers, oscilloscopes, and preselectors). These DLLs contain command/query modules that interpret standardized commands common to the different equipment categories and a Virtual Front Panel that provides a user-friendly graphical interface for “manually” controlling the device via the computer. These DLLs, when completed, will provide a basis for rapid development of automated measurements with a wide range of instruments.

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 (BPL) measurements: a calibration procedure, a stepped frequency measurement, and an APD measurement.

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Table Mountain Research

Outputs

- Digital television field strength and video quality study.
- Radar emission spectrum measurements performed using new ITS-developed measurement system.
- Software for the simulation of non-Gaussian noise processes typically observed in urban and residential environments.
- Software to compute and plot the third- and fourth-order statistics of noise processes.

The Table Mountain Field Site and Radio Quiet Zone supports fundamental research into the nature, interaction, and evaluation of telecommunication devices, systems, and services. To achieve this goal, the Table Mountain Research Project actively solicits research proposals both from within ITS and from external organizations. This research serves to expand the knowledge base available to ITS, 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 technical reports, journal articles, conference papers, web documents, and computer programs. Some highlights of the technical program in FY 2003 are presented below.

DTV Field Strength and Video Quality Study

In 2003, concerns that existing power limits placed on the broadcast industry might limit the availability of digital television (DTV) formed the basis for a DTV field strength and video quality study. In this study, a simulated home mounted on a flat bed trailer (see figures below) was used to compare the quality of a video signal received inside the structure at various locations around the area. The simulated home was used to eliminate the variability inherent in multiple structures, limiting the results to effects due to location and incident signal level. A DVD recording of the video signal was made with field strength levels included, and the results were summarized in an NTIA Technical Memorandum (see **Recent Publications** on next page).

Figure 1. Outside (top) and inside (bottom) of the ITS "Tool Shed Measurement System," used in the DTV field strength and video quality study (photographs by W.A. Kissick).

Characterization of Man-made Noise

Since the late 1960's, ITS has characterized man-made noise from measurement results. The first approach estimated amplitude statistics with hardware detectors, which were designed and built to measure average amplitude, root mean square amplitude, peak amplitude, and average logarithmic amplitude. Subsequent systems made use of an instrument to measure the complementary cumulative distribution or amplitude probability distribution (APD) with hardware circuitry. This instrument provided an estimate of first-order amplitude statistics that could be used to calculate amplitude statistics difficult to detect with hardware, such as the median amplitude. Today this instrument is routinely emulated in software using amplitude samples measured with a spectrum analyzer.

Unfortunately, for complete characterization, even the simplest Gaussian random process needs second-order statistics, e.g., those found in the auto-correlation function and corresponding power spectral density, in addition to the first order statistics of the APD. Man-made noise processes, often much more complex, need even higher-order statistics such as third- and fourth-order cumulants and corresponding poly-spectra. These higher-order statistics are based on complex noise voltage samples such as those obtained with a modern vector signal analyzer.

In FY 2003, the Table Mountain Research project completed several tasks to help engineers understand the importance of higher-order statistics in characterizing man-made noise. First, software was written to generate non-Gaussian noise processes previously observed in urban/residential environments. Next, software was written that calculated and plotted the third- and fourth-order statistics of these simulated random processes.

Currently there is much interest in evaluating methods to share the radio spectrum. Ultrawideband modulation and “junk bands” based on spectrum sharing etiquettes are but two examples. Since interference due to these methods is likely to be non-Gaussian, it is expected that knowledge of the higher-order statistics will be useful to both designers building demodulators and regulators writing emission specifications. In FY 2004, the Table Mountain Research project plans on measuring noise in existing junk bands to further the study of the importance of higher-order statistics.

Radar Emission Spectrum Measurements

Radar transmitters produce some of the highest effective radiated power levels in the entire radio spectrum. Therefore it is critical that radar emission spectra be accurately measured for conformance with emission masks such as the NTIA Radar Spectrum Engineering Criteria (RSEC). With that goal in mind, a program for the development of radar emission spectrum measurements has been established at the Table Mountain research facility. Although it is necessary to coordinate such temporary high-power measurements with other "quiet zone" users, this coordination is usually easily accomplished. Advanced measurement techniques (both hardware and software) are used to measure emissions from actual radar transmitters.

In FY 2003, an X-band maritime surface search navigation radar was brought to Table Mountain and a set of measurements were performed using the new ITS RSMS-4. Additional radars are expected to be brought there for measurement, and additional research into radar emission measurements will be performed in FY 2004.

Recent Publications

J. W. Allen and T. Mullen, “Digital television (DTV) field strength and video quality study,” NTIA Technical Memorandum TM-03-405, Aug. 2003.

F. Sanders, “Dependence of radar emission spectra on measurement bandwidth and implications for compliance with emission mask criteria,” in “Proceedings of the International Symposium on Advanced Radio Technologies,” J. W. Allen and T. X Brown, Eds., NTIA Special Publication SP-03-401, Mar. 2003.

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Spectrum Efficiency Research

Outputs

- Development of signal capacity model.
- Signal capacity results for Washington, DC area.

NTIA is the Executive Branch agency responsible for spectrum management of Federal users. As demand for spectrum has increased, NTIA and the Federal Communications Commission (FCC) have continued to examine ways to improve the efficient use of the spectrum. For example, in June 2003, President Bush released a new initiative that directs the development of a radio spectrum policy for the 21st century to better manage the Nation's airwaves, enhance homeland security and economic security, increase benefits to consumers, and ensure U.S. leadership in high-tech innovations.

A major use of Federal spectrum is to support communications with agents from many different agencies. Typically, each separate Federal agency builds a mobile radio system, which it uses to talk with its own agents. Because there are so many of these independent radio systems, NTIA has worked hard to make these systems work more efficiently, studying and promoting isolated individual technical efficiency factors,[1] with arguably only moderate success. ITS and NTIA's Office of Spectrum Management (OSM) determined that greater improvements in Federal spectrum efficiency might be obtained by studying broader aspects of how agencies provide services to their mobile users. Specifically, we decided to compare the relative effectiveness of the many single-agency mobile radio systems now used to a possible future radio system shared between multiple agencies.

Since the 162-174 MHz band near Washington, DC is the most intensely used Federal mobile radio band, we decided to study it first. The first phase of the study (described in these pages) analyzes current Federal use of the radio spectrum by developing a quantitative model of the "signal capacity" (SC) of agency use. The second phase — planned for completion next year — will use these quantitative results to develop modern alternatives to the current individual agency systems. Depending on the apparent overall benefits predicted, one or more concepts could be selected for further development.

[1]R.J. Matheson, "A survey of relative spectrum efficiency of mobile voice communications systems," NTIA Report 94-311, Jul. 1994.

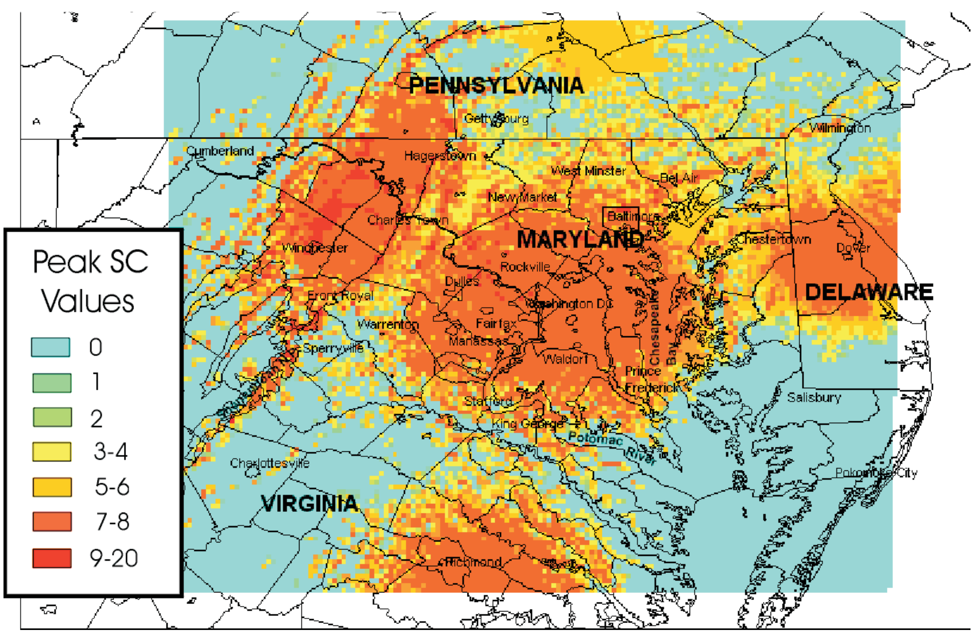

Figure 1. Example of peak signal capacity map for a few selected Federal agencies.

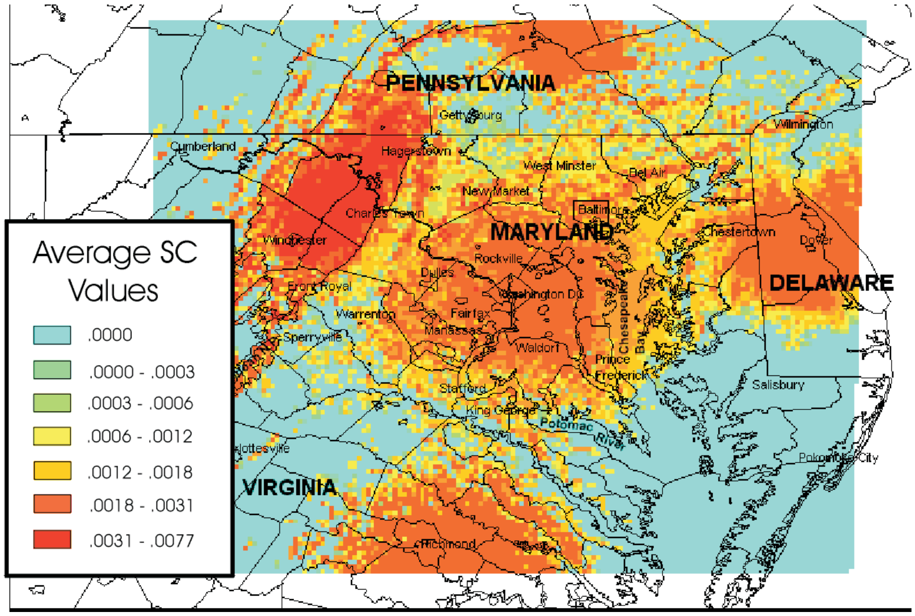

Figure 2. Example of average signal capacity map for a few selected Federal agencies.

The signal capacity model counts the number of independent radio channels that can be received by a mobile user at every location near Washington, D.C. Maps of signal capacity values for all Federal agencies were assembled, and examples are shown in Figures 1 and 2. Although the signal capacity data could have been derived in several ways (e.g., RSMS channel occupancy measurements at multiple sites), we decided to use the Government Master File (GMF) of all federal radio licenses with propagation coverage prediction programs to obtain the needed data. The GMF contains reasonably complete data on all Federal transmitters, and a terrain-based Longley-Rice model was used to calculate signals from each transmitter at 1-mile increments over an area 200 miles on a side.

Different signal capacity algorithms were developed for various mobile radio architectures, dependent on how the SC values added if adjacent sites in a network both provided coverage to a single location. In simulcast systems and some repeater systems, the coverage from adjacent sites provides the same signal content, so coverage from adjacent sites does not increase SC values. However, other architectures (e.g., trunked radio systems) provide independent signals from adjacent sites, so SC values increase according to coverage from multiple sites. Following much coordination with agency representatives, NTIA personnel assigned specific “function codes” to each GMF entry, which told the SC computer program how data from each assignment was to be analyzed. Once the SC values are calculated for a network of assignments, maps from individual networks can be added together on a point-by-point basis to get SC maps for much large collections of users.

Figure 1 (on the previous page) shows an example of a Peak SC map for a few selected Federal agencies in the Washington area. Note that a Federal user in downtown Washington or at outlying Federal installations could receive as many as 20 independent signals. Many rural areas have much smaller SC values; in fact, there are many areas that could not receive any signals at all from the selected group of agencies.

Figure 2 (above) shows a similar map of Average SC values, produced from Average SC network maps of the same selected agencies. Average SC maps contain values showing the average number of independent users per square mile that could be supported by the analyzed radio networks. The average SC maps will allow site capacity to be scaled according to the coverage area of that site in follow-on system design work based on these maps. The ratio of peak SC to average SC values gives an approximate measure of the coverage area of typical sites. In this case, for example, the maximum graphed values are peak = 20, average = .0077. The ratio between these values shows a typical site coverage area of 2900 square miles, corresponding to a circle with a radius of 29 miles.

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Ultrawideband Regulatory Support

Outputs

- Comments to NTIA on many proposed changes in UWB regulations.
- Monitoring ITU-R activities in UWB Task Group 1/8.
- Measurements to better understand new mixed-mode UWB devices.

In May 2000, the Federal Communications Commission (FCC) released a Notice of Proposed Rule Making on ultrawideband (UWB) systems, asking for a wide range of information on these systems, interference from these systems, and proposals for how to regulate them. At that time, technical opinion differed widely on how UWB systems interact with traditional radio systems, and how they should be regulated. In FY 2000 and 2001, ITS staff made extensive measurements to characterize UWB device emissions. ITS staff also made extensive measurements on UWB interference to various types of GPS receivers. This work was summarized in NTIA Reports 01-383, 01-384, and 01-389.[1] Closely following this work, engineers at NTIA's Office of Spectrum Management (OSM) used ITS measurements to predict how UWB devices would interfere with Federal systems and GPS. These predictions were summarized in NTIA Special Publications 01-43, 01-45, and 01-47.[2]

[1]W.A. Kissick, Ed., "The temporal and spectral characteristics of ultrawideband signals," NTIA Report 01-383, Jan. 2001.
J. R. Hoffman, M.G. Cotton, R.J. Achatz, R.N. Statz, and R.A. Dalke, "Measurements to determine potential interference to GPS receivers from ultrawideband transmission systems," NTIA Report 01-384, Feb. 2001.
J.R. Hoffman, M.G. Cotton, R.J. Achatz, and R.N. Statz, "Addendum to NTIA Report 01-384: Measurements to determine potential interference to GPS receivers from ultrawideband transmission systems," NTIA Report 01-389, Sep. 2001.

[2]P.C. Roosa, Jr. , et al., "Assessment of compatibility between ultrawideband devices and selected Federal systems," NTIA Special Publication 01-43, Jan. 2001.
D.S. Anderson, E.F. Drocella, S.K. Jones, and M.A. Settle, "Assessment of compatibility between ultrawideband (UWB) systems and Global Positioning System (GPS) receivers," NTIA Special Publication 01-45, Feb. 2001.
D.S. Anderson, E.F. Drocella, S.K. Jones, and M.A. Settle, "Assessment of compatibility between ultrawideband (UWB) systems and Global Positioning System (GPS) receivers (Report Addendum)," NTIA Special Publication 01-47, Nov. 2001.

The technical and commercial communities continue with many activities needed to more exactly (and often more broadly) define the operational parameters for UWB devices. Although few actual commercial UWB devices have been sold to the public yet, many devices have been under intensive technical review. These include proposed 802.11 devices operating near the 5-GHz band and short-range automotive radars operating near 24 GHz. Since many of the proposed UWB devices will use UWB modulation mixed with frequency hopping (FH) or other modulations, there has been much activity in clarifying how these "mixed modes" should be characterized and regulated. The FCC released a Memorandum Opinion and Order and a Further Notice of Proposed Rule Making on March 12, 2003. This document proposed many significant changes in the details of how various mixed-mode devices should be categorized and measured. ITS has continued monitoring these proposed changes for technical implications and providing comments to NTIA for possible policy changes.

ITS also participated in the activities of ITU-R Task Group 1/8, dealing with issues of defining and regulating UWB devices on an international basis. Although UWB devices are typically very short range and would not normally require international regulation, such devices are also very transportable and devices manufactured for use in one country could easily find their way into many other countries. Therefore, TG 1/8 is studying UWB devices to understand their operation and to discuss ways to develop compatible standards for such devices.

ITS has also made additional measurements on several types of UWB devices in FY 2003 to help clarify NTIA's understanding of UWB devices. One series of measurements provided information on how measurement readings change when the pulse repetition frequency (PRF) of a UWB device approaches the bandwidth of the measurement system. This information was needed to more precisely analyze possible UWB interference.

A series of measurements were also made by ITS on a short-range 24-GHz automotive radar that incorporated short pulses and frequency hopping. The measurement test set-up is shown in Figure 1. Although the tested device included many possible operational modes, a typical pulse lasted 0.3 microseconds and had a bandwidth of about 4 MHz. The remainder of the 500-MHz minimum bandwidth needed to allow the device to be included under the UWB rules was obtained by frequency-hopping the pulse over a 500-MHz range. This UWB device is an example of several new devices that meet some UWB characteristics, but operate somewhat differently from a pure UWB device. The need to make correct decisions about how such devices should be measured, and what limits should be applied to them, furnishes the motivation to undertake these measurements of various prototype devices.

Figure 2 shows an emission spectrum of the automotive radar when measured with an RMS detector having various integration times. It is typical of such measurements that "arcane details" like measurement integration time can significantly affect the numeric readings of procedures intended to set limits on the level of signals produced by these devices. Therefore, it is necessary to carefully note proposed regulatory changes in measurement details along with the specification of numerical limits on device emissions.

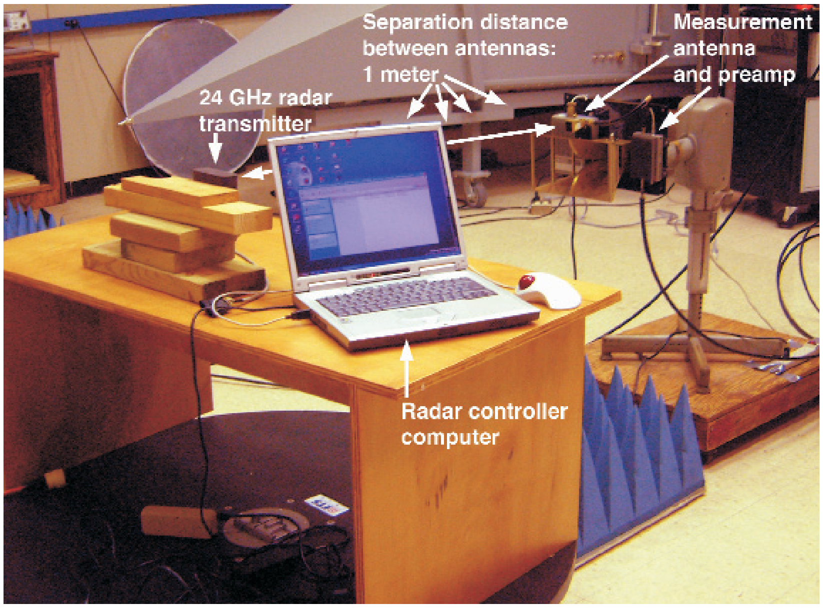

Figure 1. 24-GHz radar setup (photograph by F.H. Sanders).

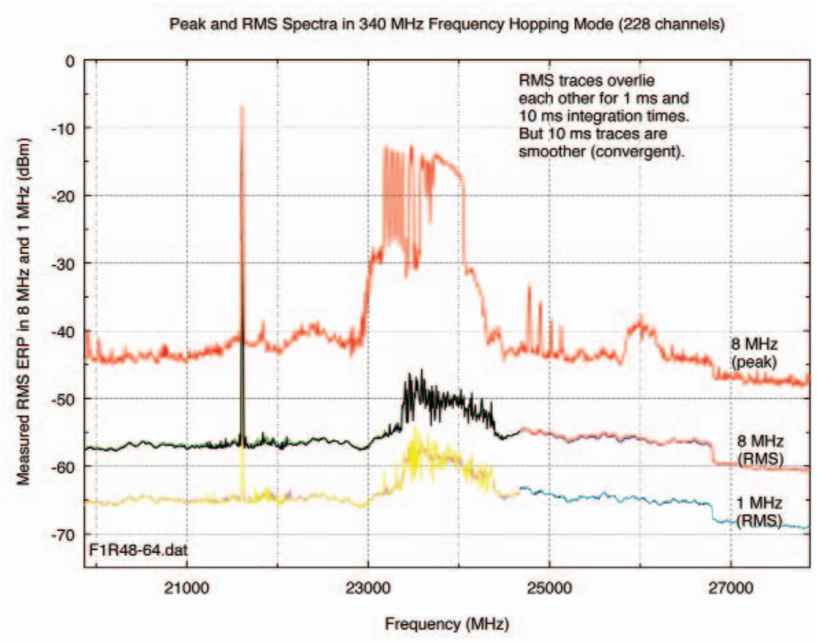

Figure 2. Emission spectrum of 24-GHz radar.

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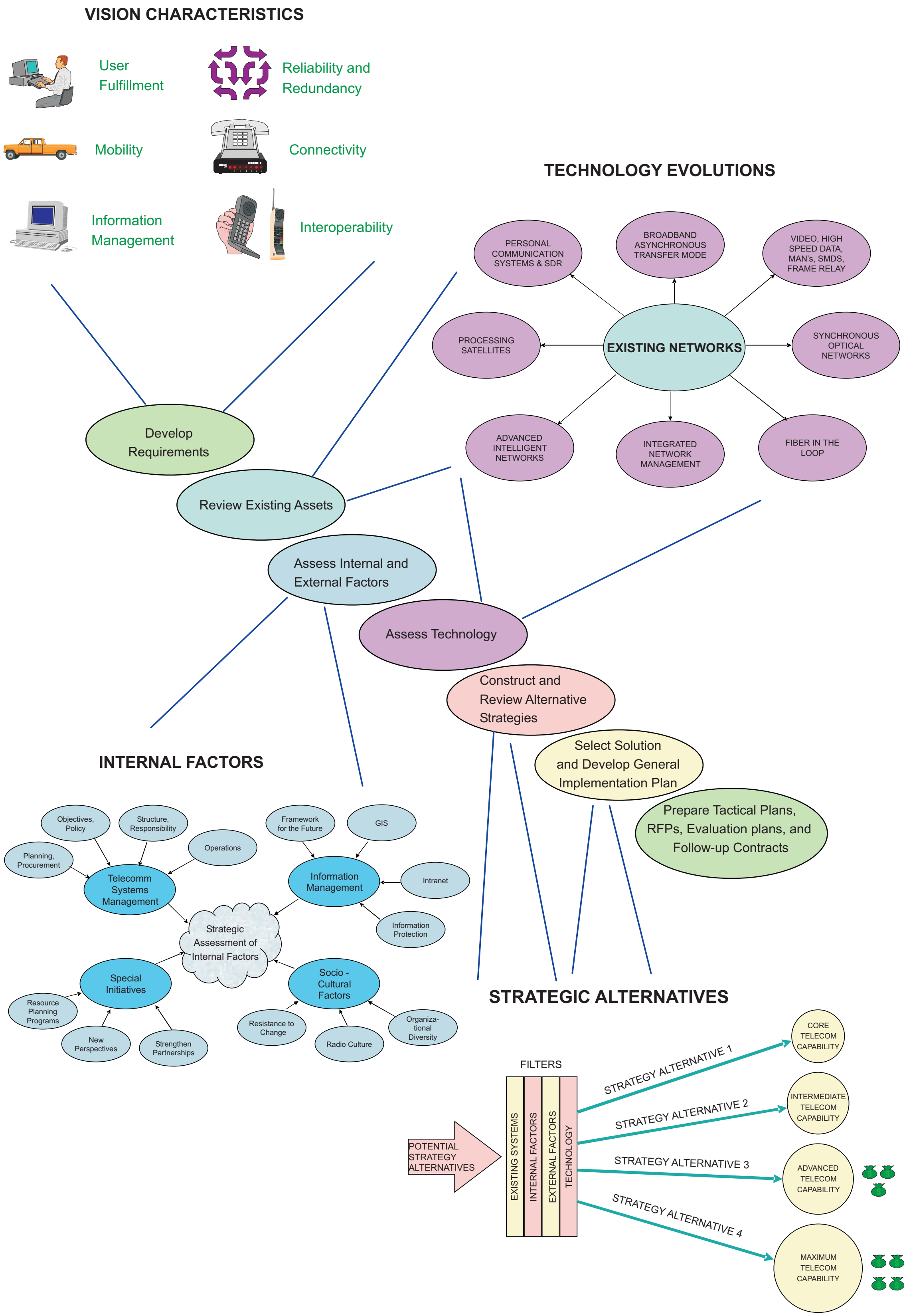

Overview of the telecommunications and information technology planning process.

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.

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 below, include: **Engineering Support and Coordination**, **Information Technology Interoperability Standardization**, and **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, and security/protection issues. This project is funded by NTIA.

Railroad Telecommunication Planning
The Institute performs radio infrastructure system planning in support of a high-speed rail pilot program, and demonstrates digital land mobile radio technology and infrastructure, compliant with TIA-102 standards. The Federal Railroad Administration funds this project.

Voice Over IP
The Institute develops technical contributions related to Internet Protocol (IP) telephony gateways and their supporting infrastructure for the TIA TR41 Standards Formulating Group. This project is funded by NCS.

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.
- Summit on Interoperable Communications for Public Safety.

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, 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) AGILE Program, Department of Justice Office of Community Oriented Policing Service (COPS), National Communications System (NCS), Public Safety Wireless Network (PSWN) program, Federal Law Enforcement Wireless Users' Group (FLEWUG), and NTIA.

Standards Support

ITS provides contributions to several standards development organizations supporting justice, public safety, and homeland security goals. The proposed technical solutions offered in such contributions are validated in the Institute's Interoperability Research Laboratory (IRL). This process will be especially useful in the coming year for Project 25/Telecommunications Industry Association TR-8 interface definition work.

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 and State government agencies were feasible and consistent with long-term interoperability strategies. Evaluations were conducted on behalf of NIJ's AGILE Program, SAFECOM, the COPS Program, and the Department of Homeland Security's Emergency Preparedness and Response Directorate.

Figure 1. An ITS engineer conducting performance measurements on digital land mobile radio equipment in the ITS Interoperability Research Laboratory (photograph by E. Gray).

Figure 2. An ITS engineer making equipment configuration changes on land mobile radio base station equipment in the ITS Interoperability Research Laboratory (photograph by E. Gray).

Test and Evaluation

The IRL has been designed to accommodate a wide variety of testing requirements for public safety applications that have arisen, are occurring now, or are expected in the near future. Interoperability and performance testing of standardized products has already commenced (e.g., for Project 25 radio equipment) with portable, mobile, base station, and repeater equipment being scrutinized in the conventional mode of operation (see Figures 1 and 2). (Trunked system operation will be investigated in FY 2004.) Test and evaluation has also been done on an interim interoperability solution (a crossband technology device) and on a hybrid network product (that interconnects a radio frequency network to the Internet). T&E in all of these areas will continue in earnest during FY 2004. In addition, laboratory assessments of R&D concepts and prototypes are expected to occur next fiscal year, with some emphasis being placed on the examination of software defined radio functionality.

Technical Coordination

On behalf of its sponsors, ITS planned, conducted, and documented the *Summit on Interoperable Communications for Public Safety* that was held at NIST in Gaithersburg, Maryland, on June 26/27, 2003. With the purpose of coordinating technical efforts related to wireless telecommunications and information technology interoperability, over 50 different Federally-supported programs, and 104 representatives, were located and invited, and participated in the summit. It was the first opportunity for program managers to share viewpoints regarding public safety communications and interoperability. To facilitate further coordination among participants, a briefing book was produced for all attendees that contained salient information about all of the programs, and what particular public safety requirements each program was targeting. Information on the summit is available at http://pssummit.its.bldrdoc.gov.

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, economic benefit studies, etc. During FY 2003, ITS compared the performance and application of conventional radio systems against trunked radio systems for public safety applications. A technical report providing the results has been drafted and is undergoing internal ITS review. Once released, it will help guide agencies as to the advantages and disadvantages of each system for particular operational scenarios.

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

Outputs

- Support to Global Justice Information Sharing Initiative.
- Administration of Justice Standards Clearinghouse on-line.
- XML Data Model and Data Dictionary development.

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

The 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) AGILE Program, and the Department of Justice Office of Community Oriented Policing Service (COPS).

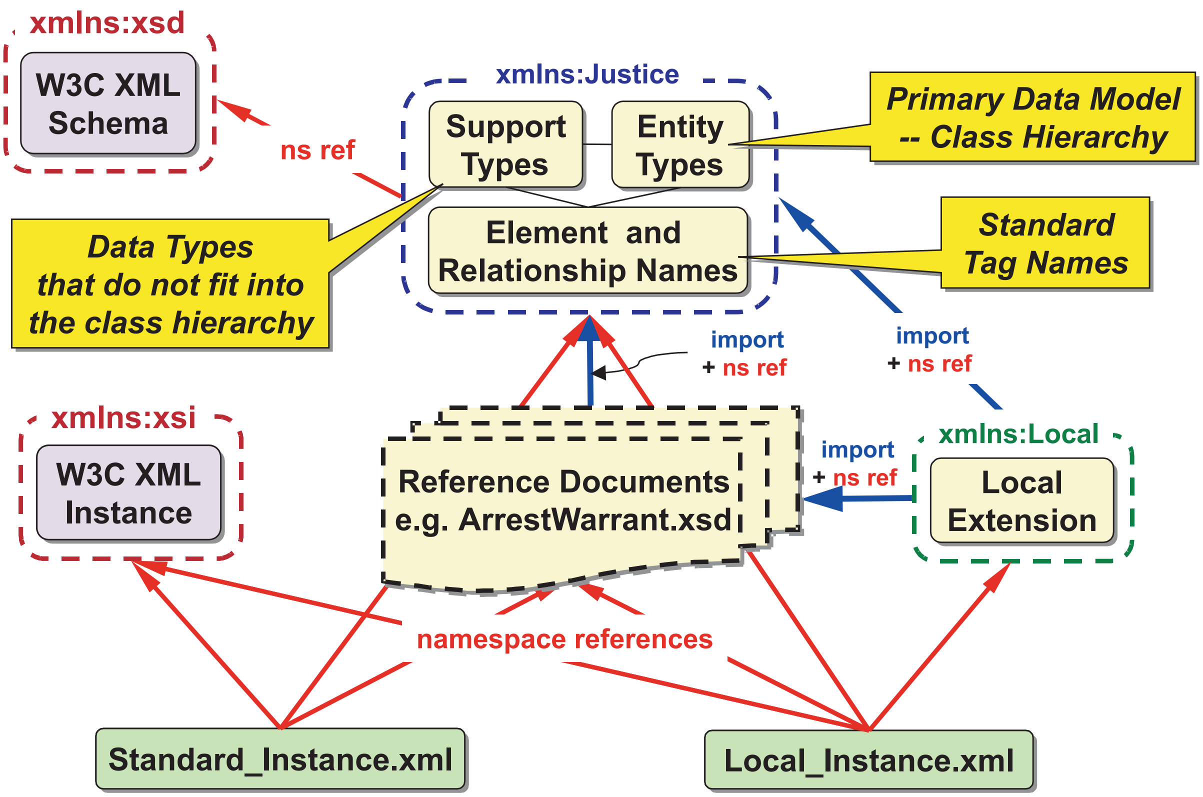
Support to Global Justice Information Sharing Initiative

The Global Justice Information Sharing Initiative (Global) is a group of groups representing all practitioners in the justice community (e.g., law enforcement, courts, corrections, prosecutors, defenders, etc.; see http://it.ojp.gov/global/index.html). In particular, ITS worked with Global's Infrastructure/Standards Working Group (GI/SWG) on a wide variety of tasks. The most significant of those is the background work needed to develop a nationwide architecture for information sharing among the justice and public safety communities. Significant progress has been made on the architectural framework and related strategic plan. The GI/SWG is currently in an iterative process to ensure that the elements of the framework can accommodate current and future information sharing requirements of the practitioners at the local, State, Federal, and tribal levels.

Administration of the Justice Standards Clearinghouse On-Line

Also in conjunction with Global, ITS designed and tested the prototype web page and search engine for the Justice Standards Clearinghouse (JSC), a repository of IT and communication standards and specifications. The JSC is designed to assist public safety agencies in sharing information and communicating productively through increased awareness and accessibility of standards. This has been achieved by making the technical specifications and standards — as well as user comments regarding those standards — available to the practitioners via an online standards clearinghouse. The clearinghouse is hosted on the Office of Justice Programs (OJP) Website at http://it.ojp.gov/jsr/public/index.jsp.

Currently there are more than 70 standards and specifications available for public access in the clearinghouse, and ITS is playing an ongoing role in the addition of new standards through administration of the site and validation of the data that is entered there.



Structure of the justice/public safety/homeland security XML Data Model.

XML Data Model and Data Element Dictionary Development

In prior years, ITS had played a significant role in providing technical assistance and coordination in the initial development of an 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 FY 2003, the XML development work skyrocketed, with an order of magnitude increase in the size of the Data Element Dictionary and the development of an associated Data Model.

The development of an XML Data Model is a significant step forward in achieving information sharing 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 figure above shows the structure of the justice/public safety/homeland security XML Data Model. The core of the Data Model is the XML Data Element 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. A beta version of the dictionary is currently available for public comment at http://it.ojp.gov/jxdd .

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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.

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 and State public safety practitioners to collegially design a nationwide strategic plan for wireless interoperability, and (3) the identification and/or development of standards that address the defined requirements and are in concert with the strategic plan. Standardization efforts are aimed at allowing local, State, and Federal agencies to exchange information, without requiring substantial changes to internal systems or procedures.

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) AGILE Program, Department of Justice Office of Community Oriented Policing Service (COPS), National Communications System (NCS), Public Safety Wireless Network (PSWN) program, Federal Law Enforcement Wireless Users' Group (FLEWUG), and NTIA.

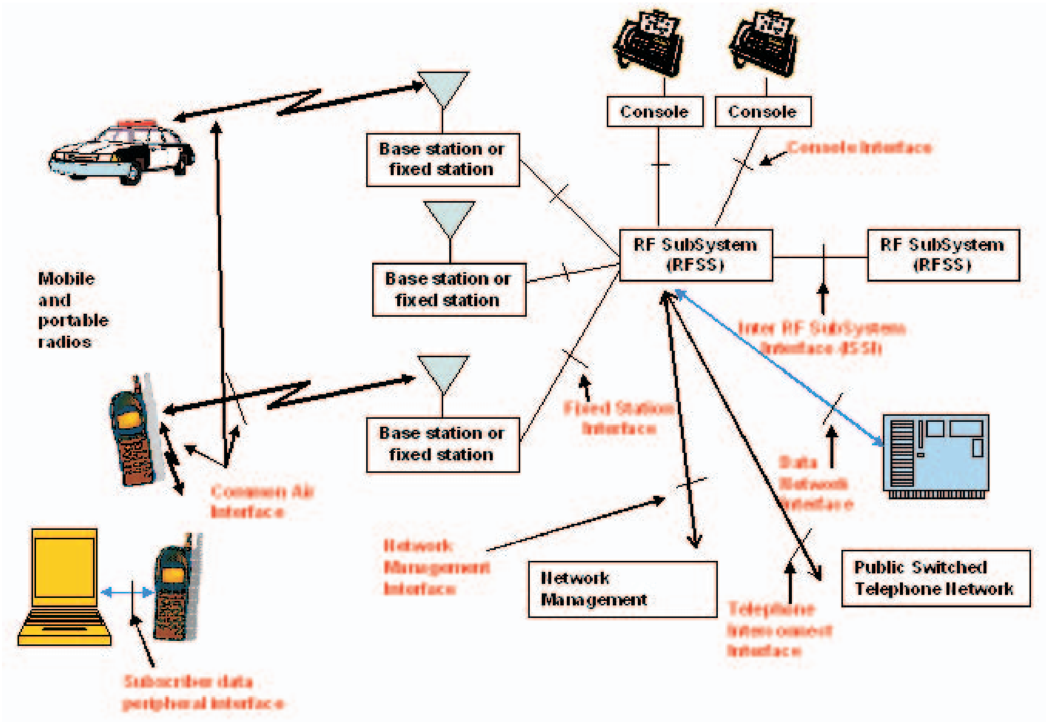
Wireless Telecommunications Statement of Requirements (SOR)

No comprehensive set of wireless telecommunication requirements has been written for public safety since the highly regarded PSWAC (Public Safety Wireless Advisory Committee) Final Report was published in 1996. Yet, 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. Therefore, on behalf of the public safety community, ITS took the lead in developing a contemporary SOR during the latter half of FY 2003. By the end of the fiscal year, several sections were drafted, with a final product targeted for practitioner review on or about January 1, 2004.

In general, 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 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 Strategic Planning

Through its sponsors, the Institute is supporting the development of a nationwide strategic plan for wireless 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, 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.



Project 25 system interfaces.

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, 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 2" work is now addressing interoperability standards for narrowband (6.25 kHz channel) digital LMRs, the specification of interface standards for (Phase 1) 12.5-kHz digital LMRs also continues. "Phase 3" (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 wideband 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 wideband mobile applications. To date, the Institute has provided user operational requirements to Project MESA. These requirements represent the United States position.

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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.
- Report to NCS on baseline computer simulations for network survivability and ETS studies.

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 several projects, including Packet-Switched Networks, and Network Survivability and Restoral. For both of these projects, computer simulation, 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 for ANSI-accredited Technical Subcommittee T1A1. Within this project, an ITS engineer served as co-editor of a new T1 technical report: T1.TR.79-2003 “Overview of Standards in Support of Emergency Telecommunications Service (ETS).” An ITS engineer is now serving as editor on three new draft Standards and Technical Reports related to ETS in T1A1.2.

Traditional analysis methods are not adequate to predict the effects of large service outages in the current and future network environments. Therefore, ITS is using network modeling and simulation tools to address the needs of T1A1.2, NS/EP, and the Nation. While modeling and simulation are powerful tools for the assessment of threats

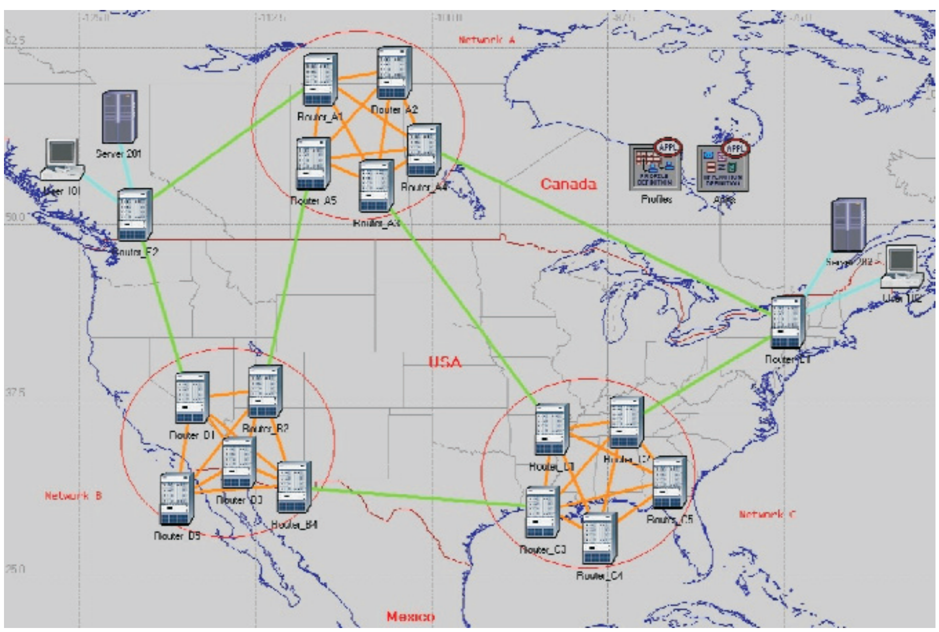

Figure 1. Simulation for testing routing protocols.

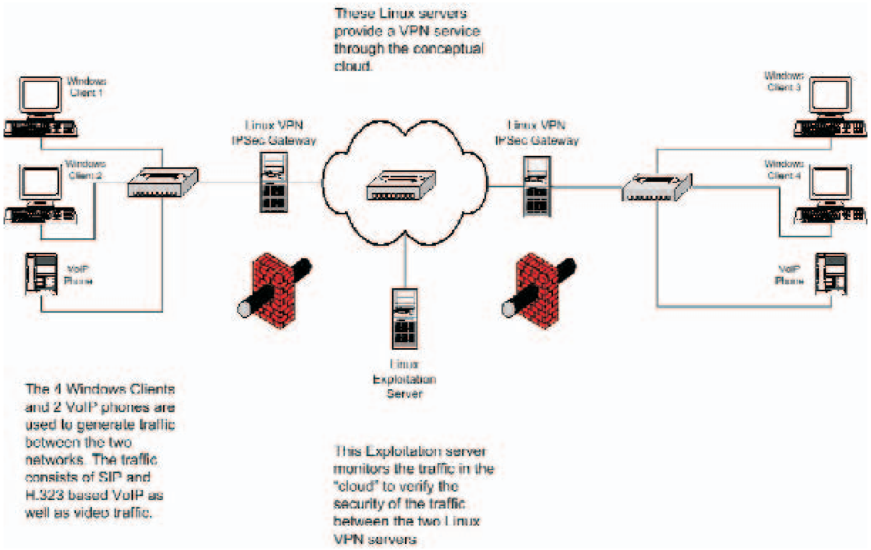

Figure 2. Laboratory setup for testing security and ETS protocols.

and mitigation techniques, the simulations must be well grounded in the physical measurement of important parameters. One goal of the project has been to produce baseline models for reference network architectures that can be used in standards development as well as in future network research by ITS and others. Figure 1 on the previous page shows a model developed to investigate aspects of routing protocols. In Figure 1, the orange lines represent links that are internal to a network and use an Internal Gateway Protocol (IGP). The green lines represent links that connect the different networks. These links use an External Gateway Protocol (EGP) such as BGP4. Within a network, most of the nodes will share the same network prefix, so the IGP can optimize the route that a packet takes to the destination node once it arrives in the network. An EGP exchanges higher-level information between networks so that the packets can be sent to the appropriate network for distribution. The BGP4 protocol has some convergence issues that this simulation, and similar ones, can help to identify.

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 just recently been standardized and they are 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 Recommendation J.TDR, "Requirements and Specifications for Telecommunications for Disaster Relief over IPCablecom Networks," in Study Group 9.

Another important study underway at ITS is a series of tests of GETS over IPCablecom networks. The evolution of GETS from a PSTN-only service to one which 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. Figure 2 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 2004, ITS will continue to address work on the development and standardization of ETS in T1A1, 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 2004 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

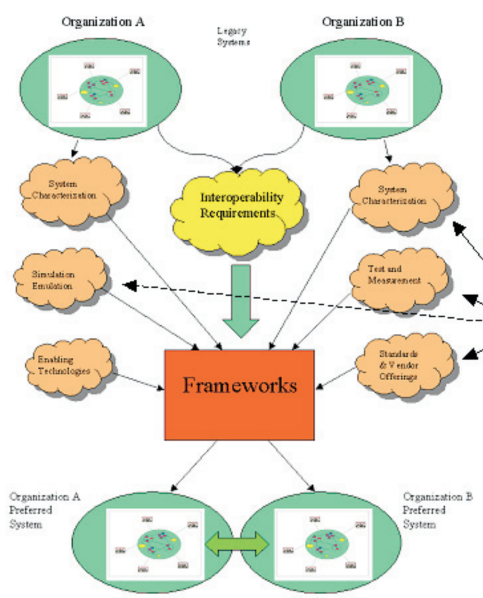
Outputs

- Definition of structured planning process for telecommunication and IT networks.
- Suggestions for types of tools to assist in network design and administration.
- Definition of a structured approach for applying tools and methods in the analysis of network interoperability issues.

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. The previous two years' work focused on the selection and use of a suite of neworking 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 examining tools and methods useful in supporting two important aspects of network design and administration: network management and network security. This past year's efforts focused on the development of a structured approach to applying these tools, along with a systems engineering method to address the complex issue of network interoperability.

Network Interoperability

From a technical networking perspective, network interoperability involves the migration of existing (Legacy) systems which are not interoperable to current (Preferred) systems which are interoperable. Interoperability is a knowledge dimension (see Figure 2 on next page) of network systems engineering involving the technical ability of two or more cooperating networks at a given point in time to satisfy users' telecommunication needs (e.g., exchange of user information at specified quality levels). The ability to characterize and analyze network interoperability depends significantly on characterizing and understanding the following issues:
1. A complete understanding of the interoperability problem domain including an understanding of interoperability requirements and the problems generated by these requirements. An understanding of the organizations from which these requirements emerge. A thorough understanding of the



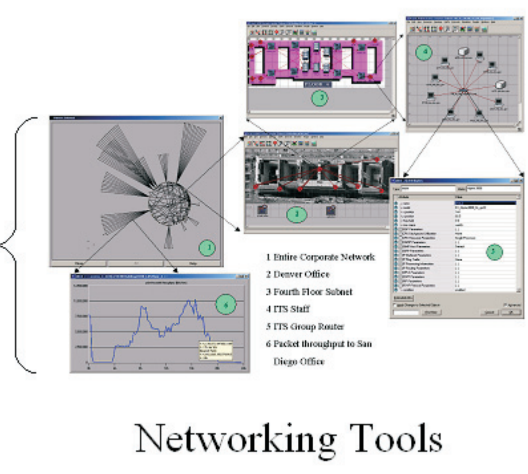


Figure 1. Graphical depiction of a structured approach to network interoperability analysis.

characteristics of the systems involved, including network type, topology, interfaces, components, services, traffic and utilization levels, and security and management infrastructures.

2. The use of existing or emerging enabling technologies to facilitate the development of interface and migration interoperability solutions.

3. The use of networking tools including test and measurement equipment and software as well as evaluation methods that aid in the design of alternative solutions and ensure that solutions meet goals and performance requirements. This includes tools for network simulation and emulation, network monitoring and management, and security assessment and protection.

4. The judicious use of frameworks within which the interoperability requirements can be described and solved using structured methods and decision-making techniques.

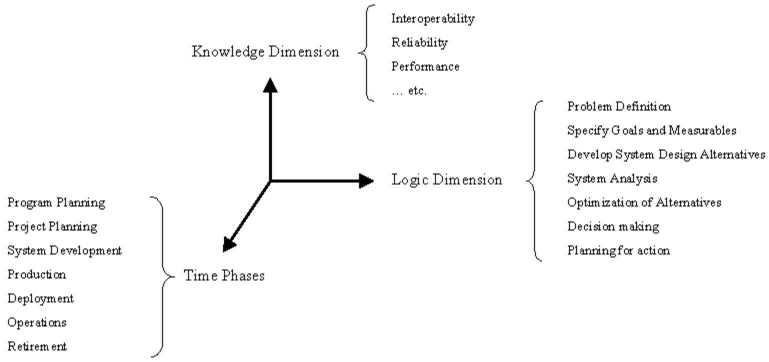


Figure 2. A three dimensional framework for systems engineering analysis.

Figure 1 on the previous page shows this structured approach to interoperability analysis in graphical form. The frameworks shown aid in developing an interoperability solution by offering a structure within which alternative solutions can be developed and compared. The systems engineering framework chosen for this project is a 3-dimensional framework of time, logic and knowledge dimensions. The time dimension consists of seven phases which describe the life cycle of most projects, the logic dimension describes steps followed in solving problems for each time phase of the project life cycle, and the knowledge dimension describes those branches of engineering and project management that guide the project staff in defining and solving problem areas. Figure 2 above shows this framework. For each knowledge dimension, the seven time phases help guide the project from inception to retirement. For each time phase, the seven logic steps aid in the definition of problems to be solved and guide the development team in the design of alternative solutions.

ITS applied this methodology to a hypothetical laboratory interoperability project involving three organizations, each of which has implemented a Voice over IP (VoIP) network using different vendor solutions and different technologies. It has now become necessary to make these systems capable of calling each other. The goal of the effort is to deploy a cost effective solution for interoperating these VoIP networks. In this simple case, we assumed that the organizations involved had similar missions so that organizational considerations did not result in any technical constraints.

Following the structured approach resulted in several alternative design solutions that satisfied the interoperability requirements. One solution was costly but had the most flexible hardware and very good customer support. A second solution was excellent for configuring and managing large networks but had significant overhead in software operation. A third solution was the least costly and simple to use but would not scale as well in large organizations. In addition, each solution had tradeoffs between voice quality and bandwidth requirements which could be a significant factor depending upon the infrastructure used (wireless or wireline). Since these VoIP networks operate over the existing IP infrastructure, it is also important to monitor the existing utilization levels on the network to ensure that the chosen solution will operate over a wide range of levels. Lastly, it is important to be able to simulate the existing system and the alternative solution designs to ensure that we can simulate scenarios which may be experienced. Using the ITS Interoperability Research Laboratory and the suite of networking tools for network discovery, monitoring, security, and management resulted in the development of excellent, well-understood, alternative solutions which could now be presented to management for final selection.

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Railroad Telecommunication Planning

Outputs

- Technical support to the Federal Railroad Administration (FRA) for all matters related to railroad telecommunications.

This project involves providing technical consulting on a continuing and as-needed basis to the Federal Railroad Administration (FRA), relative to any technical issues related to railroad telecommunications that may arise. For example, prior years' activities related to the Oregon Department of Transportation (ODOT) Pilot Project, which investigated the efficacy of utilizing TIA102-compliant radios in a railroad private land-mobile radio (PLMR) environment, and have been detailed in previous years' Technical Progress Reports, continued in FY 2003.

In FY 2003, a task that resulted from the FCC's Second Report and Order (R&O) 03-34 was undertaken by the Institute. The R&O is a matter with wide-reaching implications for the railroad industry. It concerns itself with, among other things, the mandatory migration of "wideband" (emission designator 16k0F3E) PLMR systems to "narrowband" (11k0F3E or 11k0F1E) systems. The railroad industry had raised concern that such a migration process will present significant challenges to implement.

The railroad PLMR infrastructure is comprised of more than 15,000 base stations, 45,000 mobile radios, and 125,000 portable radios nationwide. Each railroad manages its own PLMR infrastructure, and is responsible for ensuring that its base station assets provide the necessary RF coverage throughout its own territories, which are scattered nationwide.

It is common practice to find one railroad's locomotive operating in another railroad's territory, utilizing that "foreign" railroad's PLMR infrastructure. Furthermore, a locomotive could be expected to be found anywhere in the country at any given time — locomotives are not necessarily "captive" to a particular geographic area.

Hence, the dilemma in migrating to a nationwide radio infrastructure is this: with the sheer number of radios involved nationwide, owned and managed by different railroad companies, each railroad would be challenged to coordinate the simultaneous conversion of all its assets nationwide to narrowband technology all at once, and to coordinate such a massive undertaking with all the other railroad companies. Obviously, there will be a "transition" period where "mixed-mode" operation (wideband receivers operating with narrowband transmitters and vice versa) will be the norm. For example, a locomotive whose legacy radio had not yet been replaced, and that was operating in a territory whose base station had already been transitioned to narrowband technology, would be receiving a narrowband signal by its wideband receiver. Thus, the question arose as to the effects of such mixed-mode operations on the performance of land-mobile radios. It is this aspect of a migration that the railroads and the FRA wished to explore further.

Among other testing, the Institute subjected various commercial-grade radios of different manufacture to these mixed-mode operating conditions. The resultant data was provided to the FRA sponsor. The Association of American Railroads incorporated this work into comments that it filed last August in response to the aforementioned R&O.

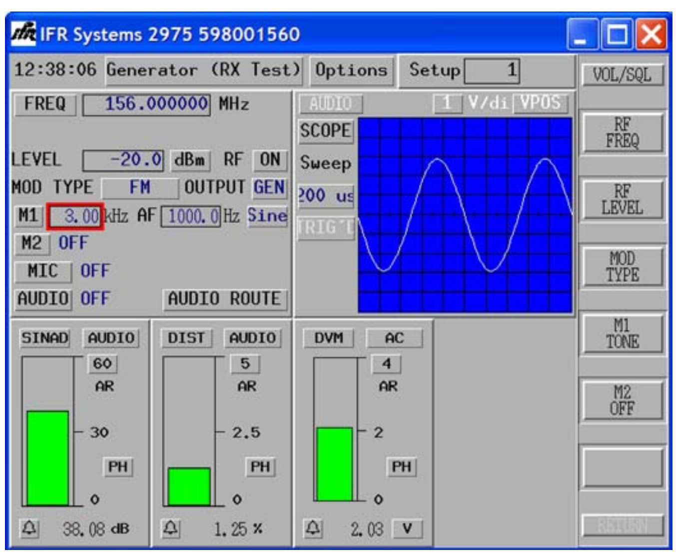

Figure 1. Wideband transmitter deviation with wideband receiver bandwidth.

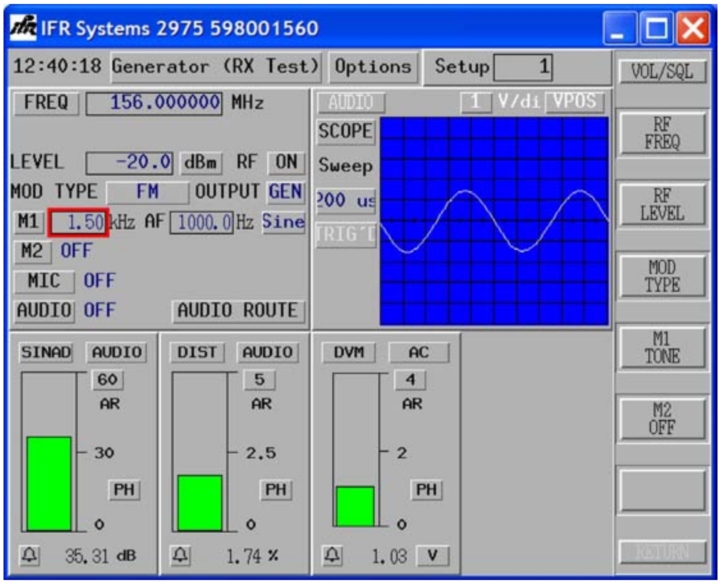

Figure 2. Narrowband transmitter deviation with wideband receiver bandwidth.

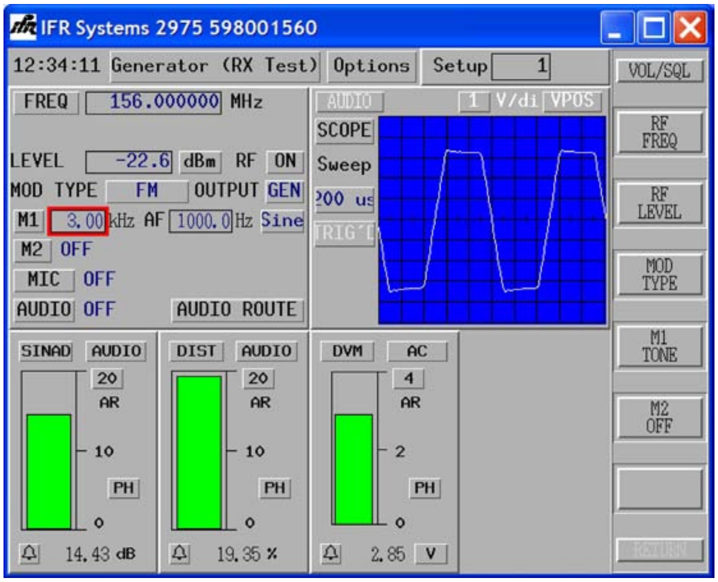

Figure 3. Wideband transmitter deviation with narrowband receiver bandwidth.

One important issue, revealed as an outcome of this work, is illustrated in Figures 1 through 3. Notice how the amplitude of the demodulated audio in Figure 1 (on previous page), the "legacy" configuration, is twice as large as the demodulated audio signal in Figure 2, an example of "narrowband transmitter/wideband receiver" mixed-mode operation.

Although an operator could simply turn up the radio's volume control to compensate for the decreased volume, the issue here is this: Suppose a locomotive roams out of a "legacy base station" region into a "narrowband base station" region. What if the engineer did not notice that at some specific milepost marker, he had entered the new base station coverage area and that therefore he had to increase the volume control setting on the locomotive radio? Is it possible, in the noisy acoustic environment of a locomotive cab, that the engineer might miss a critical radio transmission from the dispatcher?

Or consider the converse case, depicted in Figure 3, where a wideband transmitter signal is received by a narrowband receiver. It is quite clear from the figure that the demodulated audio is distorted. Could an engineer misunderstand a dispatcher's instructions because of such distortion?

It is issues such as these that the measurements revealed, and it is issues such as these that the railroad industry must now consider as it develops a wideband-to-narrowband migration strategy.

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Voice over IP

Outputs

- Metrics and measurement methods for real-time traffic over long 802.11b links.
- Standards contributions (TR-41.1) detailing the behavior of real-time VoIP traffic over long 802.11b links.

The market availability of Voice over Internet Protocol (VoIP) equipment continues to increase, due to the many advantages that this technology offers. These advantages include efficient resource utilization, a homogeneous network offering both voice and data, potential for other multimedia transmission (e.g. video), and lower data bandwidth requirements than traditional telephony.

As wireless local area networks (LANs) based upon IEEE 802.11b (Wi-Fi) technologies become more ubiquitous, attempts are being made to utilize VoIP over radio channels as well as the fixed location wired networks more traditionally associated with VoIP systems. However, propagation effects within the wireless channel can substantially degrade the Quality of Service (QoS) of a VoIP system. As VoIP and Wi-Fi technologies converge, knowledge about the type and extent of these effects assumes increasing importance.

In order to evaluate some of the potential impairments implicit in VoIP transmission over Wi-Fi channels, ITS has created a testbed with three 802.11b long links. Two of these links, of length 1 mile and 10 miles respectively, are being used to evaluate the effects of 802.11b long link transmission on network parameters related to VoIP. They simulate two different environments, rural and suburban, and also represent two slightly different radio setups.

The shorter link is essentially a peer-to-peer link that runs from the ITS Wireless Networking Research Center to a test location one mile distant on a nearby hill. This link uses directional antennas, but is otherwise unamplified. Since its path traverses open fields, it represents a rural environment.

The second link has one end node on the same hill, but it passes over a well-populated residential area, with all of the potential interferers that are implied by such a traversal. The link terminates in a node situated in the ITS field site on the Table Mountain plateau. This link utilizes amplification to achieve the distance required, in the form of a constant power 250 mW output amplifier and a standard 17 dB input amplifier. Although the shorter link runs in peer-to-peer mode, this longer link is terminated at both ends by wireless access points. Both links use 24 dBi directional antennas at each end and both are line-of-sight.

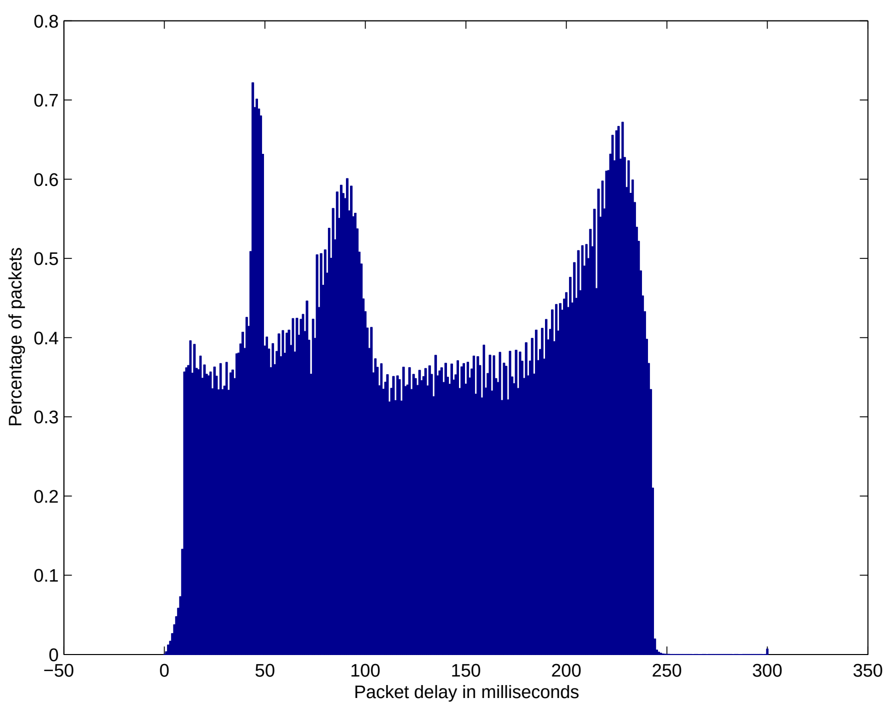

Figure 1. Packet latency distribution over a 1-mile peer-to-peer 802.11b link.

Both links achieve true realizable throughputs of approximately 4 Mbps, a value that is consistent with 802.11b technology operating at maximum burst speed. Initial experiments concentrated on the measurement of jitter and packet loss in the system. Both of these parameters are of great importance in services like VoIP that require a real-time transport capability — jitter because packets that are delayed beyond the time length of the jitter buffer must be dropped, causing gaps in the output stream, and packet loss because the real-time nature of the required transport makes it impractical to retransmit lost packets.

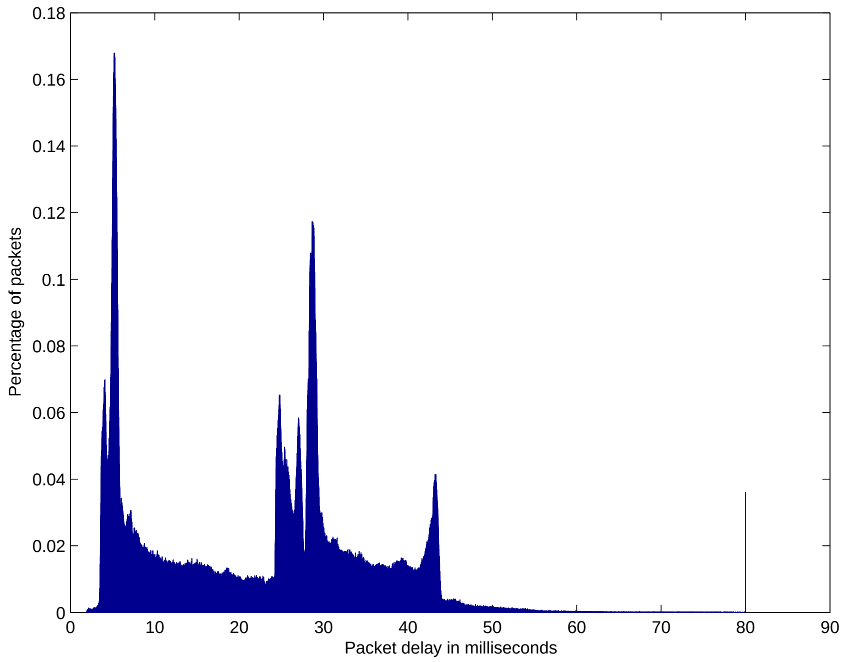

Figure 2. Packet latency distribution over a 10-mile 802.11b link.

Representative results from the two links are shown in Figure 1 (on the previous page) for the 1-mile link and Figure 2 (above) for the 10-mile link. It is immediately apparent from the figures that the shorter link has a much greater variation in latency than the longer link. Although the short link has a smaller minimum value — 0.3 milliseconds versus 1.9 milliseconds for the long link — the mean value for the short link is considerably greater than that of the long link — 129.8 milliseconds for the 1-mile link and 22.4 milliseconds for the 10-mile link. Losses for the short link also exceed those of the long link, although neither figure is high. Packet loss for this experiment was 0.11% for the short link and only 0.02% for the long link. The standard deviation of the short link delays is 94.6 milliseconds, and that of the long link delays is 45.6 milliseconds. By this metric, the jitter on the two links is similar within a factor of 2.

In real time VoIP transmission, a jitter buffer must be maintained to deal with delayed and out-of-order packets. Packets that are delivered outside the time range of this buffer are discarded. Contrary to what might be inferred from the standard deviation numbers alone, the figures show that the delay variation for the short link peer-to-peer connection is approximately six times greater than that of the long link.

A comparison using a different jitter metric, the Inter Quartile range, gives more insight into these distributions. This value expresses the time difference between packets in the third quartile of the distribution and those in the first quartile. For the short link, this metric gives 126.0 milliseconds and the long link is evaluated at 22.2 milliseconds. These somewhat counterintuitive data may indicate that the peer-to-peer mode of 802.11b transmission is a bad choice for VoIP traffic due to poor jitter characteristics. This conjecture, as well as the reasons for the multimodal nature of both delay distributions, is under current investigation.

It is clear that the wireless channel is significantly more complex than a wired channel in regard to real-time traffic. Studies of this transport mechanism must include information about the radio environment as well as traditional network parameters. In addition, new and relevant metrics and measurement methods for these information channels must be devised. ITS research is aimed at providing this information.

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Telecommunications Engineering, Analysis, and Modeling Division engineer installing an antenna at the Green Mountain Mesa field site, part of the short & long range wireless test links (photograph by C. Redding).

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.

Continuing to add to our wireless test facilities and research capabilities, ITS engineers have set up short and long range wireless test links to further research 2.5G and 3G technologies. The Wireless Networks Research Center (WNRC) in combination with these test links 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 79 for more information about the WNRC and page 71 for information about the wireless links at Green Mountain Mesa.)

Areas of Emphasis

ENGINEERING

Outdoor IEEE 802.11 Testbed Using multiple long range outdoor links, the Institute investigates the operating parameters of 802.11-based wireless data systems, which are becoming a significant telecommunications resource. This work is funded by multiple Department of Defense (DoD) agencies.

PCS Applications The Institute participated in the Telecommunications Industry Association (TIA) committee TR46.2 and now will participate in the T1 subcommittee T1P1.2. ITS is also developing a series of PCS interference models. The project is funded by NTIA.

Third Party Test Evaluation for Other Agencies The Institute assists the U.S. Coast Guard in modernizing and upgrading its communication capabilities by acting as a third-party technical consultant. The project is funded by the U.S. Coast Guard.

Wireless Network Analysis and Forecasting The Institute is actively investigating wireless networks and services expected to be used in the future, including the interfaces between various technologies. This work is funded by multiple DoD agencies.

ANALYSIS

Telecommunications Analysis Services The Institute provides network-based access to its research results, models, and databases supporting applications in wireless telecommunications system design and the evaluation of systems. 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.

Outdoor IEEE 802.11 Testbed

Outputs

- Propagation induced data channel impairments.
- TCP and UDP testing.
- Signal strength to throughput correlation.
- VoIP parameter measurements — jitter and delay.
- Video over Wi-Fi.
- RF characterization of 802.11 signals.
- Spectral behavior in the 2.4 GHz band.

As prices have fallen, the number of 802.11-based wireless local area networks (WLAN) has significantly increased. This technology represents a significant telecommunication resource and therefore is of interest to ITS and NTIA. In the past year, efforts have been made to investigate the operating parameters of 802.11-based wireless data systems from a number of viewpoints.

The low cost of 802.11 equipment has been accompanied by a concomitant wide variation in capabilities. A secondary aspect of the large number of different systems involved in ITS testing has been the capability to investigate the interoperability between different 802.11 WLAN cards and access points (AP). This work has also pointed out compatibility issues regarding the use of 802.11g WLAN cards in 802.11b systems and vice versa.

Because the wireless channel is more complex than the wired channel, protocols like 802.11b exhibit sophisticated behavior at the physical layer which is not easily discernable to the application. A particular result of this behavior concerns the hidden effects of physical layer impairments upon network performance. A portion of the experiments conducted at ITS are designed to investigate the correlation between network parameters and radio frequency (RF) channel characteristics. For example, gross signal strength measurements may be poor indicators of achievable network throughput. In addition, retransmissions mandated by error indications at the physical layer may adversely impact jitter and latency parameters. Although this impact is not detrimental to transmission control protocol (TCP) data transmissions, it may prove to be significant for real-time packet-based communications using realtime transport protocol (RTP), i.e., Voice over IP (VoIP). ITS is uniquely qualified to investigate realtime voice services over Wi-Fi networks because of its existing voice quality program.

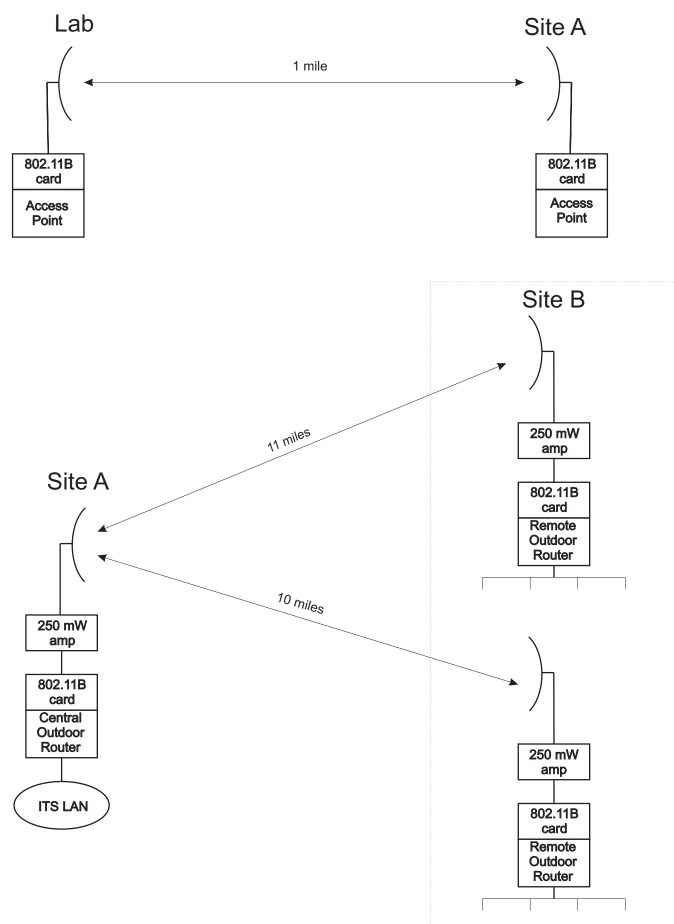

Figure 1. Long range outdoor links between the Green Mountain field site and the Table Mountain field site near Boulder, CO.

Another realtime application that promises to be of increasing interest is packet video over 802.11 networks. Experiments within this realm can take advantage of existing video quality measurement expertise at ITS. These experiments take the form of low frame rate transmissions and thus represent a different measurement regime from the commercial video quality that has been previously studied.

Currently, ITS has set up multiple long range outdoor links, shown in Figure 1 (on previous page) and Figure 2 (below), to explore the impact of environmental factors on communications over 802.11 based carriers. The links consist of 1, 10, and 11 mile distances. This testbed utilizes no proprietary technology but is based on commercial off the shelf equipment. A high gain directional antenna, shown in Figure 3 (below right), is employed at each of the links to provide the required directionality and gain. The experimental installation is capable of providing information about the RF characteristics of the channel as well as multiple packet network parameters. For non-realtime TCP networks, this includes throughput measurements, and for real time transmissions, measurements like delay, jitter and instantaneous packet loss are available.

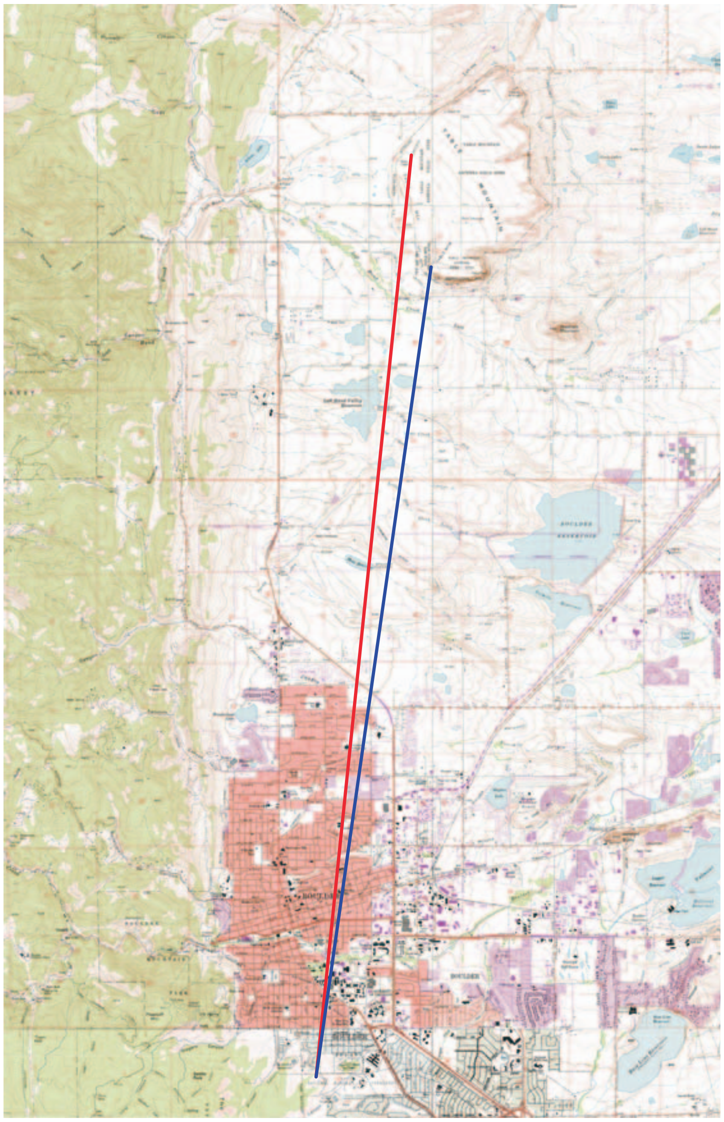

Figure 2. Long range outdoor links between the Green Mountain field site and the Table Mountain field site near Boulder, CO.

Figure 3. High gain directional antenna employed at one outdoor link at the Table Mountain field site (photograph by C. Redding).

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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.

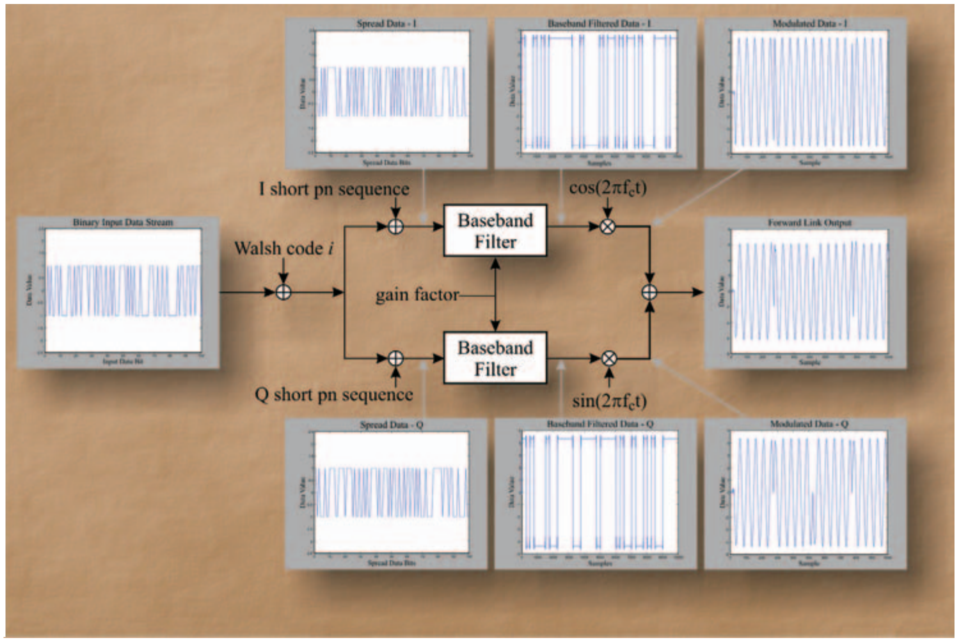
Personal Communications Services (PCS) has become an important resource for establishing emergency communication services following natural or man-made catastrophes. Such disasters can damage the wireline telecommunication system, forcing users to migrate to cellular resources. This sudden influx of 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-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 Telecommunications Industry Association (TIA) committee TR46.2 (Mobile & Personal Communications 1800 — Network Interfaces). As a member of TR46.2, ITS contributed to the development of the Telecommunications Systems 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 is being transferred to the T1 subcommittee T1P1.2 (Wireless/Mobile Services and Systems — GSM/3G Radio). ITS will continue to be involved in interference issues with this new group.

Work in detecting, identifying, and mitigating co-channel interference requires tools to characterize the interference experienced by PCS air-interface signals. PCS interference models are tools that can be 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-95B standard, and leading to models covering proposed third generation (3G) systems. The model performs system-specific interference prediction to determine co-channel interference from both immediate and adjacent cells.

The communications industry has proposed and developed new technologies to address system limitations such as system capacity, coverage, and data transfer rates. 3G systems have been proposed to support the goals established by the International Telecommunication Union (ITU) with IMT-2000. These systems include cdma2000 and W-CDMA, known as UTRA (Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access) in Europe. These technologies present new issues for the existing PCS networks. The new 3G systems will need to coexist with current PCS systems for a period of time. In light of this requirement, the models are being developed such that all output data of the various technologies will be compatible. This compatibility will allow users to characterize potential problems between the different technologies as 3G systems are implemented, as well as characterize interference problems with existing PCS networks.



Simplified PCS self-interference model showing typical waveforms for the forward-link process.

The conceptual model is a structural model 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 (but is not required 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 quadrature phase-shift keyed (OQPSK) modulation scheme. The model calculates each channel signal contribution separately from all other channel signals and then adds the processed signal to the other signal contributions to form a composite output signal. The power level for a single channel is an arbitrary gain factor of the baseband filter which is set separately for each channel. 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 (see figure above) 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. ITS is currently working on the verification and validation of the first, ANSI 95-B, model. The validation process will include both software and hardware aspects of the model.

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Third Party Test Evaluation for Other Agencies

Outputs

- Written technical feedback on design and test documents.
- Witnessing of field and factory tests on location.
- Meeting attendance as subject matter experts.

One aspect of ITS's mission is to assist other Government agencies with their communications needs and help them to resolve any telecommunication issues that may arise in achieving their own mission. ITS has acted on many occasions as a third-party evaluator and/or technical communications consultant to other Government agencies. The U.S. Coast Guard project described below is an example of ITS playing such a role.

In FY 2003 ITS provided assistance to the U.S. Coast Guard. The Coast Guard has undertaken a project to modernize and upgrade its current National Distress and Response System (NDRS). This project will enhance the Coast Guard's communication capabilities, provide a common operating environment, and provide Coast Guard personnel with tools to perform their missions. The NDRS is the maritime 911 system for the coastal U.S. and the communications infrastructure for all Coast Guard coastal missions. The new system was originally called the National Distress and Response System Modernization Project (NDRSMP) and is now titled Rescue 21. Rescue 21 will consist of many 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. A typical operational scenario of Rescue 21 is shown in the figure on the next page.

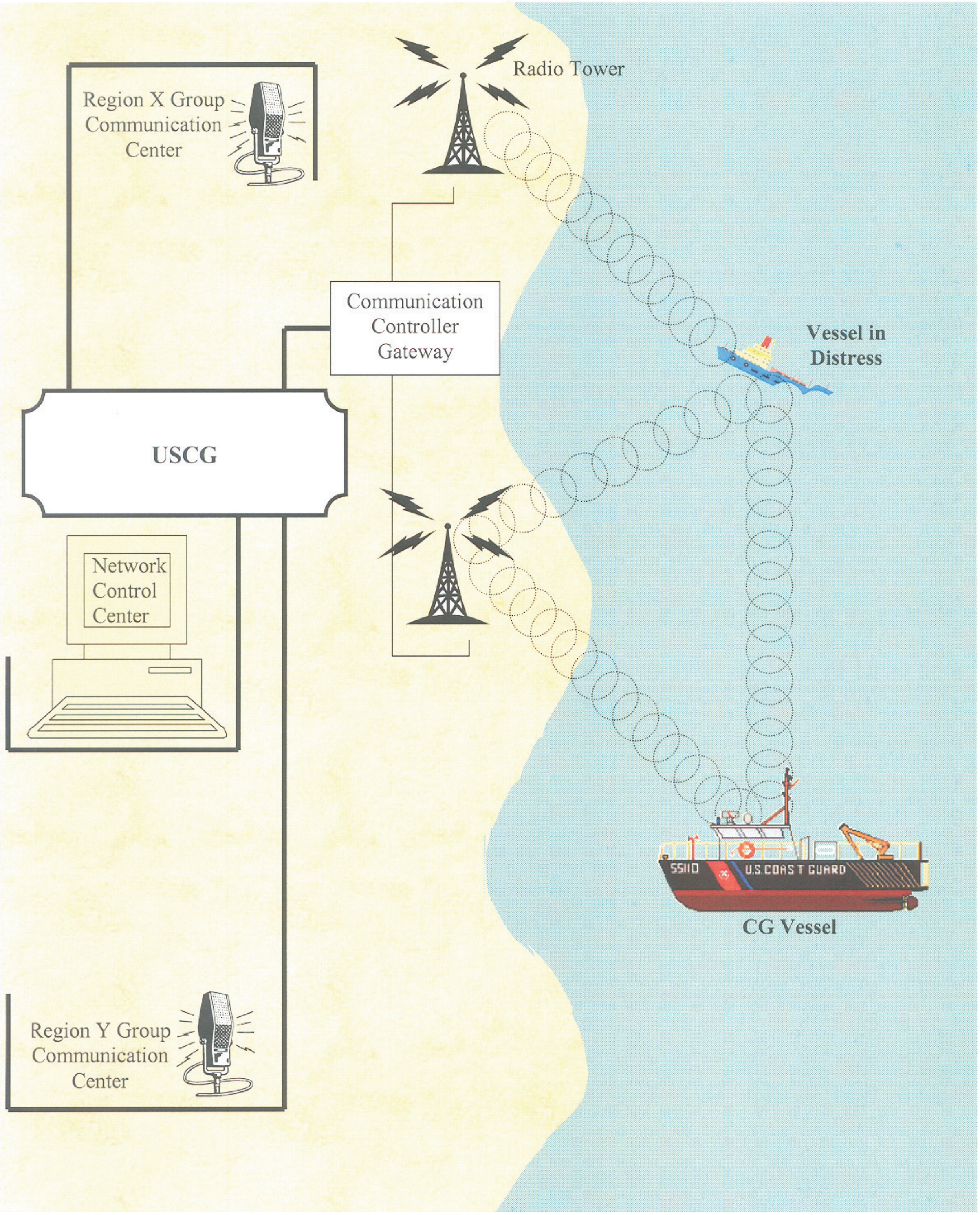
Rescue 21 is in the Developmental Testing and Evaluation (DT&E) Phase. DT&E includes two tests, a Formal Qualification Test (FQT) at the contractor's facility and a System Integration Test (SIT) in the field. ITS is providing technical assistance in reviewing the test plans and procedures as well as design documents and various analyses provided by the contractor to the Coast Guard. The Coast Guard is planning on installing the first field sites for test under the SIT in FY 2004.

ITS focused its technical feedback to the Coast Guard in the following technical areas: performance, availability, RF coverage and propagation models, P25 specifications and requirements, potential RF interference, and direction finding (DF).

In general, ITS can assist other agencies in the following areas:

- Request for Proposal Writing
- Proposal Evaluation
- Design Specification Writing and Evaluation
- Test Plan and Test Procedure Writing and Evaluation
- RF Coverage Analysis
- Propagation Model Comparison
- Test Parameters and Sampling Requirements Determination
- Independent RF Tests and Monitoring
- Voice and Video Quality Tests
- Network Analysis
- Security and Encryption
- Availability and Performance Analysis

ITS continues to provide technical feedback on design documents, analyses, test plans and test procedures, helping the Coast Guard verify the feasibility of the system and whether or not specifications and technical requirements were met contractually. ITS will also act as a third-party test evaluator for the FQT and SIT portions of the Rescue 21 project, witnessing those tests along with Coast Guard representatives.



Typical operational scenario for the U.S. Coast Guard Rescue 21 system. The GCC system design main network components are RF, Gateway, Coast Guard Data Network (CGDN), Router, LAN and DB Server.

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Wireless Network Analysis and Forecasting

Outputs

- Forcasting of future wireless technologies.
- Usage studies of commercial wireless networks.
- Secure wireless network analysis.

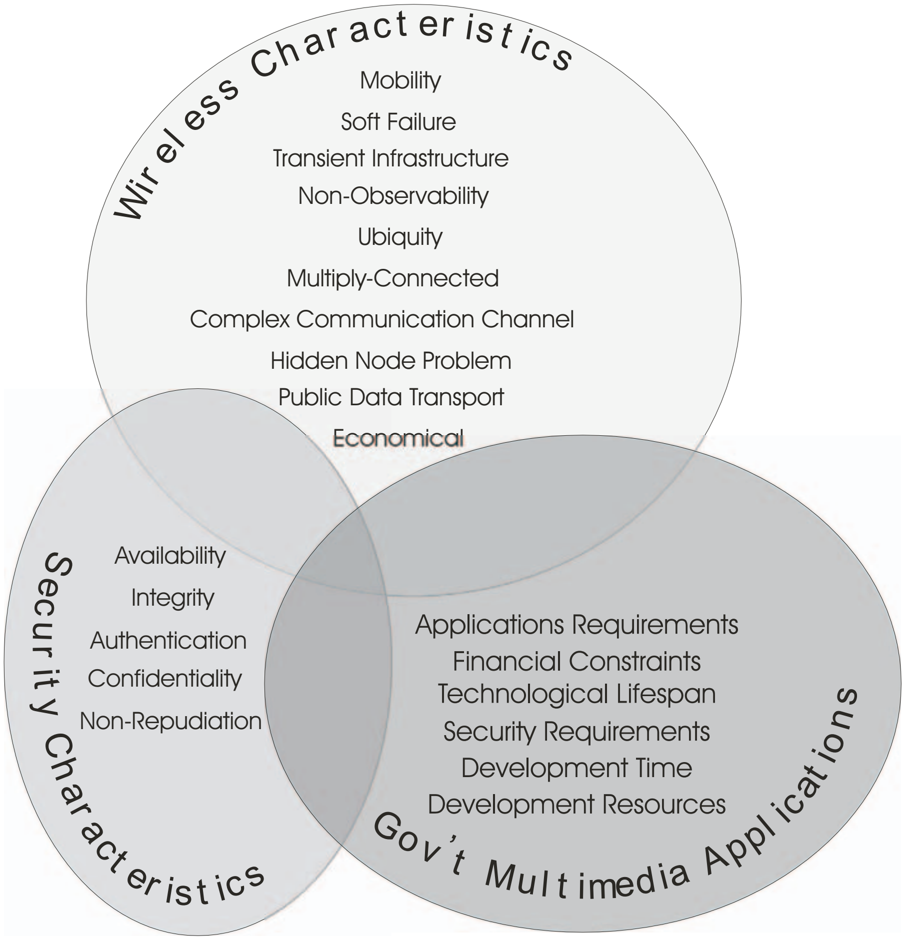
ITS produces analytical services that aid in the fielding of Federal communications products that rely on public wireless infrastructure. The studies that ITS has conducted are used to advise and inform Federal wireless users and designers. The work of the Institute can assist Federal wireless communications in meeting financial and technical criteria. In addition, ITS has done extensive research for a variety of agencies including the maintenance and operation of secure Government communications. Often as part of a comprehensive report, ITS includes reasoned opinions on the future of wireless technologies.

The Institute is actively investigating the kinds of wireless networks and services Federal users will be seeing in the future. These networks are being examined for suitability to interface to mobile Government security services. In particular, common interfaces are being closely examined since they may aid in the rapid adoption of emerging wireless technologies. ITS is attempting to identify the interfaces, both software and hardware, that will allow a broad range of Government wireless communications services to be developed and deployed. Future wireless networks, such as IEEE 802.15 and 802.16 (WiMAX), which are on the verge of being fielded promise to make broadband services widely available. IEEE 802.15 will support data rates of up to 54 Mbps with a range of tens of meters. This technology will provide the capability to send real-time video over piconets in the unlicensed 2.4 GHz band. Piconets are also identified as wireless personal area networks (WPAN). IEEE 802.16 is designed for data rates of up to 155 Mbps in a point-to-multipoint metropolitan area network (MAN). A MAN facilitates the connection of multiple wireless LANs over a range of 50 km.

Wireless communication links are used to extend the wired networks to solve the first mile/last mile connectivity problem. The advantages of economy and flexibility are making wireless data links more attractive relative to fixed infrastructure. The inherent limitations of a fixed infrastructure restrict user mobility, and it is more expensive to upgrade. IEEE 802.11 (Wi-Fi) networks essentially extend the range of wired networks rather than operating as autonomous and/or independent networks. Wired networks are extended via wireless access points, where multiple wireless communications links connect to a central point. The nodes that make up a Wi-Fi network communicate through a wireless access point, rather than peer-to-peer. This topological similarity with wired networks does not exploit the advantages of wireless links, which possess the unique features of mobility and self association. Peer to peer communications, such as those defined in the 802.11 standard and Bluetooth, take only partial advantage of the self-association characteristic of wireless communications. Self-associating wireless networks are known as ad hoc wireless networks. ITS is examining the use of ad hoc wireless networks for use in Federal communications architectures. Research at the Institute is focusing on how to make these ad hoc wireless networks suitable and secure for Federal wireless users.

Other application requirements, such as mobility, affect the type of data service that can be provided to Federal users. If no mobility is required, optical or point-to-point radio frequency (RF) technology may be satisfactory. If a high degree of mobility is required, cellular technology may be the only solution. Security requirements may also dictate particular choices. As always, financial considerations are often the predominant motivation for the Government to use public wireless networks. An additional financial motivation is the potential long-term stability of a technology. Finally, service development time and resource availability may affect the type of wireless communications service that can be used.

Government communications services share common features with public services. Many Government communications applications require levels of performance and quality of service that are no different from private sector services. However, some Federal requirements can fall outside the capabilities of the commercial market. Government data



Intersection of security, wireless, and Government multimedia requirementsin public networks.

services can be elevated to the level necessary to preserve national security. For these crucial services, the requirements demanded from wireless service providers may be difficult to achieve using public networks. Secure application requirements may be so stringent that a proprietary network is necessary.

The intersection of security and wireless characteristics shown in the figure above represents commercial implementations of wireless security. This intersection is overlapped by Government multimedia applications requirements. Future wireless services will require that Federal users are familiar with the intersections in the figure to effectively meet the communications needs of the future. ITS provides the analysis necessary to understand all three areas.

While the constraints that wired infrastructure imposes on wired network design are well known, wireless data transport constraints are less well understood. Network-centric designers often overlook the unique characteristics of wireless that can lead to network functionality unavailable on wired infrastructure. On the other hand, the wireless communications environment has numerous constraints that call for very sophisticated and complex network designs. The difficulty in designing applications for wireless environments is the requirement that the designer be well versed in both networking and wireless disciplines. The strengths of wireless can bring a new dimension to the way applications and Federal users relate to data. Yet, the weakness of wireless, foremost being public data transport, can have catastrophic consequences — especially in networks where security is important. ITS draws on its expertise in RF propagation and knowledge of networking to provide a comprehensive view.

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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 US 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 (p. 77-78) 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

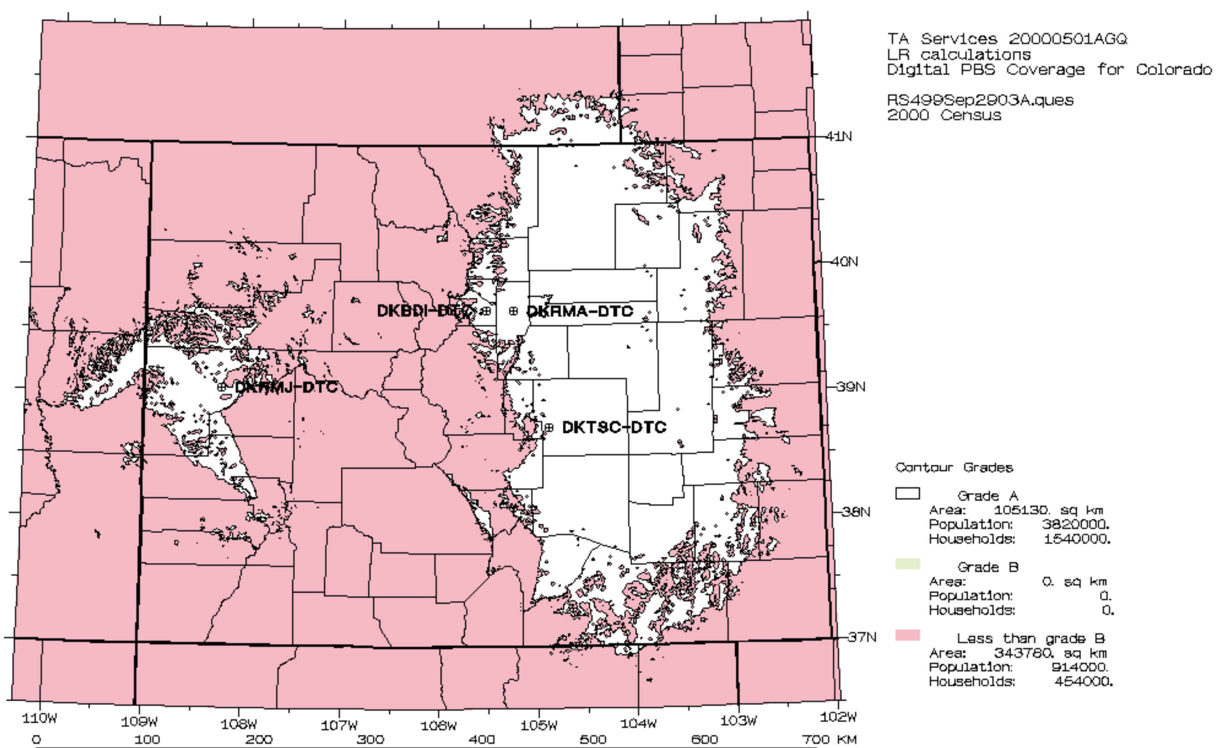

Figure 1. Digital PBS TV coverage for Colorado.

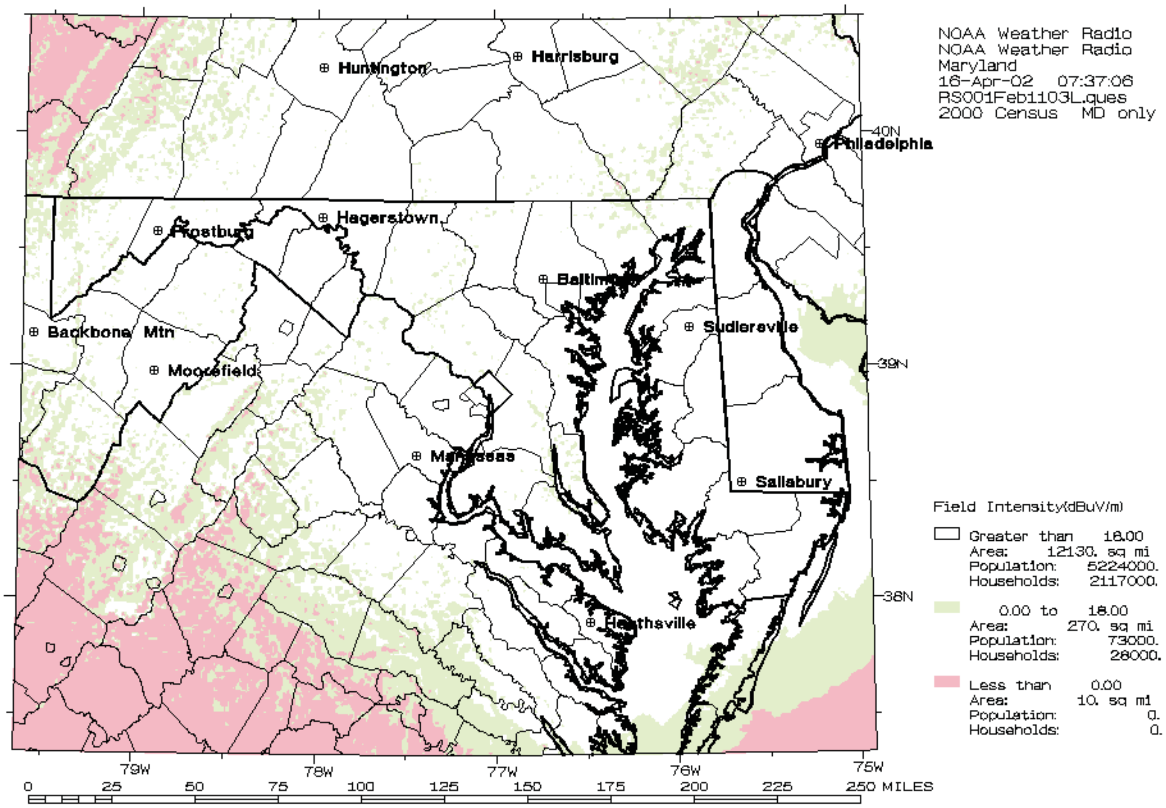

Figure 2. NWS station coverage for Maryland.

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 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 Colorado.

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 of this year for Hurricane Isabell on the east coast. Figure 2 above shows the calculated NWS coverage for Maryland. TA Services calculates that 98.6% of the Maryland 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 created by the program or imported by the user.
- Analysis of interference and overlap coverages of multiple transmitters.
- The ability to create and modify catalogs of imagery at various resolutions and city catalogs of building information.
- 2.5D or fly-through 3D visualization with interfaces to 3D visualization tools.

ITS continues to develop a suite of Geographic Information System (GIS) based applications which are available to public and private agencies for propagation modeling and performance prediction studies. A GIS efficiently captures, stores, manipulates, analyzes, and displays all forms of geographically referenced information in a user-friendly and flexible manner. Databases for use in GIS systems are now commonly available at affordable prices and include such data as terrain, satellite photo imagery, aircraft imagery, road infrastructure, communications infrastructure, building locations and footprints, land type and use, water bodies, streams, population densities, and many others. These are distributed in many GIS supported formats and can be maintained in relational database management systems (RDBMS) which can be connected to the GIS. The Institute has modified and distributed this tool to many groups with modifications tailored to specific applications.

One form of this GIS tool is called the Communication Systems Planning Tool (CSPT). CSPT is a menu-driven propagation model developed for applications at frequencies as high as 50 GHz. The accuracy of the results and the usefulness and flexibility of the presentation of the results are enhanced by the power of the GIS background. CSPT allows the user to import digital imagery or other remote sensing data which have been converted to 3-dimensional models of the region. This environment is then taken into consideration as the model calculates the results of the desired analysis. Contained within CSPT are propagation "engines" valid at frequency ranges used by cellular, personal communications services (PCS), radio, TV, pagers, microwave, and other communication links. New propagation models can easily be connected to the GIS with minimal effort, providing the user with greater flexibility and future growth.

The user begins his/her analysis by defining an area within which a study will be performed. This analysis area can be defined graphically by zooming into an image of the world or by defining the latitude and longitude of the boundaries of the desired area. As the user defines the analysis area, the tool displays imagery of this area at a resolution appropriate to the scale of the view area. This imagery is displayed from image catalogs available through the tool that cover much of the world. The user then imports desired GIS information such as building data, roads, rivers, special imagery, or application-specific GIS data. Figure 1 below shows an analysis area of the Waikiki beach area around the Royal Hawaiian Hotel, including building footprints and color imagery.

Figure 1. Analysis area of Waikiki Beach, Hawaii.

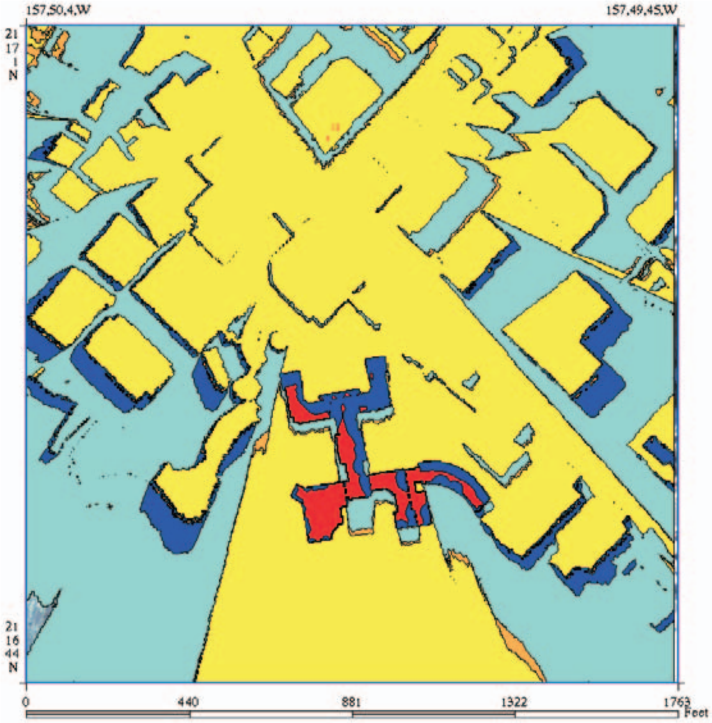

Figure 2. CSPT outdoor/indoor coverage prediction.

Then 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. ITS is currently developing a coupled indoor/outdoor propagation model which will allow the user to predict signal strength penetrating a building or escaping from a building.

Figure 2 (left) shows the hypothetical coverage of a transmitter on a building top north of the Royal Hawaiian Hotel. This coverage shows both the outdoor and indoor predicted signal strength around the hotel.

Figure 3 (below) shows this coverage in a 3D fly-through form useful for detailed visualization. Predictions such as this can be very useful in public safety applications where coverage predictions within buildings are critical in safety of life missions.

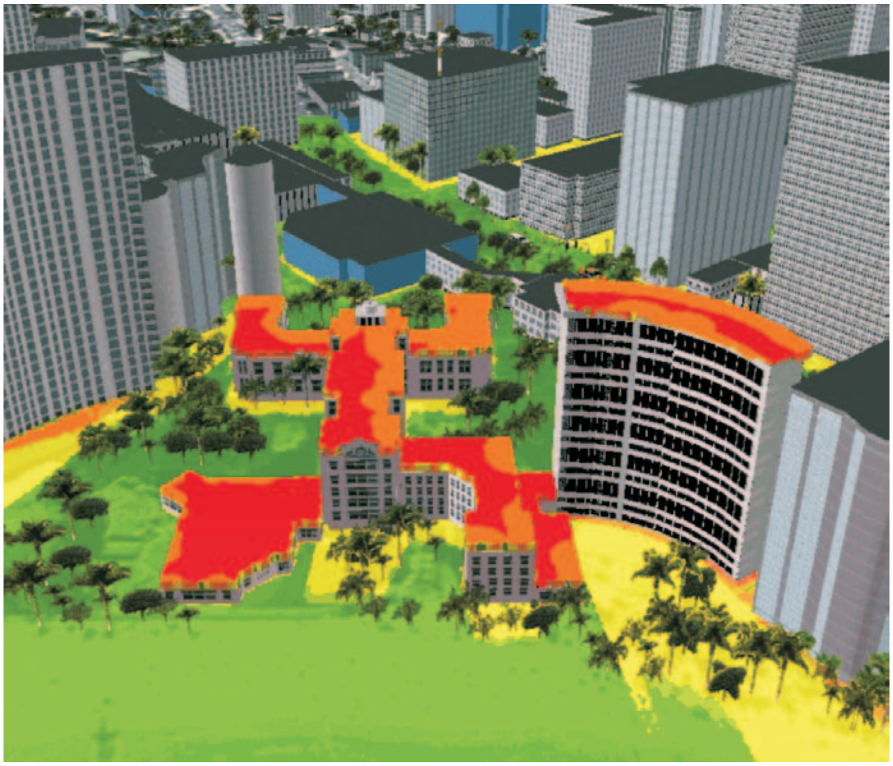

Figure 3. Same area of coverage shown in Figure 2, in 3D fly-through form.

CSPT is available for Windows® NT platforms. CSPT contains an extensive help system: most menus have a "help" button which displays an explanation of the options on that menu. A user's manual is available. We suggest that users have an account with ITS on our TA Services computer so that we may provide phone support.

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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 uses. These additional users and new services require greater bandwidths than before, which for wireless users means more radio spectrum. As more users require 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 co-exist 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.

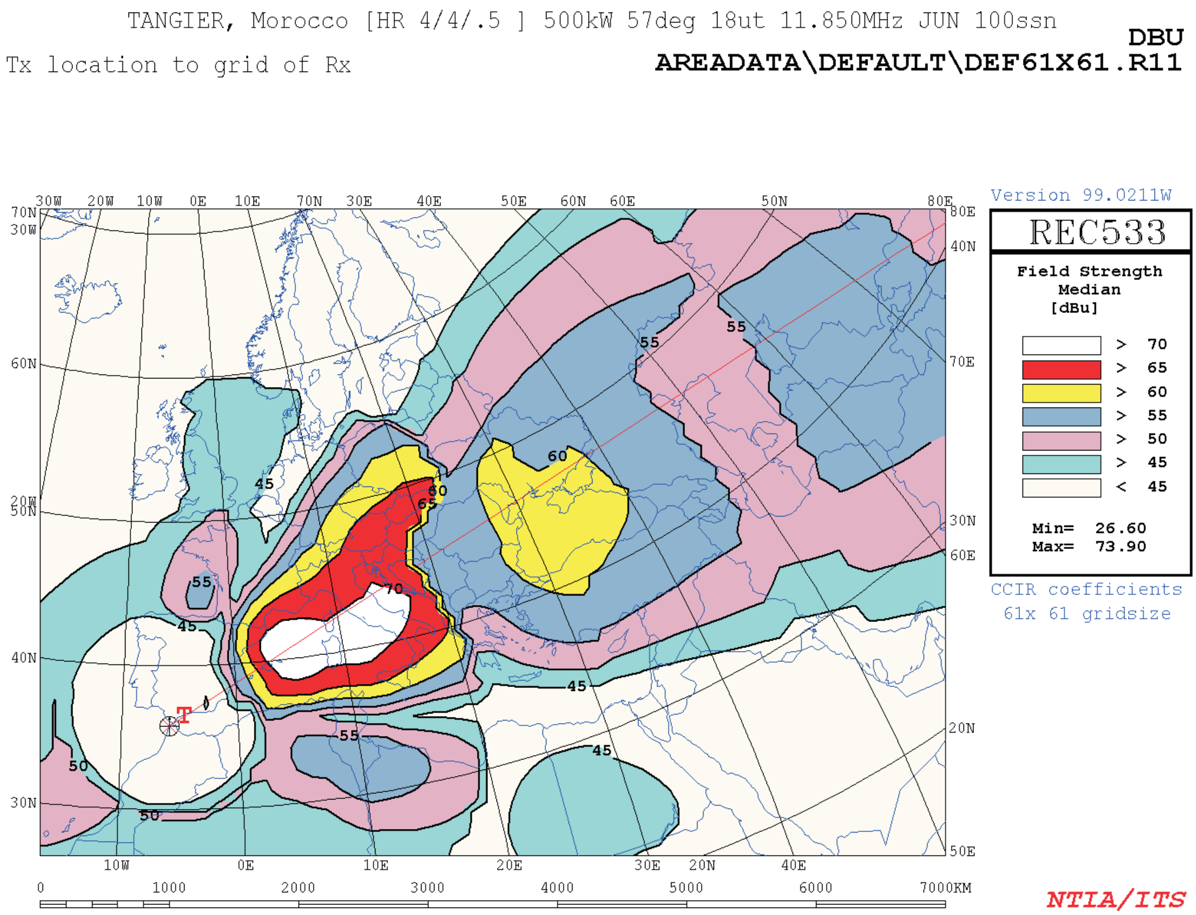
ITS and other research organizations have been developing and evaluating propagation models to predict wireless signal coverage more accurately. These propagation models are more responsive to the needs of cellular and private land mobile radio service providers, which make up the vast majority of wireless communications systems in use today and in the future. A common model used by system planners is the ITS Irregular Terrain Model (ITM), also known as the Longley-Rice model. It can analyze wireless communications systems at frequencies from 20 MHz to 20 GHz.

While a good predictor in irregular terrain, ITM does not have the capability to utilize land-use, land-cover databases to predict losses due to man-made objects, such as buildings and bridges. ITS is evaluating the incorporation of land-use, land-cover databases into the ITM propagation prediction model to provide more accurate predictions than those calculated without knowledge of the obstacles. The improved predictions will allow service providers to better evaluate locations for base stations and to predict where additional base stations might be needed to fill in areas of inadequate signal coverage. Since better databases are now available for land-use, land-cover descriptions, the predictions of signal loss associated with the various land-use, land-cover categories could provide better agreement with measurements. An effort is also currently underway at ITS to develop an improved effective antenna height algorithm in ITM, to make more accurate propagation loss predictions over irregular terrain.

Another common model is the Okumura-Hata model. It is a good predictor in urban and suburban environments, but it does not handle irregular terrain nor does it handle changing environments, e.g., from urban to suburban to rural. ITS is also evaluating the means of incorporating terrain obstacle information into the Okumura-Hata model, to make it more responsive to the changing environment.

ITS participates in the international development of 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. ITS supports this effort by participation in the International Telecommunication Union — Radiocommunication Sector (ITU-R) Study Group 3 (Radiowave Propagation). An ITS staff engineer is the Chair of the U.S. contingent of Study Group 3. Study Group 3 has recently developed and adopted such a model, ITU-R Recommendation P.1546, which blends features that the services had previously used independently of one another, thereby clarifying and unifying planning and coordination activities across the services.

ITS is a member of ITU-R Study Group 3 Working Parties 3K and 3M. Working Party 3K deals with point-to-area propagation where propagation aspects concerning terrestrial path-general and path-specific prediction methods in the frequency range 30 MHz to 3 GHz are addressed. In addition, Working Party 3K deals with propagation aspects of short-path personal communications and wireless local area networks (LAN) in the frequency range 300 MHz to 100 GHz, and terrestrial wireless access systems.



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

Working Party 3M deals with propagation aspects of terrestrial point-to-point communication, Earth-space communication, interference, and coordination.

ITS also participates in ITU-R Study Group 3 Working Party 3J. Working Party 3J deals with the propagation effects of clear atmosphere, clouds, precipitation, noise, vegetation, and obstacle diffraction. Working Party 3J involvement also includes ground-wave propagation, global mapping, and the statistics of radio-wave propagation.

ITS is also a member of ITU-R Study Group 3 Working Party 3L. Working Party 3L deals with ionospheric propagation above and below 2 MHz, in addition to trans-ionospheric propagation. In its membership of the ITU-R Study Group 3 Working Party 3L (Ionospheric Propagation), ITS is responsible for maintaining the High Frequency (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 website)

http://elbert.its.bldrdoc.gov/hf.html

An example of the type of output the software can produce is shown in the above figure.

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Propagation Model Development & Comparisons

Outputs

- Comparison of algorithms in ITM and TIREM models.
- Comparison of ITM and TIREM models to various measurement datasets.
- Support of the U.S. Army in propagation model comparisons.

Propagation model development in FY 2003 focused on intercomparison and harmonization of the two radio frequency electromagnetic wave propagation models employed by the U.S. Government, the Irregular Terrain Model (ITM) and the Terrain Integrated Rough Earth Model (TIREM). This work was sponsored by NTIA's Office of Spectrum Management (OSM) and by ITS. In addition, the U.S. Army at Ft. Huachuca, Arizona, sponsored model comparisons against measured data for several propagation models in use by the U.S. Army Information Systems Engineering Command (USAISEC). Progress in each area for FY 2003 is described below.

ITM & TIREM Intercomparison

ITM was developed by ITS, and TIREM by OSM/IITRI. Since both models were based on NBS Technical Note 101,* their propagation prediction algorithms were very similar thirty years ago. ITM has remained virtually unchanged since the mid eighties, but TIREM has undergone many significant changes during the same time period.

In FY 2001, ITS began a project to describe and compare the algorithms used in ITM and TIREM. This work continued in FY 2003. The algorithms for the line-of-sight (LOS), diffraction, and troposcatter regions are being examined, as well as how each model utilizes an effective antenna height for these calculations. The final report will provide a better understanding of these algorithms, propose explanations for why ITM and TIREM produce different answers, and suggest methods for obtaining the same answers with each model which also agree more closely with measured data.

*P.L. Rice, A.G. Longley, K.A. Norton, and A.P. Barsis, "Transmission loss predictions for tropospheric communication circuits," NBS Technical Note 101, vols. 1 & 2, May 1965 (rev. May 1966 and Jan. 1967).

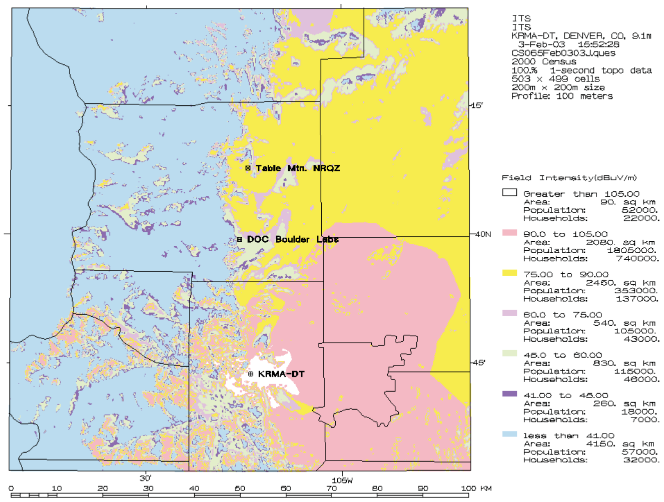
ITM & TIREM Harmonization

The goals of this work are to improve the predictive accuracies of ITM and TIREM, and to reduce or eliminate, where possible, differences between the models' predictions for circuits with equivalent input values, while preserving the increased predictive accuracies. This study was originally begun in FY 2001 to compare ITM v1.2.2 and TIREM v3.14 predictions to several measured radio propagation datasets. The set of measured data consists of over a dozen datasets containing more than 41,000 measurements, which range from 20 to 10,000 MHz. Many types of terrain (plains, hills, mountains, etc.) are included, and a wide variety of antenna heights and polarizations for the transmitter and receiver antennas were used for the measurements. If the data used to develop the empirical model cover all possible propagation situations, then the model should apply as a tool to perform radio-wave propagation predictions along any path. However, there are propagation scenarios not contained in this database.

Difficulties arose when the results of two previous comparison studies were examined. The two studies considered data from datasets with substantial commonality and found comparable mean and variance statistics for the models' prediction errors. Furthermore, there was evidence that the measurements and predictions, and, hence, the prediction errors, were subject to significant correlation. Computation of meaningful statistics in the presence of correlated data was a major problem encountered in this study.

Initial results from the study demonstrate that there is substantial correlation in the data and the statistics are significantly affected by it. This correlation is due to many of the measurements having been made at multiple frequencies and antenna heights on the same path. When propagation conditions for the measurements and hence predictions were found to be good or bad for a particular path, they were good or bad for all frequencies and heights along the path. Univariate statistical analysis of the data relies on data samples in which the individual measurements have been randomly drawn from a large universe of radio-wave propagation measurements. These samples should be independent and have identical frequency distribution. When the data samples are correlated, this independence assumption is violated.

ITS has proposed and tested a mechanism for dealing with this data correlation. The measurements on one path are considered independent of those taken on another path. The excess loss relative to free space predicted by ITM is compared to the measured data, and the difference is used as the statistical random variable. By segregating the data so that it is taken from different paths, a multivariate statistical analysis can proceed. This enables testing the significance of the distribution of the means, medians, and standard deviations of the difference between model loss predictions and measured data.



ITM prediction (using USGS 1 arcsec terrain data) of field strength for proposed digital TV broadcast antenna on Lookout Mountain near Golden, CO.

Effective Antenna Height Study

Transmitter and receiver effective antenna heights above the dominant reflecting plane are computed by an algorithm within ITM. The effective antenna heights along the propagation path are determined from the terrain contour, structural antenna heights above ground level, and distance to horizon from each antenna. ITM uses effective antenna heights except when computing horizon elevation angles, distances to horizons, and Fresnel zone clearances, while TIREM uses structural heights exclusively. This difference has a significant impact on propagation loss predictions. Thus, the correct value of reference attenuation depends on the values of effective antenna height. Effective antenna height changes the predicted propagation loss by as much as 45 dB relative to predictions using only a structural height.

An investigation was performed to determine the behavior and dependency of ITM propagation loss predictions as a function of effective antenna heights. ITM was used to make propagation loss predictions for most propagation paths in the measured data. In one case, the ITM effective antenna height algorithm was used to select the effective antenna height. In a second case, the effective antenna height was fixed at the structural height. The predicted and measured values of propagation loss were compared for both cases. The loss deviation is the predicted value of attenuation from the model minus the measured value of attenuation.

The comparison of ITM predictions to measured data has generated several different behavior characteristics related to this internal computation of effective antenna height. This information will provide guidance in selecting an improved effective antenna height computation. In some cases, ITM computes a large effective antenna height that differs substantially from the structural height, resulting in a large deviation between the value of predicted and measured transmission loss. There are cases where, if the effective antenna height were made equal to the structural height, then the deviation could be reduced. However, in many cases, the deviation resulting from measured paths using the structural height is much larger than the deviation for the measured paths using the effective height. There are also many measured paths where the optimum value of effective antenna height is somewhere between the ITM-determined effective antenna height and the actual structural antenna height. The effective antenna height is always greater than or equal to the structural height. Further study of the behavior of ITM in different scenarios will provide information for the development of a new effective antenna height algorithm that minimizes the deviation between predicted and measured propagation loss.

Recent Publication

N. DeMinco and P. M. McKenna, "Evaluation and comparative analysis of radio-wave propagation model predictions and measurements," *Applied Computational Electromagnetics Society Symposium Digest*, vol. X, Mar. 2003.

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ITS Telecommunications Theory Division engineers preparing an advanced antenna system for data collection (photograph by F.H. Sanders).

Telecommunications Theory

The rapid growth of telecommunications in the last 50 years has caused crowding in the radio spectrum and high levels of loading in many telecommunications networks, both wireless and wireline. New radio technologies must be developed and implemented to alleviate spectrum crowding. The parameters that limit network performance need to be thoroughly understood, and that knowledge needs to be brought to bear on improving the performance of existing and new networks. Tools to monitor the quality of audio and video information on communication channels also need to be developed and used so that network mechanisms can be adjusted in realtime 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.

ITS transfers the results of its work in all these technology areas to both public and private users, where the knowledge can be transformed into better telecommunications, new and better products, and new opportunities.

Areas of Emphasis

Advanced Antenna Testbed
The Institute has developed an advanced antenna testbed to be used in the investigation of "smart" antennas, which can greatly increase the capacity of wireless communications systems. The project is funded by NTIA.

Applied Electromagnetics
The Institute conducts research on the radio propagation channels that will be employed in new wireless communication technologies such as personal communications services and third generation (3G) wireless. Projects are funded by NTIA and DoD.

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

Effects of 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 network 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.

Advanced Antenna Testbed

Outputs

- Wideband radio channel sounding measurements.
- Antenna array diversity gain data.
- Angle of arrival input data for adaptive antenna schemes.
- 16-element MIMO response over a conductive ground plane.

The use of wireless mobile personal communications services (PCS) and wireless local area networks (WLANs) is expanding rapidly. Multiple-access schemes based on frequency division, time division, and orthogonal coding are presently used to increase channel capacity and optimize channel efficiency. Adaptive or “smart” antenna arrays can further increase channel capacity through spatial division. Antenna arrays can produce multiple beams as opposed to a simple omni-directional antenna. Numerous narrow beams can be used to divide space, allowing the re-use of multiple-access schemes, and thereby increasing channel capacity. Adaptive antennas can also track mobile users, improving both signal range and quality. For these reasons, smart antenna systems have attracted widespread interest in the telecommunications industry for applications to third generation wireless systems.

ITS has developed an advanced antenna testbed (ATB) to serve as a common reference for testing adaptive antenna arrays and signal combining algorithms, as well as complete systems. The ATB builds on wideband channel measurement systems previously developed by ITS. These systems use a maximal length pseudo-noise (PN) code generator to apply binary phase-shift keying (BPSK) modulation to a radio channel carrier frequency at the transmitter. The received signal is correlated at the receiver with the known PN code producing an impulse-like response. The impulse response characterizes the channel over a wide bandwidth (up to 50 MHz) about the carrier frequency. Digitization of the received data allows for post-processing to examine various combining algorithms and digital beam forming schemes. Channel sounding can be done continuously or in selected bursts.

Figure 1. 16-element transmit and receive antenna arrays used for MIMO testing at the NIST open area test site. The closer array is the receiving antenna (photograph by P. Papazian).

A recent ATB application is a 16-element multiple input, multiple output (MIMO) experiment. Two 16-element MIMO arrays were fabricated and tested and then deployed at the NIST open area test site, as shown in Figure 1 on the previous page. The objective of the test was to measure the **H** matrix in a known RF environment. This allowed a comparison between the Bell Labs layered space-time (BLAST) theory and the measurement capability of a wideband system using orthogonal coding (see **Recent Publications** below).

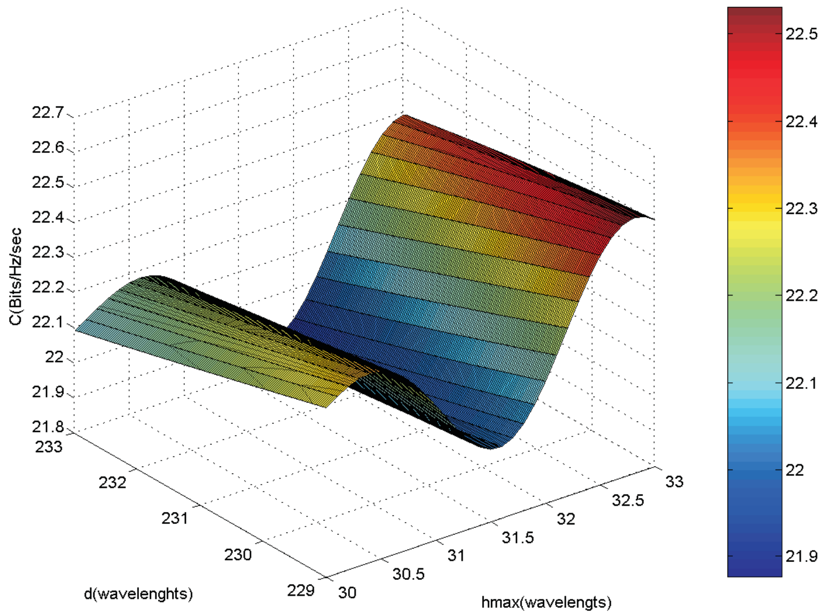

Figure 2. The capacity (C) of a 16x16 element array situated over a ground plane versus the antenna array separation (d), and the height above the ground plane of the top element of the receiving array (hmax).

A transmitter capable of generating 16 orthogonal pseudo-noise codes, one for each transmit element, was designed and fabricated using field programmable gate array (FPGA) technology. The signal received on each antenna element will then consist of the signal from all 16 transmitters after combination by the radio channel. After recording the sixteen receive channels, the 256-element channel matrix **H** can be assembled from the data. The MIMO capacity ***C*** for a communications link with n_T transmitters and n_R receivers can then be calculated using the following formula:

$$C = \log_2\left[\det\left(I + \frac{\rho}{n_T} HH^+\right)\right] bits / hz$$

$$where\ I = identity\ matrix$$

$$\rho = signal\ to\ noise\ ratio$$

$$H = complex\ transmission\ matrix$$

$$H^+ = hermetian\ transpose\ of\ H$$

Since it was known that small changes in transmitter separation and array height could change the **H** matrix, a parameter study was done to evaluate the effects of array positioning errors. Some results of this study are shown in Figure 2 above.

The ATB system is portable: both transmit and receive systems may be van-mounted. ATB measured data can be applied to the design of smart antenna PCS systems, evaluating system performance, channel model development and verification, and large communications system simulations. (See the Tools & Facilities section, p. 69, for more information about the ATB.)

Recent Publications

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.

P.B. Papazian, Y. Lo, J.J. Lemmon, and M.J. Gans, "Measurements of channel transfer functions and capacity calculations for a 16x16 BLAST array over a ground plane," NTIA Report TR-03-403, Jun. 2003.

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Applied Electromagnetics

Outputs

- Analytical models in applied electromagnetics.
- Metamaterials theoretical investigation.

ITS has a rich history of developing theoretical electromagnetic (EM) models for a wide variety of propagation scenarios. Recently, an emphasis has been placed on the EM behavior of complex structures and materials to support innovative designs of sophisticated devices for more versatile radio applications. EM theory is based on solutions to Maxwell's equations. When applied to realistic scenarios with broken symmetries and limiting dimensions, solutions involve complex variables and integrals with no closed-form solution. Although computational methods (e.g., finite-difference time-domain and finite difference) provide means to solve such problems, we focus on analytical techniques to provide intuitive understanding of physical phenomena.

Modeling the EM properties of homogeneous media gives a classic example of analytic modeling. Considering a tangible number of sources, closed-form theoretical solutions are obtainable for the electric and magnetic fields everywhere in space. However, this method is not practical for modeling of the prohibitively large number of sources that occur at the atomic level. Methods involving spatially-averaged or macroscopic field quantities are more relevant. In the presence of applied fields, macroscopic field relations are dependent on average moment densities of the medium and are derived from multipole expansions of the averaged charge and current densities. All multipole moments combine to form classical models for permittivity ($\boldsymbol{D}=\epsilon\boldsymbol{E}$) and permeability ($\boldsymbol{H}=\boldsymbol{B}/\mu$).

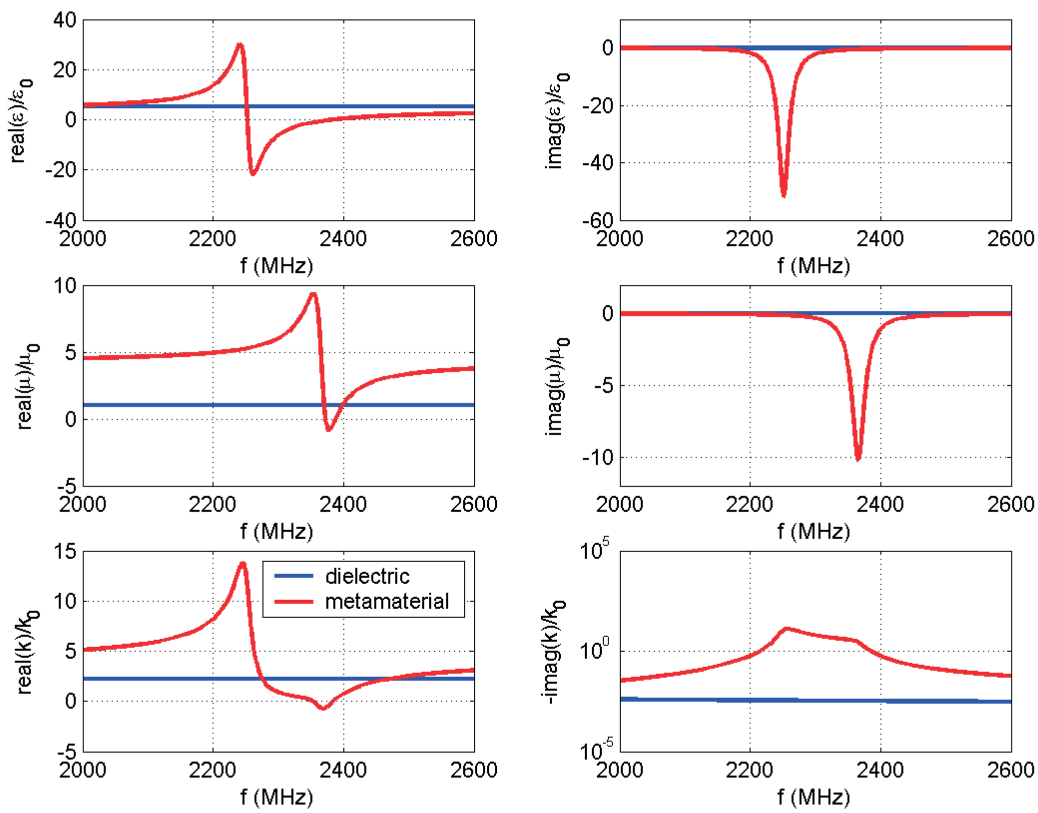

Figure 1. Double-negative material properties of a metamaterial composed of non-conducting spherical particles compared to material properties of a dielectric.

In applied EM scenarios, the scatterers inside man-made structures are typically metal or dielectric objects with dimensions ranging from relatively large to nanometer size. Whether induced moments arise from atomic-size scatterers or from macroscopic aggregates of matter, as long as wavelength is substantially larger than the dimensions and spacings of scatterers, the concept of effective medium parameters remains valid. Similarly, quasi-static approximations at relatively large wavelengths provide means to model complex structures and geometries into effective properties. For example, complicated 2d arrays and thin layers can be modeled with equivalent impedance surfaces, periodic arrays of conducting wires or small metal particles can be modeled with a sheet of average current, and arrays or random mixtures of particles in 3d can be modeled with effective medium parameters.

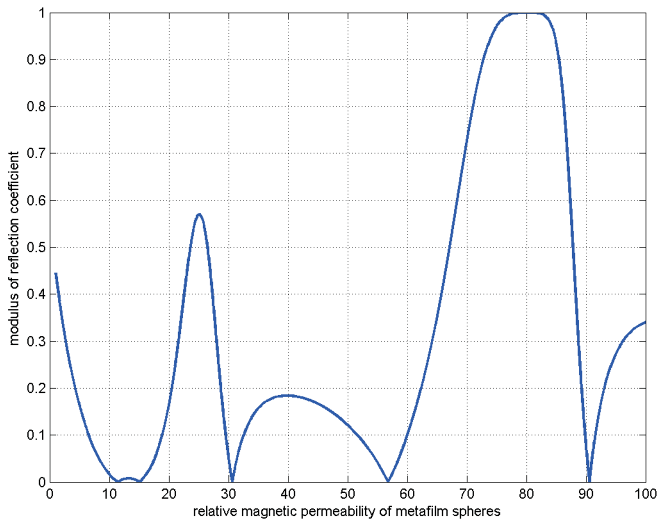

Figure 2. Metafilm reflection coefficient modulus versus magnetic permeability of spherical particles inside metafilm.

When wavelengths are comparable to and smaller than the dimensions and spacings of the scatterers, fields no longer see the composite as an effective media and more elaborate techniques to analyze the EM field interaction are necessary. Some interesting highly-dispersive EM behavior occurs. For periodic composite materials, resonances occur due to the size of the scatterer. At wavelengths near resonance, the electric and magnetic polarizations associated with individual inclusions can be simultaneously 180° out of phase with the applied **E** and **H** fields; the consequent phase velocity is in the opposite direction of the energy flow of the propagating wave in order to uphold the radiation condition. This scenario is equivalent to simultaneously negative real parts of ϵ and μ (see Figure 1 on previous page). Materials of this type have not been found in nature and have been referred to as double-negative, negative-index, and left-handed materials. They have received a great deal of attention because of their great potential for new applications.

Metamaterials are engineered composites that are designed to take advantage of such properties. These types of man-made materials are commonly engineered by designing specifically shaped scatterers embedded periodically through a volume in order to achieve a desirable bulk effect. Obviously, the more control we have over the properties of the metamaterial, the more applications we can get out of it. In fact, it has been shown that a metafilm composed of magneto-dielectric spherical particles can be designed to have total transmission or total reflection (see Figure 2 above). Further, if the inclusions were made from a material wherein its properties could be changed in real-time (e.g., with a biasing field or voltage), then a controllable surface can be realized. It is not too hard to imagine adaptable antennas and radomes that control the direction of emission, enhance emission rate, suppress interference, and perform other types of system optimization.

In our efforts we have conducted comprehensive and mathematically rigorous analyses of fundamental electromagnetic concepts applied to metamaterials. Topics include modeling the electric and magnetic polarization of metamaterials, deriving the propagation characteristics for various fundamental geometries, and exploring limitations imposed by finite dimensions of the bulk composite. Investigation into electronically controlling the electric and magnetic properties of metamaterials will also be a subject for study in pursuit of adaptable applications.

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Audio Quality Research

Outputs

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

Digital coding and transmission of speech and audio signals are enabling technologies behind many innovations in telecommunications and broadcasting including digital cellular telephone services, voice over Internet protocol (VoIP) services, and digital audio broadcasting systems. Speech signals can be coded and transmitted at rates as low as 4 kbit/s with good resulting quality. More general audio signals that include music and other sounds can be coded and transmitted with remarkably high fidelity at rates between 16 and 256 kbit/s per channel. 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, one generally must trade off quality, bit-rate, delay, and complexity. In addition, the robustness of digital coding and transmission algorithms is critical in applications that use lossy channels. Important examples of lossy channels include those provided by wireless systems and those provided by the Internet. The ITS Audio Quality Research Program seeks to identify and develop new approaches that increase quality and robustness or lower the bit-rate, delay, or complexity of digital speech and audio coding and transmission. The ultimate result of such progress should be better sounding, more reliable, more efficient telecommunications and broadcasting services at lower costs.

In most digital speech and audio coding and transmission systems, a set of complex time-varying interactions among signal content, source coding, channel coding, and channel conditions 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. Throughout FY 2003, subjective and objective audio quality testing was conducted to support Audio Quality Research efforts. In addition, customized objective speech quality estimation tools were developed to support other ITS efforts that are focused on the characterization of commercially available communications systems. Some of the laboratory equipment used to in the ITS Audio Quality Research Program is shown in Figure 1 below.

Two additional FY 2003 research efforts are briefly summarized here. In packetized speech transmission systems (the most prominent example is VoIP) transmission delay can vary significantly and rapidly, even within a single spoken phrase. This delay

Figure 1. Some of the laboratory equipment used to support the ITS Audio Quality Research Program (photograph by S. Wolf).

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, and program staff worked to develop an algorithm to do this.

This algorithm must compare the input and output signals of the speech transmission system under test. But many systems of interest will distort speech waveforms, so a conventional waveform correlation solution often fails. The new algorithm uses speech envelopes that are generated by rectifying and low-pass filtering speech waveforms. High frequency information is lost in this stage, but significant robustness to waveform distortion is gained, and speech envelopes have proven very useful for determining coarse estimates of delay. To refine those coarse estimates, the next stage of the algorithm compares speech power spectral densities since these representations retain important properties of the speech signal, even when the waveforms suffer significant distortion. Figure 2 (above right) shows speech waveforms, speech envelopes, and speech power spectral densities for example input and output speech signal segments.

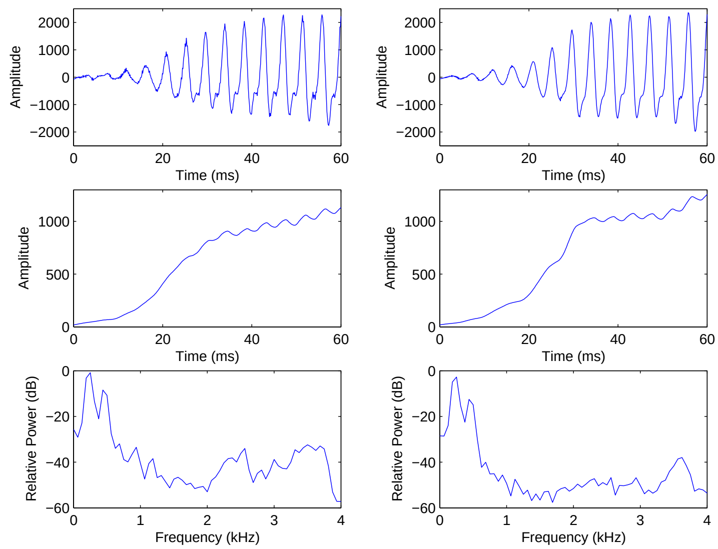

Figure 2. Speech waveforms, envelopes, and power spectral densities (top to bottom) are used to estimate the time-varying delay between a system input (on left) and output (on right).

In a separate effort, program staff worked towards more robust speech coding through the 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 physical or virtual channels. The MDC encoder does not know which of the channels are working and which of the channels have failed at any given time. On the other hand, the MDC decoder will know which of the channels have worked. 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.

Throughout FY 2003, the Audio Quality Research Program staff continued with selective upgrades to the ITS Audio-Visual Laboratories, including the introduction of a 5.1 channel digital audio system. The Audio Quality Research Program continued to transfer technology to industry, Government, and academia throughout FY 2003. Program staff prepared publications, delivered invited lectures and presentations, provided laboratory demonstrations, and completed peer reviews for journals and workshops. More detailed Program results are available at http://www.its.bldrdoc.gov/home/programs/audio/audio.htm

Recent Publications

S.D. Voran, "Channel-optimized multiple-description scalar quantizers for audio coding," in *Proc. IEEE 10th Digital Signal Processing Workshop*, Pine Mountain, GA, Oct. 2002.

S.D. Voran, "Perception of temporal discontinuity impairments in coded speech – A proposal for objective estimators and some subjective test results," in *Proc. MESAQIN (Measurement of Speech and Audio Quality in Networks) Conference*, Prague, Czech Republic, May 2003.

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Effects of Radio Channel on Networking Performance

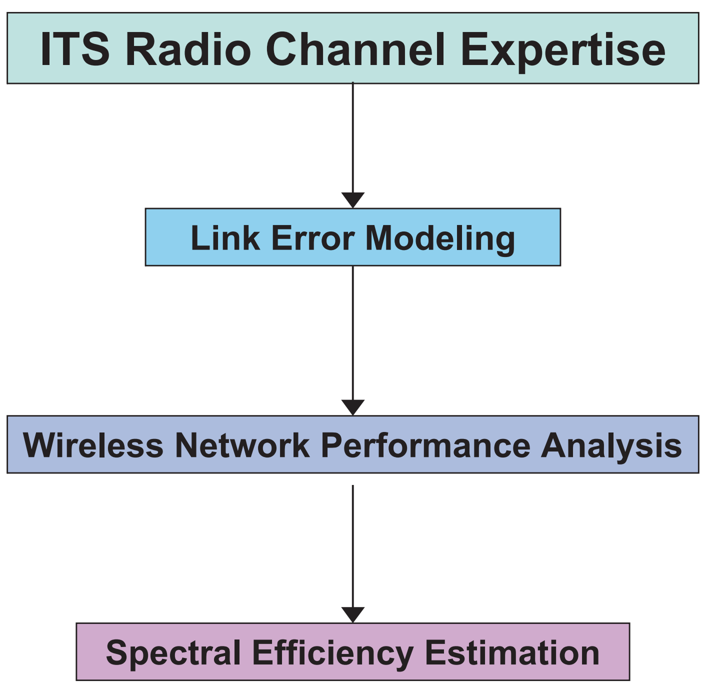
Outputs

- Models of bit, frame, and packet error random processes.
- Quantitative analysis of effects of radio channel on network performance.
- Estimation of the impact the radio channel has 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 communications 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 “Wi-Fi” 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 performance of the network measured in terms of decreased throughput, increased delay, and lost packets. This degradation ultimately limits the usefulness of allocated spectrum.

The Institute is currently striving to translate its radio channel expertise into information that helps designers analyze performance and regulators estimate spectral efficiency of wireless networks. This is being accomplished by focusing on three tasks: (1) accurate modeling of the link error random process resulting from radio channel impairments, (2) investigation of analytic techniques that correlate network performance to radio channel characteristics, and (3) the computation of wireless network spectral capacities which take radio channel impairments into account (see figure below).



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

Previous work included development of a radio link simulator incorporating multipath radio channel impairments and the analysis of bit and frame errors generated by the simulator. This work found that bit and frame errors due to frequency selective multipath had independent, geometrically distributed time intervals. This work is significant because it justifies the use of interval simulation which greatly reduces the computational burden of network simulations. In the past fiscal year we have focused on the statistical analysis of a commonly used radio channel random process, the Rayleigh fading process, in order to better understand statistical characteristics discovered through simulation.

It has been proposed that first-order Markov channel models can be used to adequately predict the behavior of a mobile “Rayleigh” fading channel and hence improve the reliability of mobile radio links. Previous research has addressed this question by applying information theory to the amplitude statistics of a stationary mobile radio channel. This approach required numerical analysis to show that for a particular covariance function and range of relevant parameters (i.e., Doppler frequency, symbol period), the channel is approximately first-order Markov. In our analysis, both amplitude and phase information are used to obtain analytic expressions that can easily be used to determine if a non-stationary arbitrary Rayleigh channel is necessarily first-order Markovian. The analytic results are given in terms of arbitrary covariance functions that can readily be applied to measurements. In particular, our results show that the Rayleigh fading channel is not first-order Markovian. In FY 2004, ITS plans to investigate the impact of this finding on characteristics of the link error processes used in network analysis and simulation.

Also, in the past fiscal year, ITS completed a comprehensive search of professional literature which defines 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. Review of research for two of the tasks, queuing and end-to-end retransmission, pointed to the need for more accurate channel modeling which included the higher-order statistical characterization of bit and frame error processes such as their correlation properties and corresponding power spectral densities.

For example, research into the effects of the radio channel on queuing used power spectral density analysis methods of the queuing process. This analysis is dependent on accurate modeling of the traffic, channel, and server random processes. Spectral analysis showed that queues could absorb rapid channel effects such as fluctuations of signal amplitude due to multipath fading but could not accommodate slower channel effects due to shadowing by a wall, building, or feature of the terrain. Queues overflowed and packets were lost when the power spectral density of the bit or frame error process had high low-frequency energy densities.

Similarly research into the effects of the radio channel on end-to-end retransmission showed that retransmission was beneficial, provided that the sender waited for channel conditions to improve. Two types of channel correlation properties are needed to analyze this: first, the correlation of the bit error process to determine when a link may be preventing end-to-end transmission, and second, the correlation of the radio channel to determine appropriate retransmission time-out thresholds. Research is quick to point out that the intimate relationship between end-to-end retransmission and network congestion control procedures, which assume any retransmission is due to congested switch queues, complicates this issue further.

At this time there is a limited set of analytic solutions that correlate the effect of a radio channel characteristic (such as Doppler frequency) on a networking task (such as queuing) through some network performance measure (such as throughput) for small networks. In FY 2004 these solutions will be evaluated to determine their usefulness in translating ITS radio channel measurements to network performance measures for analysis of queuing, routing, and end-to-end transmission methods.

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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 video) are required by end-users and service providers for specification of system performance, comparison of competing service offerings, network maintenance, and use optimization of limited network resources. The goal of the ITS Video Quality Research project is to develop the required technology for assessing the performance of these new digital video systems and to actively transfer this technology to other government agencies, end-users, standards bodies, and the telecommunications industry, thereby producing increases in quality of service that benefit all end-users and service providers.

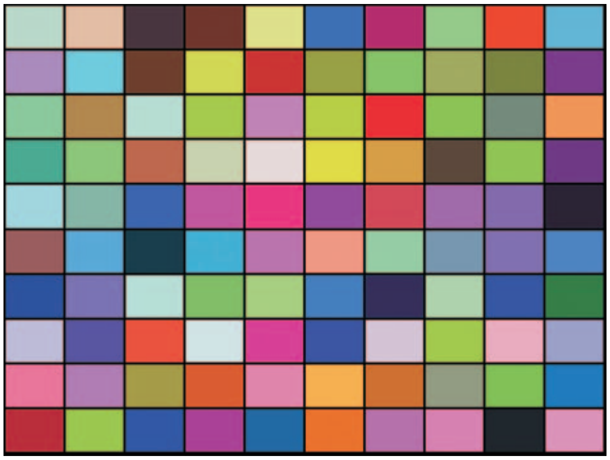
To be accurate, digital video quality measurements must be based on perceived "picture quality" and must be made in-service. This is because the performance of digital video systems is variable and depends upon the dynamic characteristics of both the input video and the digital transmission system. To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

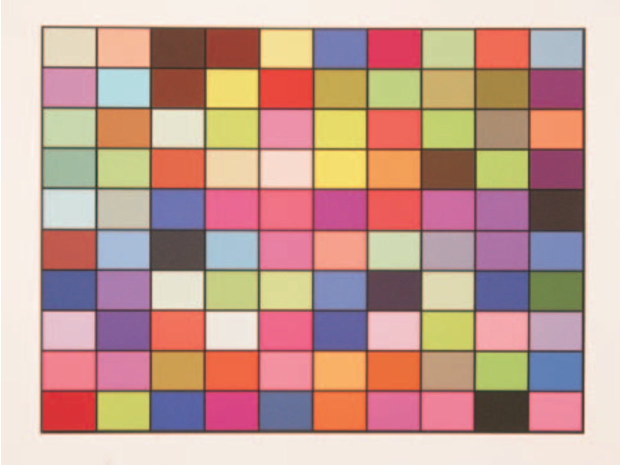
The Video Quality Research Project accomplished several highly significant milestones in FY 2003. An ITS-developed video quality metric (VQM) was prepared and submitted to the ITU Video Quality Experts Group (VQEG) for independent testing and verification. A total of 8 international VQM proponent submissions were evaluated for two different video tests (525-line U.S. video standard and 625-line European video standard) during the Dec. 2002 to Feb. 2003 time frame. Impaired video files (unknown to all proponents) were processed through the ITS VQM software and the results were returned to VQEG for independent analysis. Of the 8 submissions, the ITS VQM submission was the clear "winner" of the competition. The ITS submission was the only VQM in the top performing group for both the 525-line and 625-line video tests. For the U.S. standard 525-line video test, the ITS VQM achieved a correlation coefficient to the subjective data of almost 95%, near the theoretical limit. These test results are even more remarkable because the ITS VQM submission was a "reduced-reference" measurement system, whereas the other proponents submitted "full-reference" measurement systems. The ITS VQM submission only requires approximately 1/100 of the reference data to make a measurement. As a result of these international achievements in 2003, the ITS VQM was standardized by ANSI in July 2003 (ANSI T1.801.03-2003). ITU-T Study Group 9 and ITU-R Working Party 6Q have also included the ITS VQM in their upcoming Draft Recommendations that will be finalized next fiscal year. To assist companies and potential licensees in the deployment and use of the patented ITS VQM technology, evaluation software that implements the above national and international standards was posted on the ITS web site. Since the evaluation software was posted, nearly 200 U.S. and 100 international individuals and companies have downloaded it. ITS staff members received a Department of Commerce Silver Medal for this work.

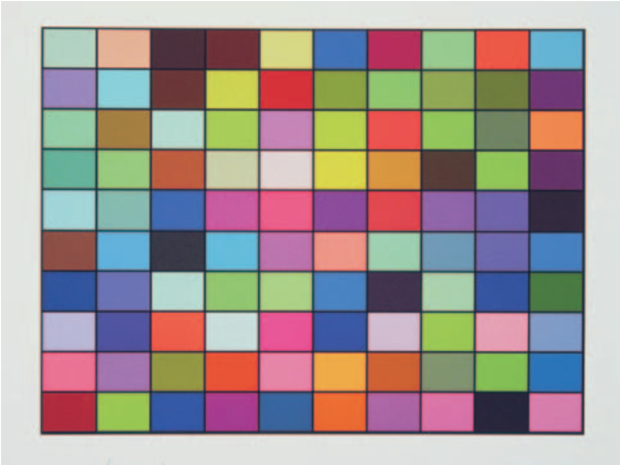
Significant progress was also made in FY 2003 in the following areas: developing and validating Single Stimulus Continuous Quality Evaluation (SSCQE) subjective testing methods, developing methods to combine multiple subjective data sets into one large coherent data set (required to effectively utilize ITS's massive subjective data base for

VQM development), construction of a subjective and objective high definition television (HDTV) laboratory, and development of color calibration algorithms for digital still and video imaging systems. Since the limited space provided here is not sufficient to describe these research activities, the reader is encouraged to examine the publications below for further details.

The figure (right) demonstrates application of the color correction algorithms that were developed to remove linear and non-linear color distortions. The linear correction involves the use of a color correction matrix that 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 in the uncorrected image (e.g., red, green, and blue). This algorithm can correct for color distortions that are more complicated than a simple gain and DC shift in each of the color components.







Demonstration of color correction: Original (Top), Camera (Middle), Calibrated (Bottom).

Recent Publications

ANSI T1.801.03-2003, “Digital Transport of One-Way Video Signals — Parameters for Objective Performance Assessment.”

M. Brill et al., “Accuracy and cross-calibration of video quality metrics: New methods from ATIS/T1A1,” *Signal Processing: Image Communication Journal*, special issue on Video Quality, Nov. 2003.

M. H. Pinson and S. Wolf, “Comparing subjective video quality testing methodologies,” in *Proc. SPIE Video Communications and Image Processing Conference*, Lugano, Switzerland, Jul. 2003.

M. H. Pinson and S. Wolf, “An objective method for combining multiple subjective data sets,” in *Proc. SPIE Video Communications and Image Processing Conference,* Lugano, Switzerland, Jul. 2003.

S. Wolf, “Color correction matrix for digital still and video imaging systems,” NTIA Technical Memorandum TM-04-406, 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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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 Labs 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.
- General Electric Company
- GTE Laboratories Inc.
- Hewlett-Packard Company (HP)
- Industrial Technology, Inc.
- Integrator Corporation
- Intel Corporation
- Lehman Chambers
- Lucent Digital Radio
- Lucent Technologies
- Motorola Inc.
- Netrix Corporation
- Telesis Technology Laboratories
- 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. Recent CRADAs are described below.

- Intel Corporation and ITS have completed cooperative research and development in the area of telecommunications and multimedia. The areas of interest include subjective and objective video quality, subjective and objective audio quality, and wireless communications. PC software that measures the quality of received video signals is available on ITS' web site.
- Lucent Technologies, Bell Laboratories, and ITS initiated 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.
- ITS entered into 173 new CRADAs, in FY 2003, with parties interested in evaluating ITS' Video Quality Metric (VQM) software (see figure on next page). This software objectively measures video quality as it would be perceived by end-users of a video system. ITS's VQM has been made a national standard by ANSI. VQM is also in the process of being accepted as an international standard by the International Telecommunication Union. The software is covered by ITS patents that are available for licensing under fair and equitable terms.

First page of the online CRADA for Video Quality Metric (VQM) Software, available on the ITS website at http://its.bldrdoc.gov/n3/video/vqmdownload_US.htm

- ITS entered into five new CRADAs with the private sector for the application and evaluation 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 that would be 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. In addition, ITS plans to commit substantial resources of its own to the development and standardization of these new technologies.

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ITU-T and 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 goal there — and in related national standards work — has been to motivate the development and standardization of user-oriented, technology-independent measures of telecommunication service quality. Such measures promote competition and technology innovation among equipment and service providers, facilitate interworking among independently operated networks and dissimilar technologies in the provision of end-to-end services, and give users a quantitative, practical means of defining their telecommunication requirements and selecting products that effectively meet them.

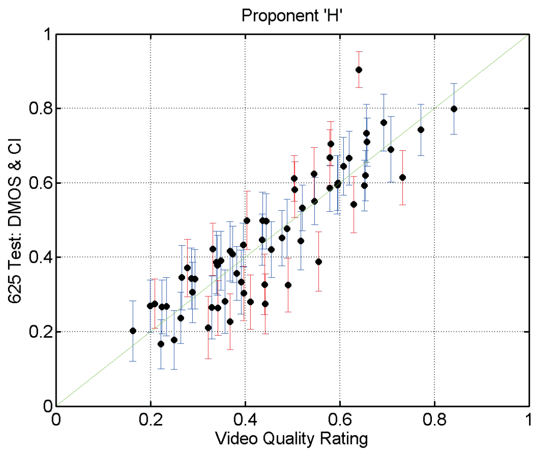
In FY 2003, the Institute provided leadership in two key ITU-T groups: Study Group 13 Working Party 4 (Network Performance and Resource Management) and Study Group 9's Working Group on Quality Assessment. SG 13/WP 4 develops performance Recommendations for high-speed synchronous digital hierarchy (SDH), asynchronous transfer mode (ATM), dense wave division multiplexing (DWDM), and Internet Protocol (IP) based network technologies. SG 9's Working Group on Quality Assessment defines quality objectives for integrated broadband cable networks and television and sound transmission. ITS also provided leadership and technical contributions to the ITU affiliated Video Quality Experts Group (VQEG) and the American National Standards Institute (ANSI) accredited T1 (Telecommunications) Committee's Technical Subcommittee T1A1 (Performance, Reliability, and Signal Processing). VQEG works in conjunction with ITU-T SG 9 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. T1A1 contributes strongly to ITU-T in all of these technology areas.

During FY 2003, the Institute's SG 13 leadership participated in managing over a dozen standards development projects, contributing to new or revised draft Recommendations in technology areas including IP network Quality of Service (QoS), optical network performance, multi-protocol label switching (MPLS) performance, and IP and ATM network resource management. ITS led SG 13/WP 4 participation in special activities including the conduct of a SG 13 “Futures Session” to plan advanced network standardization, formation of an ITU-T Joint Rapporteur Group on Next Generation Networks (JRG-NGN), and publication of an *IEEE Communications Magazine* Feature Topic on IP Network QoS. The lead article in this issue is referenced below. ITS spearheaded industry standards planning on several issues of interest to U.S. industry and government, e.g., QoS signaling for IP-based networks. The ability to control QoS in multi-service, multi-provider IP networks is expected to be important to user acceptance of voice over IP (VoIP) — and to IP-based telephony deployment, service innovation, and revenue growth.

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. Over 300 participants are currently subscribed to this reflector.

During FY 2003, VQEG completed a 3-year evaluation of proposed "full reference" VQMs for assessing the video quality of standard definition television. Eight proponent laboratories from six countries submitted candidate VQMs for evaluation. Seven research organizations from three countries formed an independent laboratory group that conducted the evaluation. The laboratory group developed a comprehensive test plan, coordinated it among the participants (and interested standards bodies), selected test material (unknown to the proponents) comprising a representative sample of distribution quality television content, processed the selected video "clips" through widely used video compression systems, and obtained subjective ratings of the source and degraded video quality using human viewer panels. The proponents independently evaluated the same source and degraded video clips using their candidate objective VQMs. The laboratory group performed a comprehensive analysis of the resulting data to confirm the validity of the subjective test results and to compare the subjective and objective ratings. VQEG presented the results in a final report to ITU-T SG 9 (see below).

The figure (above right) illustrates the correlation between subjective and objective ratings for the proponent VQM that provided the best overall correlation with the subjective results (VQM "H" in the referenced report). The y-axis represents the subjective video quality rating produced by the human viewer panels — specifically, the normalized difference between the mean opinion score (MOS) of the unimpaired source video and that of the degraded output video. The x-axis represents the corresponding normalized video quality rating predicted by the candidate objective VQM. An "ideal" objective VQM would produce exactly the same rating as the subjective viewer panels for each source and degraded video clip, and all of the plotted points would lie exactly on the diagonal. The correlation illustrated is for the 625-line television system used in much of Europe; it is numerically 0.89. For the 525-line television system used in North America, the same VQM produced an even better overall correlation (about 0.94). VQM H was the only VQM rated in the top-performing group for both the 525- and 625-line systems.



Difference mean opinion score (DMOS) and confidence interval (CI) versus video quality rating for proponent 'H.'

On the strength of these results, several cooperating standards organizations took action to standardize the VQM H objective video quality assessment algorithm during FY 2003. Committee T1 standardized the new algorithm in American National Standard T1.801.03-2003. ITU-R SG 6 submitted a new Recommendation documenting the new algorithm for ITU-R approval, and ITU-T SG 9 plans to submit a compatible Recommendation for ITU-T approval early in 2004. Details regarding the Institute's video quality contributions to ITU-R are provided in the ITU-R Standards Activities section of this report (pp. 66-67). Details regarding VQM H (which was developed at ITS) are provided in the Video Quality Research section of this report (pp. 60-61).

Recent Publications

N. Seitz, "ITU-T QoS standards for IP-based networks," *IEEE Communications Magazine*, Vol. 41, No. 6, pp. 82-89, Jun. 2003.

A. Webster, "Final Report from the Video Quality Experts Group on the Validation of Objective Models of Video Quality Assessment, Phase II (FR-TV2)," ITU-T Study Group 9 Contribution 60, Sep. 2003.

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ITU-R Standards Activities

Outputs

- Measurements performed to determine how measured levels of radar unwanted emissions vary as a function of receiver bandwidth.
- Presentations at meeting in London, UK of WP 8B International Radar Correspondence Group to consider new limits and measurement techniques for assessment of radar spurious emissions.
- Comparative measurements of radar spurious emissions performed by ITS at a laboratory in the UK for validation of the technique given in a Study Group 8 Draft New Recommendation.
- Ongoing technical support to the U.S. Administration in its investigation of advanced technologies for sharing radio spectrum between radars and short-range wireless communication devices at microwave frequencies.
- ITS-developed measurement method for broadcast television video quality, included in a Preliminary Draft New ITU-R Recommendation as a normative technique to be used internationally.

Success in worldwide telecommunications markets, as well as successful and compatible use of telecommunications technologies both domestically and abroad, 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 worldwide telecommunications standards and regulatory body, the International Telecommunication Union — Radiocommunication Sector (ITU-R), to further its objectives with regard to all forms of wireless communications on a worldwide basis. ITS in turn provides important, ongoing technical support for the U.S. Administration in several ITU-R Study Groups and Working Parties. Current areas of interest include (but are not limited to): improved methods for assessing spectrum impacts of high-power radars; advanced spectrum sharing technologies between wireless communication devices and radars; and video and audio quality-assessment technologies.

To support improved spectrum efficiency for both the private sector and governments, ITS engineers have performed ongoing technical work to assess and improve spectrum emissions from high-power radars and to pass their work to the international community in ITU-R Working Party 8B (WP 8B). In FY 2003, this work involved a series of measurements on emissions from a high-power radar at the ITS Table Mountain research facility. The spectrum measurements were used first of all to determine how the measured levels of unwanted emissions depended upon the selection of measurement bandwidth, an important consideration in the development of radar emission level masks both domestically and abroad. The results showed that measured unwanted emission levels varied at the rate of about 16log(bandwidth), as contrasted with the well-known 20log variation measured at the radar fundamental frequency. Secondly, the measurements demonstrated that spectrum measurements performed at half the far-field distance of the radar antenna were nearly identical to results obtained in the far field of the same antenna. All these results were presented at a meeting of the WP-8B Radar Correspondence Group (RCG) in London, UK in June. They are available on-line at http://www.its.bldrdoc.gov/meetings/rcg/contributions.html. Following that meeting, engineers from ITS and NTIA's Office of Spectrum Management (OSM) engineers performed system development measurements at a facility near Portsmouth, UK.

Finally, a number of proposals have been made by non-U.S. Administrations in ITU-R to introduce communication systems into bands that have heretofore been allocated for radars on a primary basis. Since the U.S. Administration has made an enormous investment in the development and deployment of both military and civilian radars, it is essential that new systems proposed for spectrum sharing with radars be shown to be electromagnetically compatible with existing and future radars. To this end, ITS engineers in FY 2003 prepared to test the new technology, called dynamic frequency selection (DFS) for the U.S. Administration.

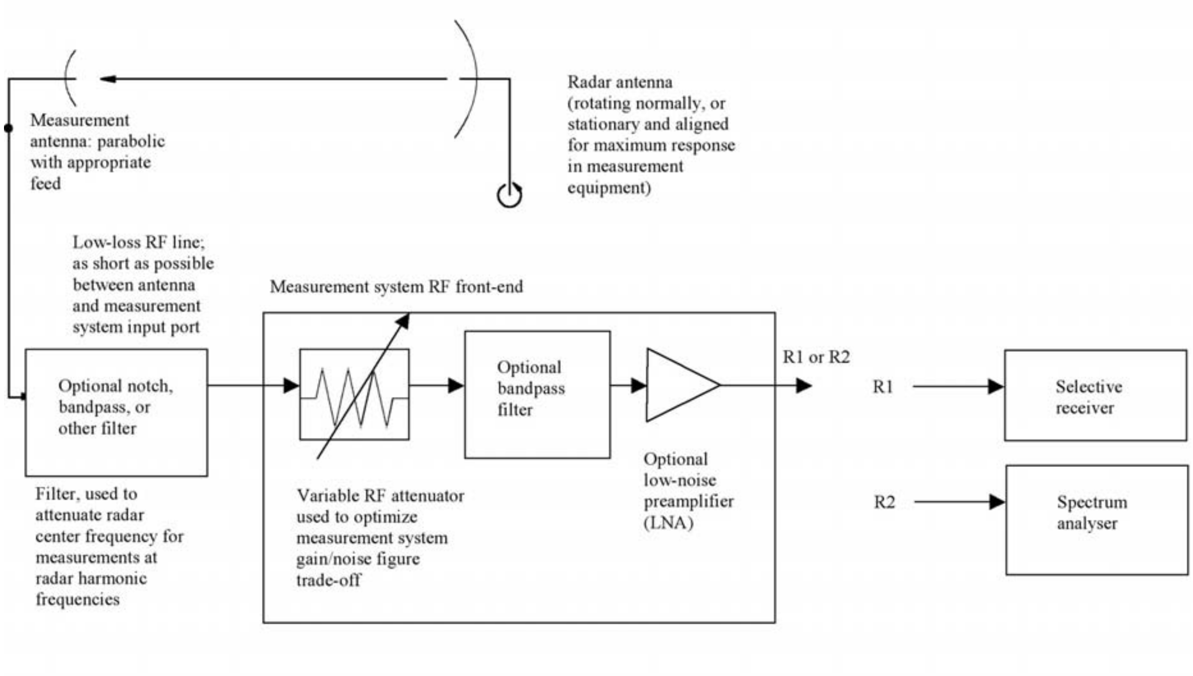

Diagram from ITU-R Study Group 8 Draft New Recommendation M.1177-2, showing ITS-designed radar spectrum measurement system that has been adopted internationally for radar emission measurements.

DFS has never been implemented operationally and presents a number of difficult, unsolved technical problems. In FY 2003, ITS and OSM engineers developed a test procedure to assess the performance of prototype DFS devices operating near 5 GHz. Initial tests will be performed early in FY 2004, and results quantifying DFS effectiveness are expected to be provided in a number of forums including the ITU-R later in FY 2004.

In FY 2003, a video quality measurement system developed by ITS engineers was made a normative worldwide measurement method in a new ITU-R WP 6Q Preliminary Draft New Recommendation (PDNR). In ITU-R Working Party 6Q (WP 6Q), this technique was included in the PDNR along with other U.S. contributions defining the scope, purpose, and application of the PDNR. Further information about this work can be found in the ITU-T section of this technical progress report (pp. 64-65).

Recent Publications

ITU-R WP-8B Radar Correspondence Group (RCG) document RCG-14, “Variation in measured levels of OOB and spurious emissions with measurement bandwidth.”

ITU-R WP-8B RCG document RCG-15, “Near-field and far-field spectrum measurements on a maritime radar.”

(Both WP-8B documents are available at http://www.its.bldrdoc.gov/meetings/rcg/ contributions.html)

ITU-R SG-8 Draft New Recommendation M.1177-2, “Techniques for measurement of unwanted emissions from radar systems.”

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ITS engineers setting up the short & long range wireless test links at the Green Mountain Mesa field site (photograph by C. Behm).

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 (see "Advanced Antenna Testbed," pp. 52-53). The system can simultaneously characterize eight wideband radio channels (expandable to 16 with multiplexing). The received signals are digitized for flexible post processing. 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) acts as 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 in the figure 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.

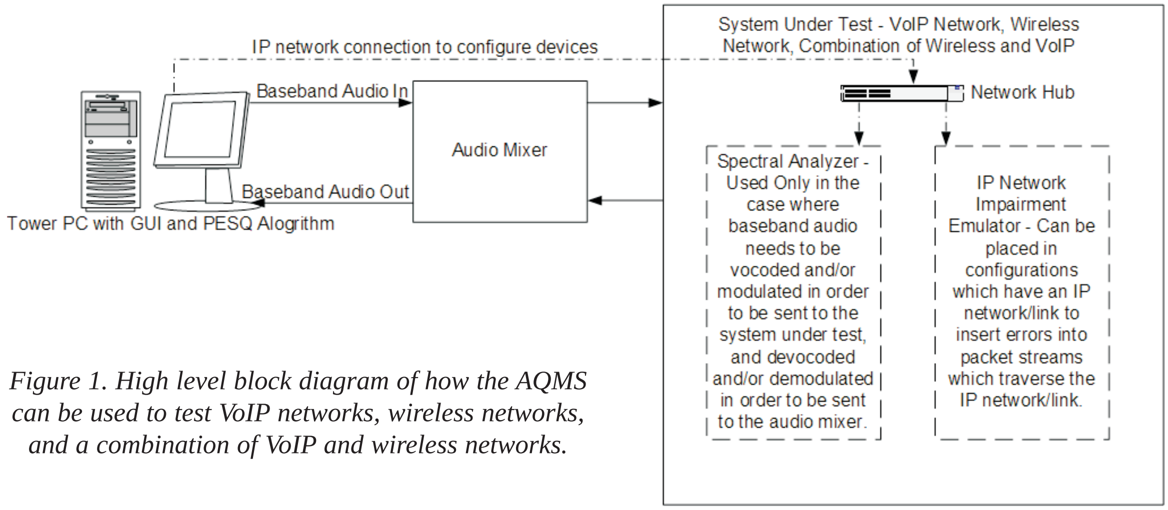

Figure 1. High level block diagram of how the AQMS can be used to test VoIP networks, wireless networks, and a combination of VoIP and wireless networks.

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 spectral 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 comprised of two UHF/VHF repeaters with the capability to transmit over IP links, and 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. The next step in the evolution of the AQMS is to add an acoustic coupling feature. This involves the use of soundproof chambers with head and torso simulators (HATS). This feature will allow mobile handsets/radios to be used during testing rather than using a piece of test equipment, like the spectral analyzer, to modulate/demodulate baseband audio.

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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 four 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 high-definition 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 playback 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 playback 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 6 TB of disk storage. Other available storage peripherals include a 12-GB 4mm tape drive, an 8-GB 8mm tape drive, and a 40-GB digital linear tape drive.

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++, processes video signals in accordance with American National Standards Institute (ANSI) T1.801.03-2003 metrics, 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. Unlike traditional analog sliding correlators, the DSCP digitizes a received pseudo-noise signal at an intermediate frequency (IF) and then post processes the data. Relative to the sliding correlator, the time over which the impulse is generated is less, and therefore, the probe is better suited to mobile applications. 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 the following 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 Network Research Center (see p. 79). 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 Internet Services

ITS provides public Internet access to NTIA/ITS publications, program information, meeting information, and on-line Telecommunications Analysis Services 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 ANSI T1 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
- Telecommunications Analysis Services. Available at http://www.its.bldrdoc.gov/tas/
- 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/
- 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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ITS 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 of diverse types with a variety of software capabilities in order to support propagation planning and modeling, as well as emerging technologies research.

The secure facilities of ITS 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 current and future 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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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.

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Network Simulation System

Data communications networks, both wireline and wireless, continue to grow and evolve. Changes to a network configuration, such as additional users or the implementation of a new transfer protocol, can result in unforeseen problems and situations. Computer simulation of these communications networks, and the proposed changes to them, can help system planners to anticipate and eliminate potential problems. Large networks are so complex that it is only by modeling and simulation that telecommunication planners can hope to predict the effects of catastrophic failures in the infrastructure.

NTIA/ITS maintains a widely held network simulation software package. By using this highly flexible software, trained ITS staff can design, configure, and implement almost any type or size of data-communications network. ITS has several licenses to use the software, including access to the basic package, radio modules, and the traffic importation and analysis module.

ITS staff are successfully using this software in support of both internal and external projects to simulate existing and proposed data communications networks. For example, ITS has built reference network models for use in network survivability and restoral studies. ITS staff also used the simulation system to extract and analyze Voice over IP (VoIP) traffic using Session Initiation Protocol (SIP) in an Internet experiment between Washington, D.C., and Boulder, Colorado.

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Pulsed CW Radar Target Generator

The Pulsed Continuous Wave (CW) Radar Target Generator is an electronic tool that is 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 models of radars. 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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QPSK/BPSK Generator

The QPSK/BPSK (quadrature/binary phase-shift keying) Generator is an electronic tool used to generate digital signals for testing purposes. The generator consists of software to generate a sampled version of the signal, an arbitrary waveform generator to create an analog version of the signal and a frequency conversion unit to shift the signal's frequency content to the desired output frequency. The ITS written software gives the user control over several parameters of the signal including the duration of the signal, the sample rate, the number of cycles per dibit (which can be an integer to place the bit transitions on zero crossings) and the signal amplitude. The frequency conversion unit mixes the signal to its final value through a frequency agile local oscillator. A bandpass filter removes the unwanted mixer products and an adjustable attenuator controls the output amplitude. The generator has been used to simulate interfering sources, within the reception range of a radar, to record any effects. Because of the frequency agility, detailed waveform parameter control, and amplitude control, this tool can be used in a large number of applications.

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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 noise measurement 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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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 system 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 Field Site and Radio Quiet Zone

Established in 1954, the Table Mountain Field Site and Radio Quiet Zone is a unique facility for radio research. Located north of Boulder, the site extends approximately 2.5 miles in a north-south direction 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 in order to minimize radio-frequency interference to sensitive research projects.

Facilities at the site include:

- **Spectrum Research Laboratory** — This is a state-of-the-art facility for research into radio spectrum usage and occupancy. The Table Mountain Radio Quiet restrictions ensure that no signal incident on the mesa overpowers any other, and an antenna farm providing both directional and non-directional antennas spanning a broad range of frequencies makes the entire radio spectrum available for study.

- **Open Field Radio Test Site** — As an elevated, flat-topped butte with uniform 2% slope, Table Mountain is uniquely suited for radio experiments. It is flat with no perimeter obstructions, and the underlying ground is relatively homogeneous. This facilitates studying outdoor radiation patterns from bare antennas or antennas mounted on various structures such as buildings and automobiles. Recent work has included the measurement of digital television signals in a simulated home, studies of measurement methods for evaluating radar signal characteristics, and evaluation of 802.11b wireless network systems.

- **Mobile Test Vehicles** — There are a number of mobile test equipment platforms available at the mesa varying from 4-wheel drive trucks to full-featured mobile laboratories.

- **Large Turntable** — This is a 10.4 meter (34 foot) diameter rotatable steel table mounted flush with the ground. Laboratory space located directly underneath the table provides a location for test instrumentation as well as the control equipment and motors needed to rotate the turntable. This facility is being renovated and is expected to be operational in 2004.

- **Two 18.3 Meter (60 foot) Parabolic Dish Antennas** — These parabolic dish antennas are steerable in both azimuth and elevation and have been used at frequencies ranging from 400 MHz to 6 GHz. Research done using these antennas has included: studies of tropospheric radio scattering, diffraction of radio waves by mountain ranges, bistatic scattering cross sections of thunderstorms, thermal radio emission from thunderstorms, and deep space radio astronomy.

In addition to these facilities, the Table Mountain Research program supports a number of research activities such as 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 asses 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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or
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Telecom Glossary 2000 Web Page

Telecom Glossary 2000 is an American National Standard, ANS T1.523-2001, and is available free to the public on the ATIS/T1 website http://www.atis.org/tg2k

In cooperation with ATIS/T1, ITS maintains a web page that serves as the Development Site for Proposed Revisions to *Telecom Glossary 2000*: http://www.its.bldrdoc.gov/projects/devglossary

This website contains the baseline document, *Telecom Glossary 2000*, as well as features that allow viewers to submit proposed glossary additions and revisions for the revision committee's consideration.

Telecom Glossary 2000 — for which proposed revisions are being solicited — contains approximately 8000 definitions in the disciplines of fiber optics communications, telephony, National Security/ Emergency Preparedness (NS/EP), National Information Infrastructure (NII), spectrum sharing, radar, radio communications, television (UHF, VHF, cable, high definition television), high-frequency automatic link establishment, radio, facsimile, networks (intelligent networks, next-generation Internet, open network architecture, ISDN, broadband ISDN, and network management), communications security, data processing, premises wiring, grounding and bonding, telegraphy, and video. Recently added disciplines include web terminology, T1 Standards, information assurance/security, and photonics.

The glossary is presented in hypertext with clickable graphics and 69,000 hyperlinks to defined terms. The website contains an ITS-developed search engine with easy-to-follow, menu-driven instructions, to allow a more organized and thorough review of the entire glossary. The advantages of the search engine include tailored, rapid access to the text of all definitions, ranking of results, and hyperlinks to all search engine results.

The Development Site for Glossary Revisions automatically generates e-mail to the glossary's editors whenever anyone submits a proposed revision (addition, deletion, or change of text) by clicking the selected buttons on the Development Site web page. That e-mail is collected automatically in a bin and reviewed for future forwarding to the Revision Committee.

The glossary and the Development-tools web sites are accessible and free to anyone with web access. Typical users include Federal purchasing agents, NS/EP implementors, NII planners, Standards writers and users, R&D workers, O&M workers, technical writers, telecom instructors, and telecom vendors.

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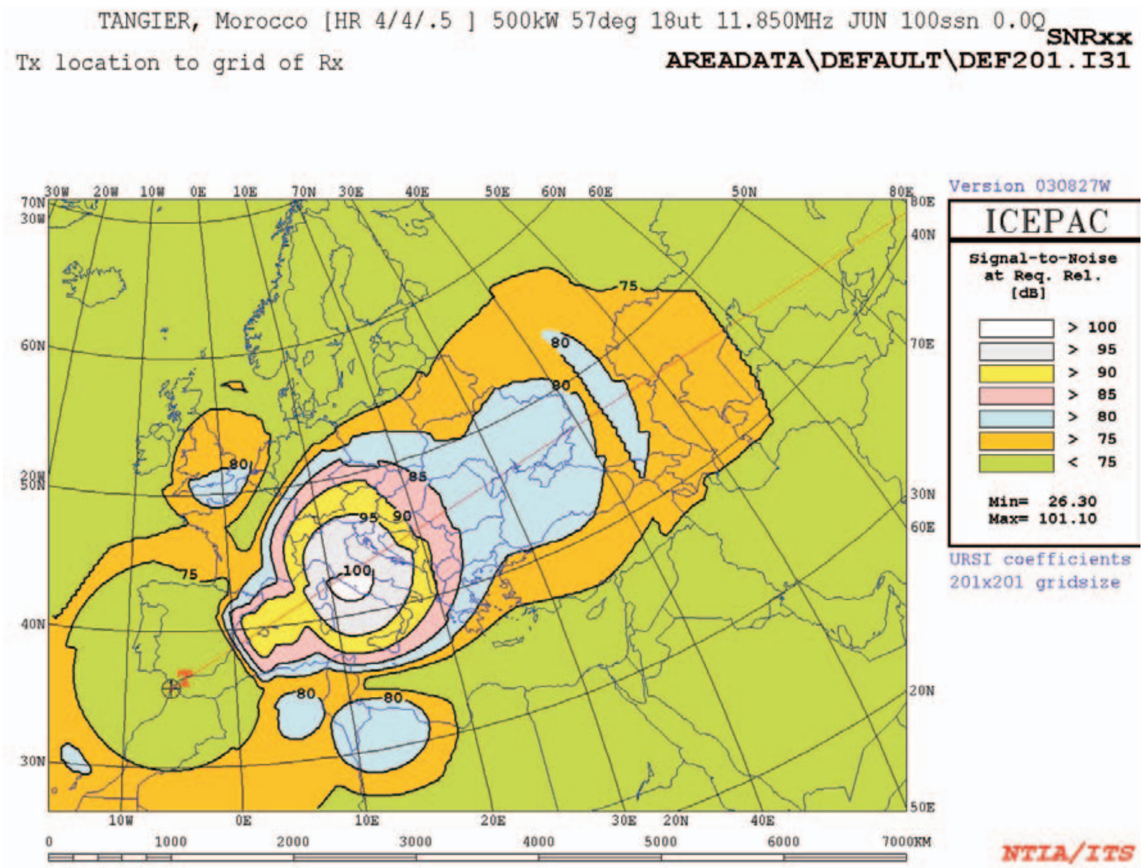
Telecommunications Analysis Services

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. 42-43). 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



Example of ICEPAC HF area coverage prediction.

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 above. 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 users of the program. The user can create new stations by hand, or by importing station information directly from the FCC database. Analyses may be performed using the existing FCC database and allotment assignments, or the user can replace a station with one created and maintained in the user's catalog.

NWS – A specialized application to assist the National Weather Service in maintaining its catalog of weather radio stations (currently about 750).

PBS – An analysis model similar to the HDTV model, but specialized for Public Broadcasting Stations (PBS). Typical outputs may consist of composite plots showing Grade A and B coverage of several stations or "overlap" plots which show areas covered by more than one station.

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

ITM – Source code available for the 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 work 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 recently 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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Wireless Networks Research Center (photograph by S. Wolf).

(Top) RSMS-3 during radar measurement; (bottom) NTIA personnel performing pulse measurements on the same radar (photographs by F.H. Sanders).

ITS Projects in FY 2003

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. Develop techniques for more robust coding and transmission of speech and audio over lossy and noisy channels. Deliverables include technical publications, algorithms, and technical presentations and laboratory demonstrations as requested.
Project Leader: Stephen D. Voran (303) 497-3839
e-mail svoran@its.bldrdoc.gov

Broadband Wireless Research Collect broadband radio-wave propagation data between 100 MHz and 100 GHz, to promote new technology to increase spectrum utilization by increasing radio-channel capacity. Data are used to verify signal coverage, model development, and military communications system reliability. Deliverables include NTIA Reports and a journal article.
Project Leader: Peter B. Papazian (303) 497-5369
e-mail ppapazian@its.bldrdoc.gov

Broadband Wireless Standards Develop technical means to improve predictions of signal coverage and interference for 3G wireless services through support to ITU-R, to Public Safety community interests in TIA TR-8 (Project 25), and to other organizations; enhance or refine propagation-related models as needed; develop evaluations of and recommendations for spectrum optimization techniques. Deliverables include standards contributions and a technical paper.
Project Leader: Paul M. McKenna (303) 497-3474
e-mail pmckenna@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.
Project Leader: Randall S. Bloomfield (303) 497-5489
e-mail rbloomfield@its.bldrdoc.gov

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

Networking Technology Continue the development of networking technology methodologies and tools to address network management and network security/protection issues. Deliverables include a technical report.
Project Leader: Val Pietrasiewicz (303) 497-5132
e-mail valp@its.bldrdoc.gov

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

RSMS Development Develop new spectrum measurement capabilities for the third-generation Radio Spectrum Measurement System (RSMS-3), including automated report production capability for broadband spectrum survey results, new digital signal processing (DSP) capabilities, data acquisition software to operate with a new generation of spectrum analyzers, acquisition and integration of a digitizer and a digital oscilloscope, and miscellaneous new measurement capabilities.
Project Leader: J. Randy Hoffman (303) 497-3582
e-mail rhoffman@its.bldrdoc.gov

RSMS Fourth Generation Development Develop and implement the fourth generation Radio Spectrum Measurement System equipped with state-of-the-art instrumentation, measurement methods, and analysis capabilities. Deliverables include the functional RSMS 4th generation vehicle, basic wideband stepped measurement, and front-end preselector modules.
Project Leader: J. Randy Hoffman (303) 497-3582
e-mail rhoffman@its.bldrdoc.gov

RSMS Operations Provide NTIA with critical measurement support to determine broadband spectrum occupancy 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 or that may be acquired by Government agencies.
Project Leader: J. Randy Hoffman (303) 497-3582
e-mail rhoffman@its.bldrdoc.gov

Spectrum Efficiency and UWB Consultation Provide technical planning and support to OSM on several technical tasks regarding possible changes to Federal Land Mobile Radio systems that could result in a substantial increase in spectrum efficiency and effectiveness. Deliverables include a report and standards contributions.
Project Leader: Robert J. Matheson (303) 497-3293
e-mail rmatheson@its.bldrdoc.gov

Spectrum Regulation and Engineering Support Provide NTIA with critical analysis and measurement support in the following areas: ITU-R Working Party 8B radar issues; assessment of emissions from PC-type computers and small electric appliances for comparison with ultrawideband device emissions; and development of formulas (or computational algorithms) for the necessary bandwidth of swept-frequency (“chirped”) radar signals. Deliverables include technical reports.
Project Leader: Frank H. Sanders (303) 497-7600
e-mail fsanders@its.bldrdoc.gov

Table Mountain Modernization Provide a clean, useful research facility to allow continued work in areas supporting the Government’s role in telecommunications. Work includes cleanup, safety issues, and site infrastructure upgrades.
Project Leader: John D. Ewan (303) 497-3509
e-mail jewan@its.bldrdoc.gov

Table Mountain Research Project Expand ITS research activity at the Table Mountain field site through the creation of a laboratory for the study of measurement methods and techniques needed to ascertain spectrum utilization and occupancy, and methods for measuring and characterizing radio noise.
Project Leader: J. Wayde Allen (303) 497-5871
e-mail wallen@its.bldrdoc.gov

Third Generation Wireless Develop an accurate attenuation, frequency selective fading, noise, and interference radio channel models for proposed third generation wireless standards, to be used by both industry and Government. Deliverables include reports which disseminate the results of tasks to the public.
Project Leader: Robert J. Achatz (303) 497-3498
e-mail rachatz@its.bldrdoc.gov

Third Generation Wireless Interference Modeling and Characterization Building on previous ITS work, develop interference models for each PCS technology, apply the models in characterizing one-on-one, one-on-many, and many-on-one PCS interference for 3G architectures, and determine operational guidelines and other practical means of mitigating observed interference effects. Deliverables include a publication and contributions to a handbook to be used by network planners and field personnel.
Project Leader: Timothy J. Riley (303) 497-5735
e-mail triley@its.bldrdoc.gov

Video Quality Research Develop the required 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, 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 (J/PS/HS) community, and other communication system products and services supporting telecommunications and information technology (IT) 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 standards contributions, reports, economic impact statements, guidelines, handbooks, white papers, and other products as requested.
Project Leader: Val J. Pietrasiewicz (303) 497-5132
e-mail valp@its.bldrdoc.gov

Department of Defense

Communication System Planning Tool (CSPT) Model Development Enhance the Communication System Planning Tool (CSPT) developed by ITS, by including an indoor propagation model and improved visualization.
Project Leader: Robert O. DeBolt (303) 497-5324
e-mail rdebolt@its.bldrdoc.gov

Enhancements to 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

Forecast of Emerging Secure Wireless Telecommunications Technologies Research emerging and evolving wireless technologies (voice, data, video, and integrated services), then conduct forecasts, map trends, and develop a series of reports that discuss the analysis, survey, and impact of those telecommunications technologies.
Project Leader: Christopher Redding (303) 497-3104
e-mail credding@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
e-mail ehaakinson@its.bldrdoc.gov

Department of Treasury

Public Safety Wireless Network (PSWN) Engineering Studies Provide engineering studies for the 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 the PSWN.
Project Leader: Eldon J. Haakinson (303) 497-5304
e-mail ehaakinson@its.bldrdoc.gov

Department of Treasury Technical Studies Provide support for the Department of Treasury efforts to evaluate technologies and spectrum options due to changes that result from equipment and band policy changes.
Project Leader: Eldon J. Haakinson (303) 497-5304
e-mail ehaakinson@its.bldrdoc.gov

Federal Aviation Administration

FAA Radio Frequency Interference Monitoring System (RFIMS) Support Disassemble the RFIMS laboratory and ship the FAA property to the FAA.
Project Leader: Brent L. Bedford (303) 497-5288
e-mail bbedford@its.bldrdoc.gov

Federal Highway Administration

Technical Support for Implementation of a Nationwide DGPS Service 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
e-mail jlemmon@its.bldrdoc.gov

Federal Railroad Administration

Railroad Telecommunications Study Continue general support to the Federal Railroad Administration as it pertains to railroad telecommunications and the activities of the 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 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
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Digital Land Mobile Radio Standards Development Assist NCS-N2 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, lead 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 T1A1 and related standards organizations; 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 (CIP) 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 (ETS) capabilities in ITU-T Study Group 9. Apply computer simulation, laboratory studies, security analyses, and/or traffic engineering to assist NCS in advancing NS/EP, PDD-63, and associated Homeland Security and Critical Infrastructure Protection (CIP) initiatives in 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 (CIP) needs. This will include participating in the TIA TR41 Standards Formulating Group (SFG) with emphasis on IP telephony gateways and their supporting infrastructure, developing technical contributions to ensure that user interfaces being developed for IP telephony satisfy NS/EP communications requirements, conducting a research and development effort to examine how TR41 standards can best be exploited to meet NS/EP requirements, and evaluating aspects of strategic interoperability.
Project Leader: Robert Stafford (303) 497-7835
e-mail rstafford@its.bldrdoc.gov

Wireless Tasking 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 J. Behm (303) 497-3640
e-mail cbehm@its.bldrdoc.gov

U.S. Army

Information Systems Engineering Command (ISEC), Fort Huachuca Compare propagation prediction models to help ISEC decide which to use in a specific project.
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

Support for Analysis of Mobile Measurements Provide information to Lucent to support the analysis of mobile transmission matrix measurement data taken by ITS. This analysis will further the advancement of MIMO technology, important for improving the spectral efficiency of wireless services.
Project Leader: Peter B. Papazian (303) 497-5369
e-mail ppapazian@its.bldrdoc.gov

Department of Commerce Boulder Labs. Top: radar measurements at Table Mountain field site; bottom: ITS vehicles parked in the back of the main facilities at 325 Broadway (photographs by F.H. Sanders).

ITS Outputs in FY 2003

NTIA Publications

J.W. Allen and T.X Brown, Eds., "Proceedings of the International Symposium on Advanced Radio Technologies: March 4-7, 2003," NTIA Special Publication SP-03-401, Mar. 2003.

No abstract available.

J.W. Allen and T. Mullen, "Digital television (DTV) field strength and video quality study," NTIA Technical Memorandum TM-03-405, Aug. 2003.

A particular concern about digital television (DTV) broadcasts is whether such broadcasts have sufficient power to be received using inexpensive indoor antennas located inside a typical home. To test this, the Institute for Telecommunication Sciences (ITS) constructed a "simulated home" mounted on a flatbed trailer. This allowed ITS to move the test home to a number of locations in the vicinity of an operating commercial DTV transmitter. By equipping this test home with commercially available DTV receivers and an indoor antenna located at the center of the home, ITS could then observe and record the DTV reception at a number of test locations. This information was further correlated with the incident field strengths by measuring the signal power outside the structure at a height of 10 meters above ground and at a location inside the structure at a height of roughly 1.5 meters above ground. This report summarizes the results of this study.

J.R. Hoffman, E.J. Haakinson, and Y. Lo, "Measurements to determine potential interference to public safety radio receivers from ultrawideband transmission systems," NTIA Report TR-03-402, Jun. 2003.

This report describes laboratory measurements to determine the extent and nature of interference to Public Safety radio receivers by ultrawideband (UWB) signals. Two Public Safety radio receivers from different manufacturers were tested in the 138-MHz band, both configured for Project 25 digital radio mode and one additionally configured and tested in analog mode. The laboratory measurements were performed by inserting increasing levels of UWB interference and measuring either bit-error rate (BER) for digital radios or signal-plus-noise-plus-distortion to noise-plus-distortion ratio (SINAD) for one of the same radios placed in analog mode. By varying pulse repetition frequency (PRF), pulse spacing schemes, and gating, a variety of UWB signals were simulated, which were either Gaussian noise-like, sinusoidal, or a hybrid of the two when passed through the receiver passband. Results showed that, when reported in terms of average UWB power in the receiver bandwidth, there is little difference in interference to Public Safety radios when comparing each of the generated UWB signal types. When expressed in terms of signal-to-interference power ratio, where interference power is defined as the power passed through the receiver passband, reference sensitivity (5% BER for digital radios and 12 dB SINAD for analog radios) occurs at approximately 10 dB, with a variation of 2 to 5 dB on either side, depending upon the receiver and signal type. When the interference power is expressed in terms of anything other than the mean power in the receiver bandwidth (e.g., wider bandwidths or peak power), the receiver response can vary greatly depending upon the nature of the interfering signal.

P.B. Papazian, Y. Lo, J.J. Lemmon, and M.J. Gans, "Measurements of channel transfer functions and capacity calculations for a 16x16 BLAST array over a ground plane," NTIA Report TR-03-403, Jun. 2003.

Wideband channel transfer function measurements were made for a 16-element transmit and 16-element receive, multiple input, multiple output (MIMO) antenna array. The measurements were conducted using the National Institute of Standards and Technology (NIST) open area test site (OATS), allowing analytic calculations of the channel transfer functions. The H matrix for the BLAST array was then determined from measured data and the link capacity was calculated using information theory. The theoretical link capacity was then calculated and found to be 22.16 Bits/Hz/s for horizontally polarized antennas and 22.19 Bits/Hz/s for vertically polarized antennas. It was then found that the measured results agreed with the theoretical calculations with 5% error using horizontally polarized antennas and with <0.3% error for the vertically polarized case. The objective of this work was to verify that wideband measurements could be used to accurately measure H and predict the capacity of a MIMO channel.

M.H. Pinson and S. Wolf, "Video quality metric software, version 2: Volume 1, SGI 64-bit code; Volume 2, SGI 32-bit code; Volume 3, Sun code; Volume 4, HP code," NTIA Software/Data Product SD-03-396, Oct. 2002.

No abstract available.

S.D. Voran, "An iterated nested least-squares algorithm for fitting multiple data sets," NTIA Technical Memorandum TM-03-397, Oct. 2002.

A multiple data set fitting problem often arises in conjunction with the development of objective estimators of perceived audio or video quality. In such development work, we often seek the best linear relationship between a set of objective audio or video quality estimation parameters and a set of subjective audio or video quality scores. In order to find the most robust and reliable relationship, we prefer to perform a least-squares fit using as many audio or video data points as possible. This motivates us to combine scores from different subjective tests. Unfortunately, scores from different subjective tests or data sets can differ in significant ways due to differing test procedures, environments, languages, and other sources. We develop a solution to this multiple data set fitting problem: the iterated nested least-squares (INLS) algorithm. This algorithm iterates between two least-squares steps. One step attempts to homogenize heterogeneous data sets through the use of a single first-order correction for all of the data points in each data set. The other least-squares step solves for the appropriate linear combination of the parameters, across all data sets. We also offer example INLS algorithm results using simulation data and data from telephone-bandwidth speech quality tests. For convenience we have written this memorandum in the language of objective estimation of perceived audio and video quality but the results are completely general and can be used to fit other types of data sets as well.

S.D. Voran, "Compensating for system gain: Motivations, derivations, and relations for three common solutions," NTIA Technical Memorandum TM-03-398, Oct. 2002.

It is often desirable to compensate for system gain, especially before objectively estimating perceived audio or video quality from system inputs and outputs. A common approach is to scale the system output to compensate for system gain. One can take three views of the system, and this leads to three different gain compensation solutions: one that minimizes distortion, one that matches input-output power, and one that maximizes signal-to-distortion 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 audio and video examples and show that these three solutions can differ significantly. We also report some of the gain compensation choices found in the objective audio and video quality estimation literature.

Outside Publications

Articles in Conference Proceedings

N. DeMinco and P.M. McKenna, "Evaluation and comparative analysis of radio-wave propagation model predictions and measurements," in *Applied Computational Electromagnetics Society Symposium Digest*, vol. X, Mar. 2003.

This paper describes recent analyses performed on propagation model predictions and comparisons of those predictions with measured data. The specific radio-wave propagation prediction model is the Irregular Terrain Model (ITM) developed by the Institute for Telecommunication Sciences. The model is valid at frequencies from 20 to 20,000 MHz. Descriptions of specific problems encountered with analyses and comparisons of predicted versus measured data are discussed. The major results of this study are:

1. Model predictions are extremely sensitive to the magnitude of the effective antenna height, and an alternative effective antenna height algorithm is necessary to improve prediction accuracy.

2. A terrain database that does not accurately represent the propagation path will severely impact the model loss predictions.

3. When the measured data samples are correlated (i.e., not independent), a multivariate statistical analysis of the available measured data must be used to properly assess stochastic behavior.

R.J. Matheson, “The electrospace model as a frequency management tool,” in “Proceedings of the International Symposium on Advanced Radio Technologies: March 4-7, 2003,” J.W. Allen and T.X Brown, Eds., NTIA Special Publication SP-03-401, Mar. 2003.

In this tutorial paper, the electrospace is described as a theoretical hyperspace occupied by radio signals, which has dimensions of location, angle-of-arrival, frequency, time, and possibly others. Because these dimensions are independent, a given radio signal has a unique descriptor in the electrospace. Signals having different electrospace descriptors can theoretically be separated by a suitable receiver. The electrospace model provides a good framework to define spectrum user rights that divide licensed spectrum into parcels that can be flexibly used in an independent and non-interfering manner, while allowing complete freedom to divide and aggregate spectrum parcels via a secondary market. Disadvantages of the electrospace model are that it assumes ideal receivers and it allows the specification of spectrum parcels that cannot practically be used in the real world. Additional rules can be added to account for non-ideal receivers.

C. McKay and F. Masuda, “Empirical study of 802.11b wireless networks in the presence of Bluetooth interference,” in “Proceedings of the International Symposium on Advanced Radio Technologies: March 4-7, 2003,” J.W. Allen and T.X Brown, Eds., NTIA Special Publication SP-03-401, Mar. 2003.

Two complementary wireless networking standards, Bluetooth and 802.11b, operate in the 2.4 GHz Industrial, Scientific, and Medical (ISM) band. Although they use different methods to modulate and transmit data, significant interference can occur. Under certain conditions, a Bluetooth-enabled device can render an 802.11b connection almost useless. This paper presents measurement results from a study on the throughput of an 802.11b link when one end of the link is subjected to interference from Bluetooth devices.

C. McKay and F. Masuda, “Empirical studies of wireless VoIP speech quality in the presence of Bluetooth interference,” in *Proc. IEEE International Symposium on Electromagnetic Compatibility 2003*, Boston, MA, Aug. 2003.

Both Bluetooth and 802.11b wireless devices operate in the same frequency range. Increasingly, Voice-over-IP (VoIP) traffic is being routed over wireless network segments where packet loss can be an issue. This paper presents the results of a study of the effects of Bluetooth devices on the quality of VoIP calls over 802.11b networks.

A. Paul, P. McKenna, and F. Najmy, “Evaluation of two site-specific radio propagation models,” in “Proceedings of the International Symposium on Advanced Radio Technologies: March 4-7, 2003,” J.W. Allen and T.X Brown, Eds., NTIA Special Publication SP-03-401, Mar. 2003.

This paper discusses evaluation of site-specific propagation models used in the VHF and UHF range of frequencies which are needed for prediction of coverage and interference, especially for wireless communication applications. It describes two ongoing tasks, one at the National Telecommunications and Information Administration (NTIA) and the other at the International Telecommunication Union (ITU). In the United States, two major deterministic site-specific propagation models have been used for a long time: the Terrain Integrated Rough Earth Model (TIREM) developed for the Joint Spectrum Center (JSC) of the Department of Defense, and the Irregular Terrain Model (ITM) developed by the Institute for Telecommunication Sciences (ITS) of NTIA. About two years ago, the Office of Spectrum Management (OSM) of NTIA started a task for comparison and harmonization of the two models (TIREM and ITM). Both ITS and OSM are working on this task in cooperation with JSC. Predicted propagation losses from both models have been compared with large numbers of measured data. The first order statistical results, such as mean prediction error and its standard deviation, are similar for the two models. However, errors for individual

paths between the two models sometimes differ by 20 dB or more. Some of the results of the comparison task and possible explanations for the discrepancies are presented. At the ITU Radiocommunication Study Group 3 (ITU-R SG 3) on propagation, Working Party 3K decided to proceed with a Preliminary Draft New Recommendation (PDNR) on a method for path-specific propagation prediction. An outline for this document, developed in 2002, is also discussed.

M. H. Pinson and S. Wolf, “Comparing subjective video quality testing methodologies,” in *Proc. SPIE Video Communications and Image Processing Conference*, Lugano, Switzerland, Jul. 2003.

International recommendations for subjective video quality assessment (e.g., ITU-R BT.500-11) include specifications for how to perform many different types of subjective tests. Some of these test methods are double stimulus where viewers rate the quality or change in quality between two video streams (reference and impaired). Others are single stimulus where viewers rate the quality of just one video stream (the impaired). Two examples of the former are the double stimulus continuous quality scale (DSCQS) and double stimulus comparison scale (DSCS). An example of the latter is single stimulus continuous quality evaluation (SSCQE). Each subjective test methodology has claimed advantages. For instance, the DSCQS method is claimed to be less sensitive to context (i.e., subjective ratings are less influenced by the severity and ordering of the impairments within the test session). The SSCQE method is claimed to yield more representative quality estimates for quality monitoring applications. This paper considers daa from six different subjective video quality experiments, originally performed with SSCQE, DSCQS and DSCS methodologies. A subset of video clips from each of these six experiments were combined and rated in a secondary SSCQE subjective video quality test. We give a method for post-processing the secondary SSCQE data to produce quality scores that are highly correlated to the original DSCQS and DSCS data. We also provide evidence that human memory effects for time-varying quality estimation seem to be limited to about 15 seconds.

M. H. Pinson and S. Wolf, “An objective method for combining multiple subjective data sets,” in *Proc. SPIE Video Communications and Image Processing Conference*, Lugano, Switzerland, Jul. 2003.

International recommendations for subjective video quality assessment (e.g., ITU-R BT.500-11) include specifications for how to perform many different types of subjective tests. In addition to displaying the video sequences in different ways, subjective tests also have different rating scales, different words associated with these scales, and many other test variables that change from one laboratory to another (e.g., viewer expertise and criticality, cultural differences, physical test environments). Thus, it is very difficult to directly compare or combine results from two or more subjective experiments. The ability to compare and combine results from multiple subjective experiments would greatly benefit developers and users of video technology since standardized subjective data bases could be expanded upon to include new source material and past measurement results could be related to newer measurement results. This paper presents a subjective method and an objective method for combining multiple subjective data sets. The subjective method utilizes a large meta-test with selected video clips from each subjective data set. The objective method utilizes the functional relationships between objective video quality metrics (extracted from the video sequences) and corresponding subjective mean opinion scores (MOSs). The objective mapping algorithm, called the iterated nested least-squares algorithm (INLSA), relates two or more independent data sets that are themselves correlated with some common intermediate variables (i.e., the objective video quality metrics). We demonstrate that the objective method can be used as an effective substitute for the expensive and time consuming subjective meta-test.

F. Sanders, "Dependence of radar emission spectra on measurement bandwidth and implications for compliance with emission mask criteria," in "Proceedings of the International Symposium on Advanced Radio Technologies: March 4-7, 2003," J.W. Allen and T.X Brown, Eds., NTIA Special Publication SP-03-401, Mar. 2003., pp. 73-79.

Radar transmitter emission criteria normally include the specification of frequency-dependent emission masks. These masks specify the amount by which unwanted radar emissions (both out-of-band and spurious) must be suppressed relative to the power levels emitted at the radars' fundamental frequencies. Compliance with emission masks is determined through measurements of emission spectra. The measured levels of radar unwanted emissions and fundamental-frequency emissions both vary as a function of measurement system bandwidth, Bm. But the variation with Bm differs between the unwanted emissions and the fundamental-frequency emissions. Moreover, the variation of unwanted emission levels varies as a function of frequency as well as Bm. This creates a problem for radar emission mask-compliance measurements.

The National Telecommunications and Information Administration (NTIA) Institute for Telecommunication Sciences (ITS) has explored this problem by performing emission spectrum measurements on a maritime surface search (navigation) radar. In the spectrum data that are presented, the radar unwanted emission levels are found to vary between 12 log(Bm) and 20 log(Bm), depending upon frequency. But the measured power of the radar fundamental frequency is found to vary as 20 log(Bm) for all bandwidths that are less than or equal to 1/(radar pulse width). The result is that the level offset between the unwanted emissions and the fundamental-frequency emission level depends upon the measurement bandwidth and the frequency of the unwanted emissions. This result implies, at a minimum, that measurement personnel must take the effect of Bm into account when performing radar emission spectrum measurements for the purpose of determining emission mask compliance. Based upon the results of these maritime radar spectrum data, some technical strategies for measuring radar emission spectra for emission mask compliance are proposed. Possible technical implications for future development of radar emission masks are also discussed.

R. Stafford, C. Behm, and C. Redding, "Over-the-air techniques to determine IS-95 base station resource allocation," in *Proc. MILCOM 2002*, Anaheim, CA, Oct. 2002.

Federal communications users are increasingly dependent on commercial wireless systems. In the aftermath of both man-made and natural disasters, commercial wireless systems will be in high demand. Federal and commercial users must compete for scarce resources during high demand situations. Since most network performance data is not publicly available, it is crucial that federal wireless network users have the same level of information as the service providers. Wireless network performance data could provide federal users with the ability to avoid congested (high call-blocking) areas, view the effectiveness of wireless priority services, and assess infrastructure vulnerabilities. Walsh channel power occupancy can be used as an indicator of IS-95 network congestion. This paper describes methods and techniques used to conduct over-the-air measurements of IS-95 Walsh channel power occupancy. This data is then used to examine short and long term traffic channel statistics for several IS-95 carriers in the Denver metropolitan area.

S.D. Voran, "Channel-optimized multiple-description scalar quantizers for audio coding," in *Proc. IEEE 10th Digital Signal Processing Workshop*, Pine Mountain, GA, Oct. 2002.

Multiple-description coding is one way to gain robustness against lossy channels. We extend the multiple-description scalar quantizer (MDSQ) to a channel-optimized MDSQ (COMDSQ) that minimizes mean-squared error for a given channel environment. We discuss necessary and sufficient conditions for the optimality of M-channel COMDSQ's and provide a procedure for the design of 2-channel COMDSQ's. We provide example results including audio files from waveform and transform coders that employ COMDSQ's.

S.D. Voran, “Perception of temporal discontinuity impairments in coded speech – A proposal for objective estimators and some subjective test results,” in *Proc. MESAQIN (Measurement of Speech and Audio Quality in Networks) Conference*, Prague, Czech Republic, May 2003.

Temporal discontinuities in received speech are a reality of Internet Telephony or Voice over Internet Protocol (VoIP) systems. These relatively new impairments pose unique challenges to objective estimators of perceived speech quality. We suggest that objective estimators may benefit from the addition of a temporal discontinuity impairment processor and we provide subjective test results that may help with the design of such processors.

We added the loss, pause, and jump impairments (nine different levels of each) to random locations in active segments of G.723.1 coded speech. We then measured the resulting perceived speech quality via a formal absolute category rating subjective experiment using the mean opinion score (MOS) scale.

The results show that these three different impairments have similar influences on perceived speech quality, even though the pause and jump impairments are exact opposites (temporal dilation vs. temporal contraction). The results also demonstrate that at a fixed impairment rate, dispersion of these impairments is less detrimental to perceived speech quality than clustering of these impairments. We offer a simple mathematical model that relates impairment parameters to experimental MOS values. It is expected that these results will be of value to those who develop objective estimators of packetized speech quality as well as those who design jitter buffers and jitter buffer management (or playout) algorithms.

Journal Articles

N. Seitz, “ITU-T QoS standards for IP-based networks,” *IEEE Communications Magazine*, Volume 41, No. 6, pp. 82-89, June 2003.

To support IP/PSTN convergence, future IP networks will need to provide reliable, differentiated QoS to a diverse set of user applications, including telephony. To achieve end-to-end QoS solutions, IP network providers will need to agree on a common set of IP packet transfer performance parameters and QoS objectives. This paper describes two new ITU-T Recommendations, Y.1540 and Y.1541, that document such an agreement.

Other Publications

P. Papazian and R. Dalke, “Local multipoint distribution services (LMDS),” in *Wiley Encyclopedia of Telecommunications*, J.G. Proakis, Ed., New York: Wiley-Interscience, 2002, vol. 3, pp. 1268-1279.

No abstract available.

Unpublished Presentations

R. Matheson, "Measurement technology and issues," invited talk at the FCC Technological Advisory Council on Noise and Interference, July 7, 2003.

S. Voran, "Procedure for evaluation of candidate vocoders," invited presentation to TIA/EIA TR-8.4, June 2003. The talk addressed specific issues associated with subjective and objective estimation of speech quality as they related to current discussions and objectives of that group.

Conferences Sponsored by ITS

International Symposium on Advanced Radio Technologies (ISART 2003)

The International Symposium on Advanced Radio Technologies (ISART 2003) was held March 4-7, 2003. 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.

One notable addition to this year's conference was the publication of the “Proceedings of the International Symposium on Advanced Radio Technologies,” NTIA Special Publication SP-03-401, Mar. 2003. For more information about this conference 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 Element Dictionary, through the XML subcommittee of the Global Justice Information Network's Infrastructure/Standards Working Group.

Paul M. McKenna, National Chair of the U.S. contingent of ITU-R Study Group 3 (Radiowave Propagation); Chair of ITU-R Task Group 3/2 on Broadcast and Land Mobile Point-to-Area Propagation Predictions; 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; Technical Advisor to NCS Federal Telecommunications Standards Committee.

Timothy J. Riley, Editor for the proposed American National Standard: "Third Generation Systems and Licensed Band PCS Interference," as a member of TIA committee TR46.2 (Mobile & Personal Communications 1800 — Network Interfaces).

Neal B. Seitz, Chair of ITU-T Study Group 13 Working Party 4 (Network Performance and Resource Management); Vice Chair of ANSI-accredited Technical Subcommittee T1A1 (Performance and Signal Processing).

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).

Representative Technical Contributions

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

High-power Radars (authors include F. Sanders, B. Bedford, R. Sole, R. Hinkle)

- "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," Draft New Report, ITU-R Working Party 8B.
- "Unwanted emissions of primary radar systems," Proposed revision of Question ITU-R 202-2/8.

Network Survivability (authors/editors include A. Webster)

- T1.TR.79-2003 "Overview of Standards in Support of Emergency Telecommunications Service (ETS)."
- T1.TR.xx-2003 Draft Technical Report "Traffic Priorities in Emergency Telecommunications Service."
- Draft New Recommendation J.TDR, "Requirements and Specifications for Telecommunications for Disaster Relief over IPCablecom Networks," ITU-T Study Group 9.

TIA TR-8 (Private Land Mobile Radio) and APCO Project 25 (authors/editors include R.S. Bloomfield).

- "Proposal Concerning Development of a Documentation Plan for ISSI Interoperability Test Methods" (IPP Task Group; Jun. 10, 2003).
- "ITS Comments on *RTP Common VoIP RTP Payload May2003.doc*" (RTP Ad Hoc Group; Jul. 8, 2003).
- "ITS Comments on *System TG RFSS Ad Hoc Group June 12, 2003*" (RFSS Ad Hoc Group; Jul. 18, 2003).
- "ITS Comments on *APCO P25 Inter-RF System Interface (ISSI) Overview (Draft TSB-102.BACC-A, June 11, 2003)*" (TR-8.19 Wireline Interface Subcommittee; Jul. 24, 2003).
- "Draft of Issue C of Planned New TSB: Project 25 ISSI Performance Specifications for Voice Services" (ISSI Task Group; Aug. 7, 2003).
- "Issue D of Planned New TSB: Project 25 ISSI Measurement Methods for Voice Services" (ISSI Task Group; Aug. 7, 2003).

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

- ANSI T1.801.03-2003, "Digital Transport of One-Way Video Signals - Parameters for Objective Performance Assessment."

Abbreviations/Acronyms

2.5-D	Two and a half Dimensional
3-D	Three Dimensional
3G	Third Generation

A

AGILE	Advanced Generation of Interoperability for Law Enforcement
ANS	American National Standard
ANSI	American National Standards Institute
AP	Access Point
APCO	Association of Public-Safety Communications Officials
APD	Amplitude Probability Distribution
AQMS	Audio Quality Measurement System
ASCII	American Standard Code for Information Interchange
ATB	Antenna TestBed
ATIS	Alliance for Telecommunications Industry Solutions
ATM	Asynchronous Transfer Mode

B

BAWT	Broadband Arbitrary Waveform Transmitter
BER	Bit Error Ratio
BGP	Border Gateway Protocol
BLAST	Bell Labs Layered Space-Time theory
BPL	Broadband over Power Line
BPSK	Binary Phase Shift Keying

C

CCIR	International Radio Consultative Committee (now ITU-R)
CD	Compact Disk
CDA	Code Domain Analyzer
CDMA	Code Division Multiple Access
CGDN	Coast Guard Data Network
CIP	Critical Infrastructure Protection
COMDSQ	Channel Optimized MDSQ
CONUS	CONtinental U.S.
COPS	office of Community Oriented Policing Service
CRADA	Cooperative Research And Development Agreement
CRPL	Central Radio Propagation Laboratory
CSPT	Communication System Planning Tool
CW	Continuous Wave

D

dB	deciBel
DC	Direct Current
DF	Direction Finding
DFS	Dynamic Frequency Sharing
	Dynamic Frequency Selection
DGPS	Differential GPS
DHS	Department of Homeland Security
DLL	Dynamic Link Library
DOC	Department Of Commerce
DOD	Department Of Defense
DOJ	Department Of Justice
DSCP	Digital Sampling Channel Probe
DSCQS	Double Stimulus Continuous Quality Scale
DSCS	Double Stimulus Comparison Scale
DSP	Digital Signal Processing
DT&E	Developmental Testing and Evaluation
DTV	Digital TeleVision
DVD	Digital Video Disc (or Digital Versatile Disc)
DWDM	Dense Wave Division Multiplexing

E

EGP	External Gateway Protocol
EIA	Electrical Industries Association
EM	ElectroMagnetics
EMC	ElectroMagnetic Compatibility
EMOS	Estimated Mean Opinion Score
EMS	Emergency Medical Services
ESSA	Environmental Science Services Administration
ETS	Emergency Telecommunications Service

F

FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FED	FEDeral
FED-STD	FEDeral STandarD
FH	Frequency Hopping
FLEWUG	Federal Law Enforcement Wireless Users' Group
FNPRM	Further Notice of Proposed Rule Making
FPGA	Field Programmable Gate Array
FQT	Formal Qualification Test
FR&O	First Report and Order
FRA	Federal Railroad Administration
FTP	File Transfer Protocol
FTTA	Federal Technology Transfer Act
FY	Fiscal Year

G

GB	GigaByte
GCC	Group Communications Center
GETS	Government Emergency Telecommunications Service
GHz	GigaHertz
GI/SWG	Global's Infrastructure/Standards Working Group
GIF	Graphics Interchange Format
GIS	Geographic Information System
Global	Global justice information network advisory committee
GLOBE	Global Land One-km Base Elevation
GMF	Government Master File
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile
GUI	Graphical User Interface

H

HAAT	Height Above Average Terrain
HATS	Head And Torso Simulators
HD	High Definition
HDTV	High Definition TeleVision
HF	High Frequency
HTML	HyperText Markup Language
HTTP	HyperText Transfer Protocol

I

IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IF	Intermediate Frequency
IGP	Internal Gateway Protocol
IITRI	Illinois Institute of Technology (IIT) Research Institute
INFOSEC	INFOrmation system SECurity
INLS	Iterated Nested Least-Squares
INLSA	Iterated Nested Least-Squares Algorithm
Internet2	2nd-generation Internet
IP	Internet Protocol
IPP	Interoperability Process and Procedures
IRL	Interoperability Research Laboratory
ISART	International Symposium on Advanced Radio Technologies
ISDN	Integrated Services Digital Network
ISEC	Information Systems Engineering Command
ISM	Industrial, Scientific, and Medical
ISSI	Inter-rf SubSystem Interface
IT	Information Technology
ITM	Irregular Terrain Model
ITS	Institute for Telecommunication Sciences
ITSA	Institute for Telecommunication Sciences and Aeronomy
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union — Radiocommunication Sector
ITU-T	International Telecommunication Union — Telecommunication Standardization Sector

J

J/PS/HS	Justice/Public Safety/Homeland Security
JRG	Joint Rapporteur Group
JSC	Justice Standards Clearinghouse
	Joint Spectrum Center
JWN	Justice Wireless Network

K

kbps	kilobits per second
kHz	kiloHertz

L

LAN	Local Area Network
LMDS	Local Multipoint Distribution Service
LMR	Land Mobile Radio
LOS	Line Of Sight

M

MAN	Metropolitan Area Network
Mb/s, Mbps	Megabits per second
MDC	Multi-Descriptive Coding
MDSQ	Multiple-Description Scalar Quantizer
MHz	Megahertz
MIMO	Multiple Input Multiple Output
MO&O	Memorandum Opinion & Order
MOS	Mean Opinion Score
MPEG	Motion Picture Experts Group
MPLS	MultiProtocol Label Switching
MW	MegaWatt

N

NASTD	National Association of State Telecommunications Directors
NBS	National Bureau of Standards
NCS	National Communications System
NDRS	National Distress and Response System
NDRSMP	NDRS Modernization Project
NGN	Next Generation Network
NII	National Information Infrastructure
NIJ	National Institute of Justice
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NPRM	Notice of Proposed Rule Making
NS/EP	National Security and Emergency Preparedness
NTIA	National Telecommunications and Information Administration
NWS	National Weather Service

O

O&M	Operations and Maintenance
OATS	Open Area Test Site
ODOT	Oregon Department of Transportation
OJP	Office of Justice Programs
OLES	Office of Law Enforcement Standards
OMB	Office of Management and Budget
OQPSK	Offset Quadrature Phase-Shift Keying
ORTA	Office of Research and Technology Applications
OSM	Office of Spectrum Management
OT	Office of Telecommunications
OTP	Office of Telecommunications Policy

P

P25	Project 25
PBS	Public Broadcasting System
PC	Personal Computer
PCS	Personal Communications Services
PDD	Presidential Decision Directive
PDNR	Preliminary Draft New Recommendation
PESQ	Perceptual Evaluation of Speech Quality
PLMR	Private Land Mobile Radio
PN	Pseudo-Random
PRF	Pulse Repetition Frequency
PSTN	Public Switched Telephone Network
PSWAC	Public Safety Wireless Advisory Committee
PSWN	Public Safety Wireless Network

Q

QoS	Quality of Service
QPSK	Quadrature Phase-Shift Keying

R

R&D	Research and Development
R&O	Report and Order
RCG	Radar Correspondence Group
RDBMS	Relational Database Management System
RF	Radio Frequency
RFIMS	Radio Frequency Interference Monitoring System

RFSS	RF SubSystem
RSEC	Radar Spectrum Engineering Criteria
RSMS	Radio Spectrum Measurement System
RSMS-3	3rd Generation RSMS
RSMS-4	4th Generation RSMS
RTP	Realtime Transport Protocol

S

SAFECOM	wireless public SAFEty interoperable COMmunications
SC	Signal Capacity
SD	Standard Definition
SDH	Synchronous Digital Hierarchy
SDMA	Space Division Multiple Access
SFG	Standards Formulating Group
SG	Study Group
SINAD	SIgnal-plus-Noise-plus-Distortion to noise-plus-distortion ratio
SIP	Session Initiation Protocol
SIPRNET	Secret Internet Protocol Routable NETwork
SIT	System Integration Test
SMPTE	Society of Motion Picture and Television Engineers
SONET	Synchronous Optical NETwork
SOR	Statement Of Requirements
SPIE	International Society for oPtical Engineering
SSCQE	Single Stimulus Continuous Quality Evaluation
SUT	System Under Test

T

T&E	Test and Evaluation
TA Services	Telecommunications Analysis Services
TCP	Transmission Control Protocol
TDR	Telecommunications for Disaster Relief
TG	Task Group
TIA	Telecommunications Industry Association
TIREM	Terrain Integrated Rough Earth Model
TR	Technical Report
TSB	Telecommunications Systems Bulletin
TV	TeleVision

U

UDP	User Datagram Protocol
UHF	Ultra High Frequency
UK	United Kingdom
UMTS	Universal Mobile Telecommunications System
UNIX	UNIpleXed information and computing service
URL	Uniform Resource Locator
US	United States
USAISEC	United States Army Information Systems Engineering Command
USCG	U.S. Coast Guard
USGS	U.S. Geological Survey
UTRA	UMTS Terrestrial Radio Access
UWB	UltraWideBand

V

VHF	Very High Frequency
VoIP	Voice over Internet Protocol
VPN	Virtual Private Network
VQEG	Video Quality Experts Group
VQM	Video Quality Measurement
VSA	Vector Signal Analyzer

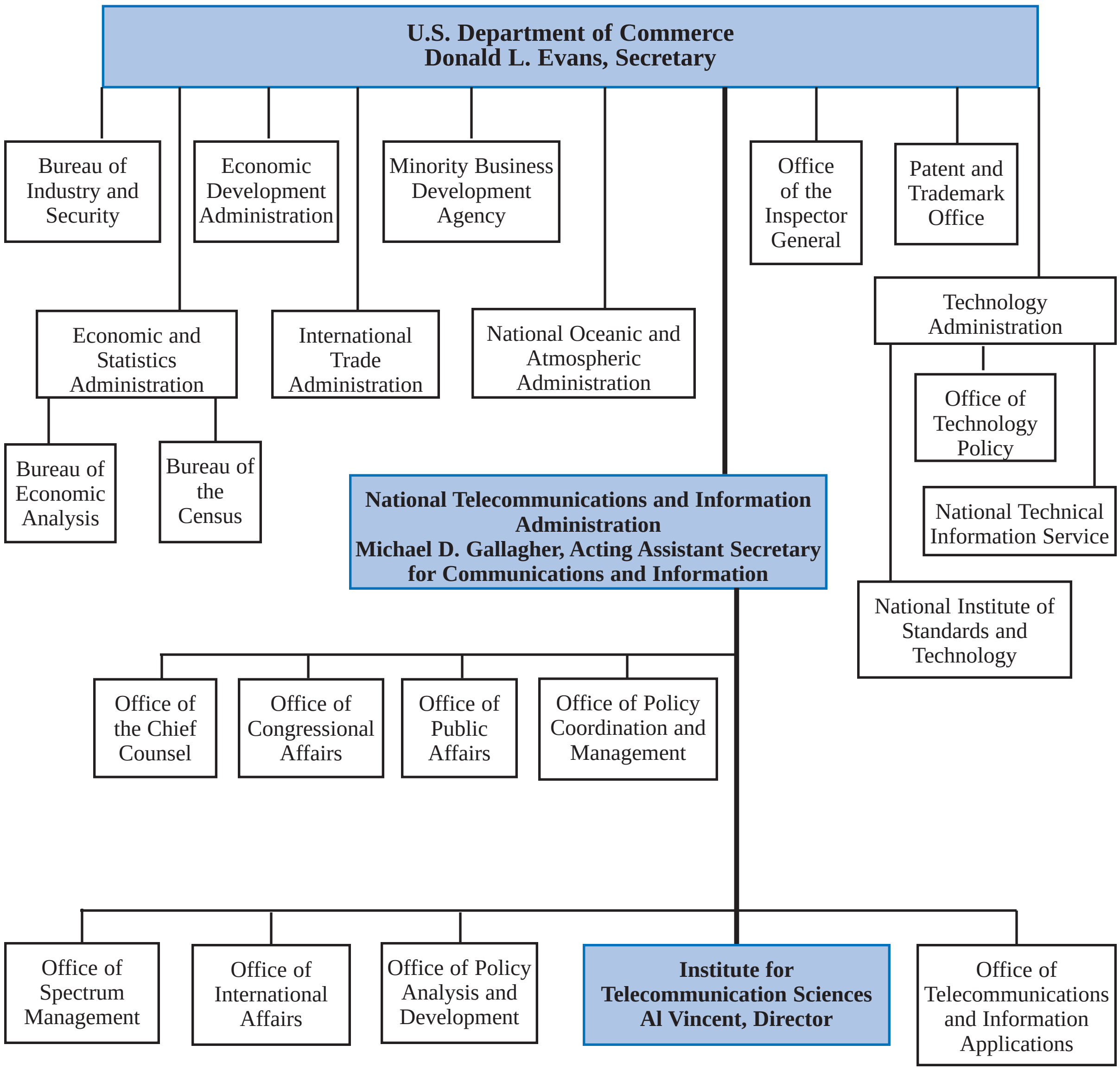
W

W-CDMA	Wideband CDMA
WCTF	Wireless Communications Task Force
Wi-Fi	Wireless Fidelity
WLAN	Wireless LAN
WNRC	Wireless Networks Research Center
WP	Working Party
WPAN	Wireless Personal Area Network

X

XML	eXtensible Markup Language

DOC/NTIA Organization Chart



ITS Organization Chart

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Lisé C. Matthews, Executive Assistant
Carole Craig, Management Support Assistant
Jill Copeland, Office Automation Assistant

ADMINISTRATIVE OFFICE

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Carol B. Van Story, Budget Analyst
Margaret A. Luebs, Technical Editor

NTIA LIAISON

Neal B. Seitz, NTIA Liaison

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Peggy Dove, Office Automation Assistant

TELECOMMUNICATIONS THEORY DIVISION

Frank H. Sanders, Chief
Amy Weich, Office Automation Assistant

TELECOMMUNICATIONS AND INFORMATION TECHNOLOGY PLANNING DIVISION

Val J. Pietrasiewicz, Chief
Kathy Mayeda, Secretary (Office Automation)

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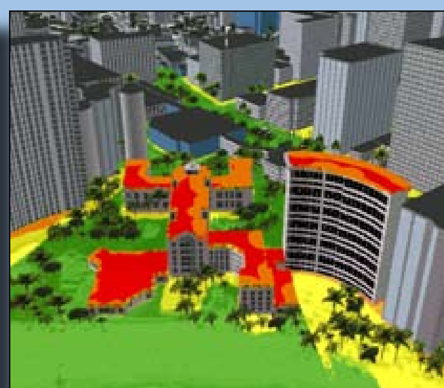

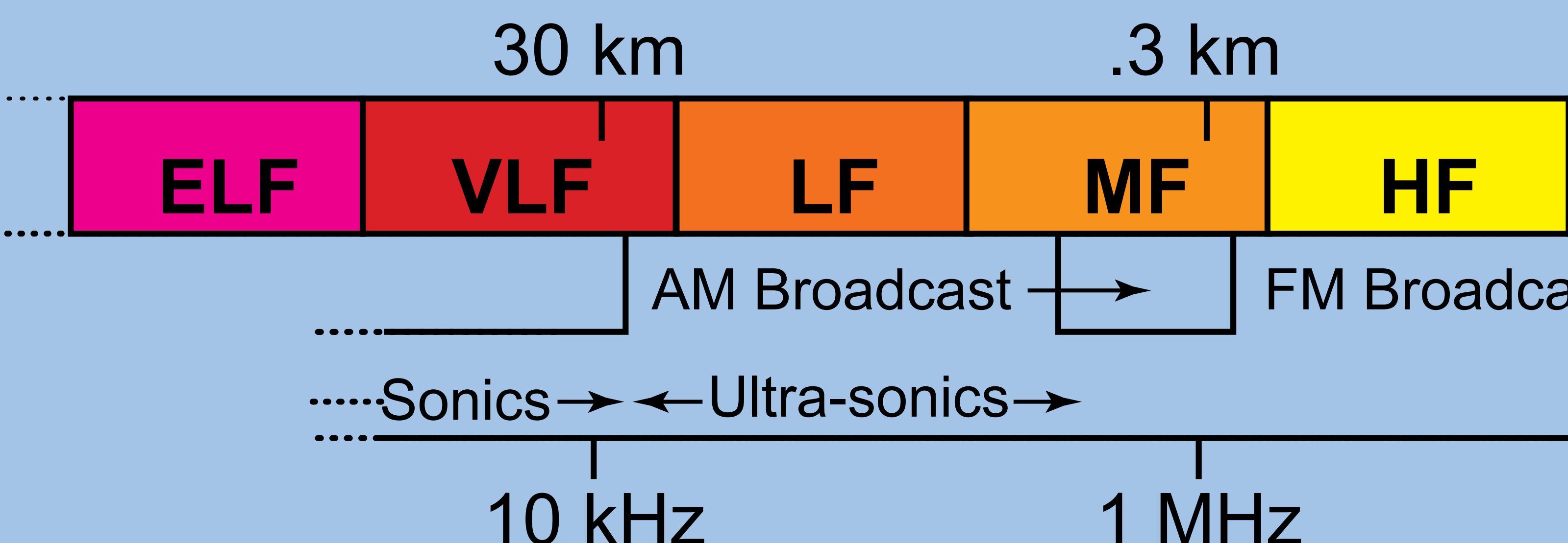

30 km
.3 km
ELF
VLF
LF
MF
HF
AM Broadcast
FM Broadca
Sonics
Ultra-sonics
10 kHz
1 MHz