Institute for Telecommunication Sciences

2002 Technical Progress Report

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U.S. Department of Commerce
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for Communications and Information

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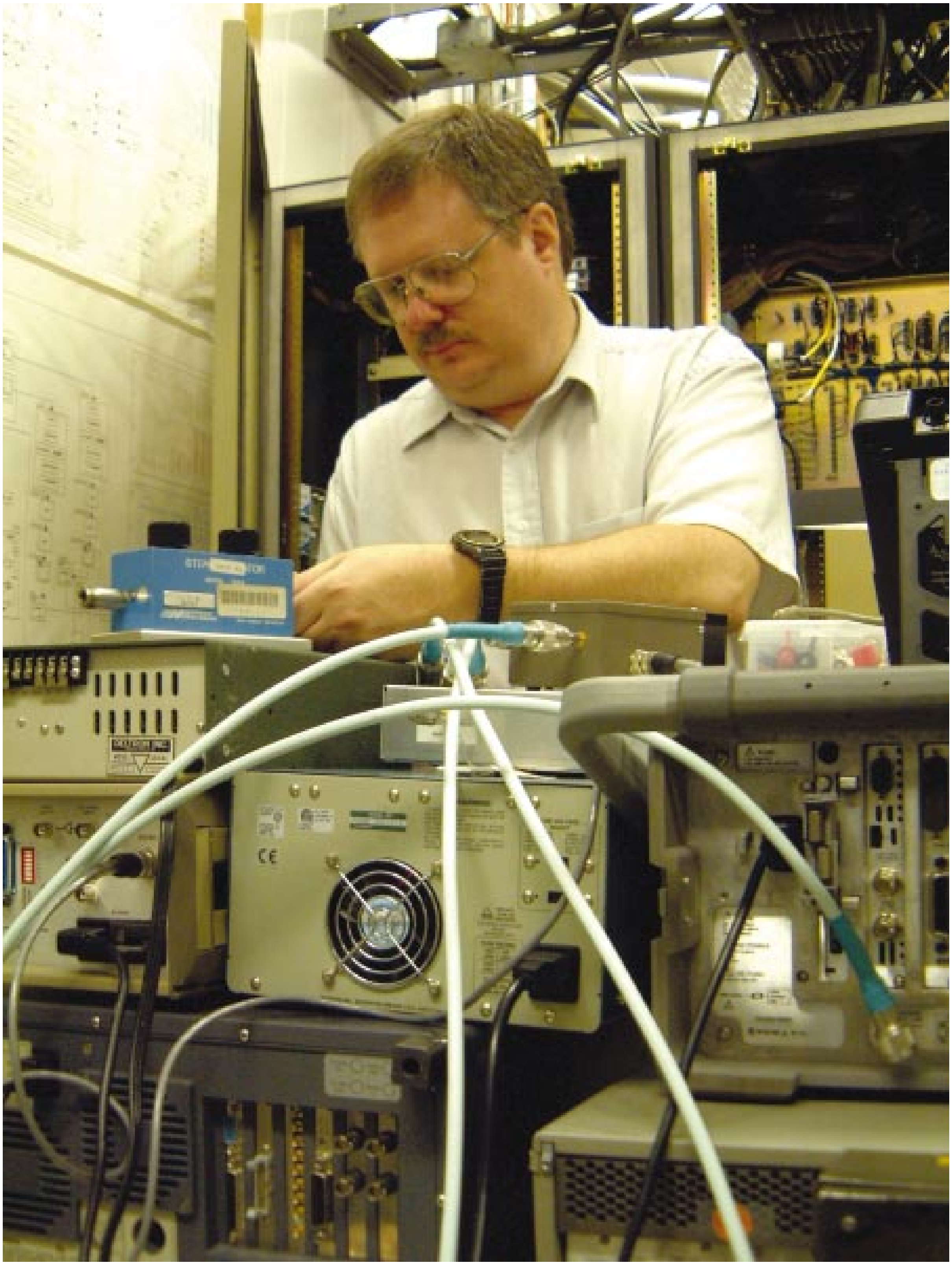
Contents



ITS engineer configures interference generation equipment at the beginning of a series of measurements on a weather surveillance radar at Norman, OK (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.

NTIA/ITS antenna mounted on the roof of the Boulder Laboratories (photograph by F.H. Sanders).

Overview

The Institute for Telecommunication Sciences (ITS), located in Boulder, Colorado, is the research and engineering arm of the National Telecommunications and Information Administration (NTIA) of the U.S. Department of Commerce. ITS employs individuals, all of whom are Federal employees, with strong engineering and scientific skills and experience to support our technical programs. The majority of our employees are electronics engineers, with a complement of mathematicians, physicists, and computer scientists. ITS' support during Fiscal Year 2002 consisted of $6.3 million of direct funding from the Department of Commerce and approximately $3.9 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. 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

ITS' 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.

The Institute'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.

The Institute maintains a Program Development Office (PDO) to lead, coordinate, and integrate program development efforts for the Institute. The PDO works to identify new program areas that the Laboratory should explore, consistent with its research and engineering mission. The Institute 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 National Communications System.

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 nonrestrictive 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.

- 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.

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.

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 Transportation, the Federal Aviation Administration, 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 2002 to both the public and private sectors.

An NTIA engineer prepares a radar for interference injection during ITS-OSM measurements at Curtis Bay, MD (photograph by F.H. Sanders).

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, active competition for access to the radio spectrum suggests that its shared use will require increasingly more complex planning and coordination tools to ensure its effective use while avoiding increased levels of interference.

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

The Spectrum and Propagation Measurements Division of ITS performs measurements of radio signals to support research and engineering promoting more efficient and effective use of today's spectrum, while opening up more spectrum in the future at ever-higher frequencies. 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 Upgrades The Institute uses its Radio Spectrum Measurement System (RSMS) to make spectrum occupancy measurements, and to help assess interference and compatibility issues. The Institute received funding for a major RSMS system upgrade in FY 2002. Details of the RSMS-4 design and development are described in the following separate sections on vehicle, measurement equipment, and software. The project is funded by NTIA.

RSMS-4 Design and Development — Vehicle A new vehicle for the RSMS-4 will provide multiple work spaces for researchers and up to 3 independent measurement systems, along with multiple antenna towers and a controlled environment.

RSMS-4 Design and Development — RF and Measurement Hardware The RSMS-4 measurement hardware will provide multiple measurement systems having improved sensitivity, bandwidth, and dynamic range. In addition to built-in measurement functions, the system supports powerful digital signal processing capabilities.

RSMS-4 Design and Development — Software The measurement and analysis capabilities of the RSMS-4 will be controlled by a greatly-enhanced set of software that will allow weeks of unattended measurements, flexible field modification of system hardware configuration and control software, remote control and monitoring of field operations, and very powerful digital signal processing capabilities.

Spectrum Compatibility Measurements The Institute participates in measurements of the emission characteristics of new or proposed systems to help determine their compatibility with each other and with existing systems. The project is funded by NTIA.

Spectral Assessment of Government Systems The Institute performs measurements on new and established Federal systems to determine their emissions characteristics, to confirm proper operation, or to identify and mitigate interference or other incompatibilities. Projects are funded by NTIA.

UWB Regulatory Activities The Institute has completed measurements to characterize ultrawideband (UWB) devices and interference to conventional radio systems. Current work includes tutorial and advisory help to spectrum regulators and to laboratories attempting initial UWB device measurements. The project is funded by NTIA.

Radio Spectrum Measurement System Upgrades

Outputs

- Uncertainty analysis of RSMS-3 measurements.
- Upgrade of ITS preselector hardware design.
- Functional Measurement Requirements document for RSMS-4.

The Radio Spectrum Measurement System (RSMS) evolves on a yearly basis. Although the Department of Commerce operated vehicle-mounted radio measurement systems as early as the 1920's (Figure 1a), the first such Department of Commerce system of the modern era (RSMS-1) was developed in the mid-1970's and was mounted in a motor home body (Figure 1b). This system provided the first computer-controlled measurements of spectrum occupancy up to 12 GHz, making a detailed statistical description of mobile radio channel usage possible.

A second version, RSMS-2, was designed and developed in the early 1980's and housed an entirely new measurement system in the same motor home body. RSMS-2 provided improved RF sensitivity and measurement capabilities up to 18 GHz in two independent computer-controlled systems. The current version, RSMS-3 (Figure 1c), holds two independent 22-GHz systems mounted in a smaller shielded 4-wheel-drive vehicular configuration, taking advantage of significant advances in commercially available measurement instrumentation and computers.

The RSMS designs have been continually upgraded to keep pace with developments in radio measurement technology, computer control technology, and the changing environment of the radio spectrum. Since the 1970's each version has lasted approximately a decade before requiring major modifications and improvements. In FY 2002, a new RF front end was designed for the RSMS, featuring improved signal handling capabilities.

ITS is currently developing a fourth generation RSMS (RSMS-4). As described in the following sections of this report, the RSMS-4 ushers in the new century and continues the 80-year-long tradition of Department of Commerce mobile radio systems with the development of a state-of-the-art system.

Figure 1a. Original Department of Commerce Radio Measurement Vehicle, 1927.

Figure 1b. First and second generation of modern RSMS (1970s and 1980s) used the same vehicular chassis.

Figure 1c. Third generation RSMS (1990s onward).

Initial efforts were directed toward developing a Functional Measurement Requirements document, (http://www.its.bldrdoc.gov/home/programs/rsms-4/functional_req_v2.pdf) after which the project was split into three areas of development: vehicle, RF and measurement hardware, and software. The Functional Measurement Requirements spell out the kinds of measurements that are expected and desired for RSMS-4 and provided the foundation for decision making in every aspect of the three areas of development.

In FY 2002, with the RSMS-4 under development, a detailed analysis was undertaken in the RSMS Enhancement Program to quantify uncertainties in the RSMS gain calibration routines. This analysis provides the basic foundation needed to compute the uncertainty of RSMS power measurements. In particular, the analysis is a first step towards quantifying, rather than simply estimating, the RSMS system's ability to perform absolute field strength measurements. A quantitative uncertainty budget is needed when making comparisons between data gathered from independent experiments. Without this kind of information it is not possible to evaluate whether a difference between experimental values indicates a discrepancy, or is an artifact of the test process. An added benefit of this work is that it provides an insight into how the RSMS test equipment and measurement routines can be configured to obtain the best possible system performance.

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RSMS-4 Design and Development — Vehicle

Outputs

- Vehicle System Requirements document (http://www.its.bldrdoc.gov/home/programs/rsms-4/vehicle_system_req.html).
- Vehicle procurement specifications.

As part of the ITS program to upgrade the Radio Spectrum Measurement System (RSMS), in FY 2002 a new measurement vehicle was designed and fabrication is now underway (see Figures 1 and 2). Although the key to the design of this new vehicle/enclosure is (as always) to provide a safe, comfortable, and productive operating environment for the operators and the measurement equipment, this new design provides somewhat different capabilities than the earlier RSMS vehicle. The new design was derived by carefully reviewing the older RSMS measurement vehicle and incorporating many suggested improvements into the new design.

The RSMS program utilizes a movable platform to perform measurements in locations ranging from those with no facilities to those with facilities including security, communications, and electrical power. The major changes from the earlier RSMS vehicle include:

1) the requirement that the enclosure be able to be disconnected from the vehicle and operated in a self sufficient mode. This will allow the enclosure to be shipped or moved without the added weight of the truck.

2) shielding of the enclosure with a minimum of 60 dB of shielding effectiveness over 100 MHz-26 GHz to be tested in accordance with IEEE Std 299-1997.

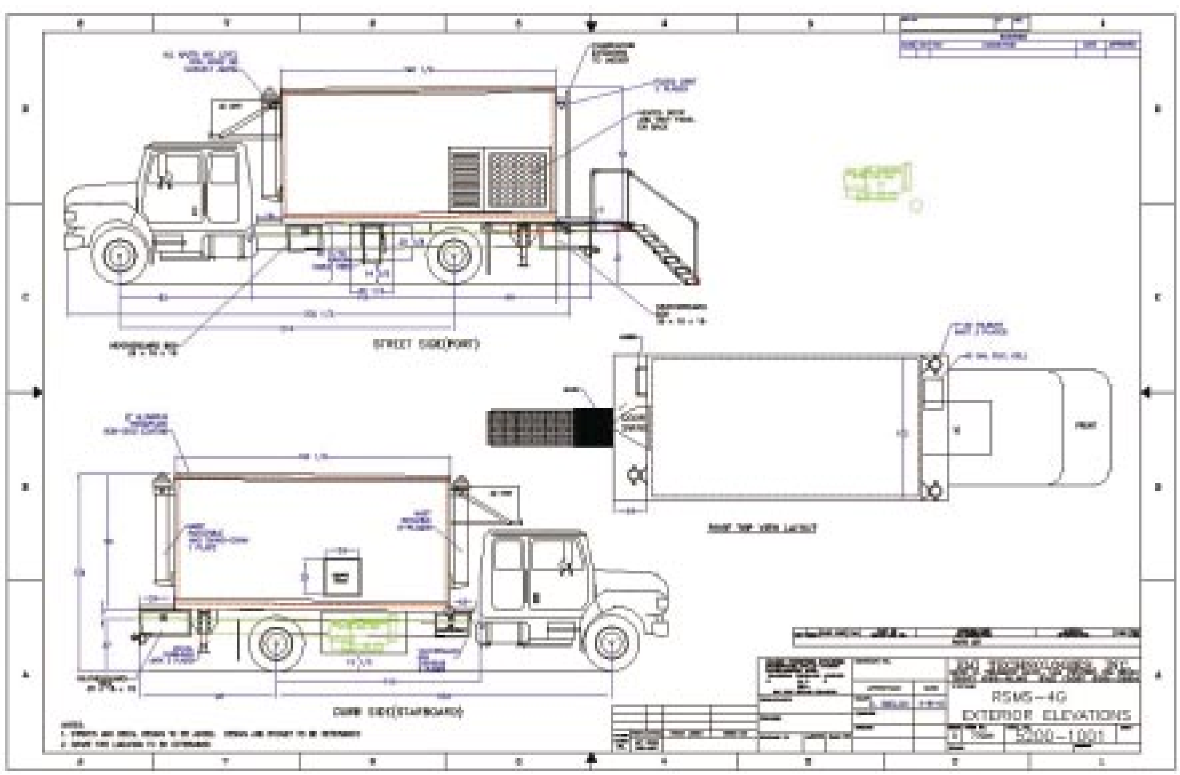

Figure 1. Side view of the RSMS-4 vehicle.

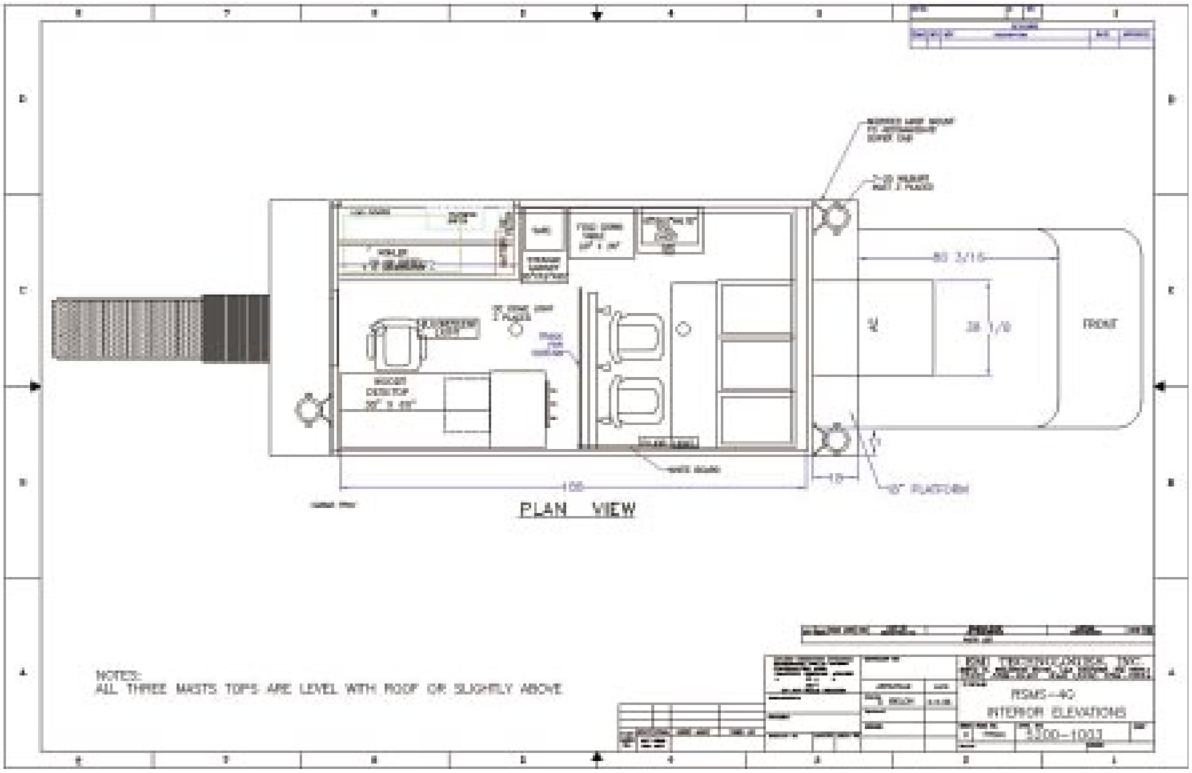

Figure 2. Side and top views of the RSMS-4 vehicle.

3) a dual power system which will operate from 110/220 VAC, as well as deep cycle rechargeable batteries. An on-board generator and fuel system will support 96 hours of continuous generator operation under 3/4 load conditions.

The new RSMS vehicle will support up to three primary operator positions, each with its own measurement system, and three 30-ft rotating pneumatic antenna towers. The technical particulars of the individual measurement systems are included in other articles in this section. The multiple measurement systems will allow efficient simultaneous measurements of multiple bands, as well as intensive multiple-perspective measurements of single-band problems. The shielding and DC power systems are intended to enable uncontaminated local noise measurements.

The vehicle will be based on a chassis with heavy-duty transmission and powerful engine, able to easily climb steep grades to hilltop sites, but also cushioning the ride with an air suspension to protect the electronic equipment payload. Adequate storage for supplies, electronic equipment and antennas, classified records, and measurements will be provided. The entire vehicle and payload must weigh less than 26,000 lb, so that it can continue to be driven by non-commercial licensed drivers.

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RSMS-4 Design and Development — RF and Measurement Hardware

Outputs

- RF and Measurement System Requirements document that defines the design parameters.
- Conception, selection, and acquisition of instrumentation for a measurement system.
- Design of an ITS-built 0.5-26.5 GHz preselector.
- Design of an ITS-built 0.1-1000 MHz preselector.

The RF and Measurements project was a part of the ITS program to upgrade the Radio Spectrum Measurement System (RSMS) to a fourth generation system. The primary goals included identifying and acquiring the instrumentation and accessories needed to create a modern state-of-the-art measurement capability. The need to measure the wider range of RF technologies present today, that is expected to expand even more in the future, demanded a system design that has more versatility, adaptability, and measurement capability. Future measurement needs were compared with current instrument capability to identify what could be achieved with Commercial-off-the-Shelf (COTS) equipment and what would require ITS-designed and -built devices. The result is a new generation RF and Measurement system.

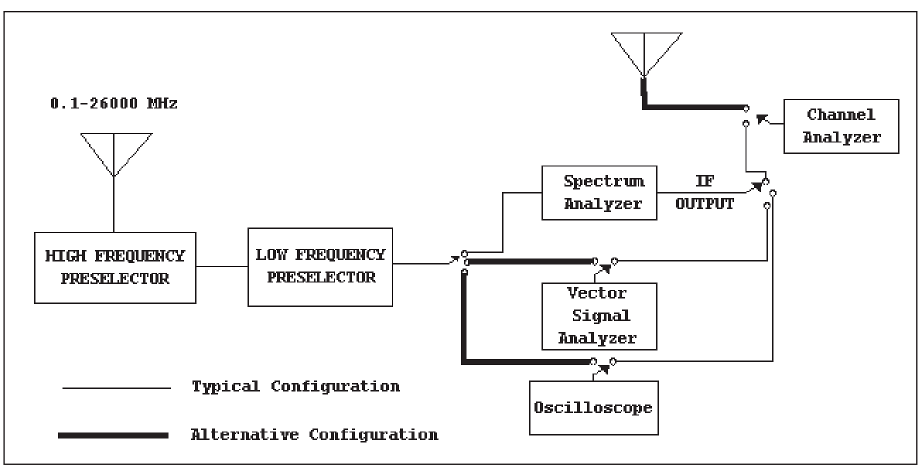

Figure 1. High-level block diagram of an RSMS-4 measurement system.

The design effort started with the Functional Measurement Requirements document, which describes the functions that the RSMS-4 shall perform. This set of requirements was global to the entire program. To provide this project with more specific guidance, an RF and Measurement System Requirements document was created. This document applied quantitative specifications to the functional requirements, providing a practical set of measurement parameters for the RSMS-4.

A major task involved the system design and the selection and acquisition of instrumentation for the RSMS-4. The designer had to define a collection of instruments that would satisfy the system requirements shown in Figure 1. Signals enter the measurement system and depending on the frequencies of interest, the High or Low frequency preselection stage is enabled. After preselection, the signal enters the measuring instruments. The Spectrum Analyzer is used primarily to make frequency-domain and time-domain-envelope measurements. The chosen unit is faster, more accurate and has a modern detection capability (root mean square or RMS) that is critical to future spectrum management challenges. Measurement bandwidths up to 8 MHz are available and an IF output provides a downconverted signal with a 30-50 MHz bandwidth. The vector signal analyzer is used to analyze magnitude and phase properties of the signal. It is also capable of analyzing the modulation format and modulation parameters. This "vector" look at signals is a powerful new enhancement that allows for a more thorough characterization of unknown signals. The digital oscilloscope can capture signals directly (in the time domain) for frequencies up to 1 GHz and indirectly beyond 1 GHz using the IF output of the Spectrum Analyzer. Since the RF spectrum is, for the most

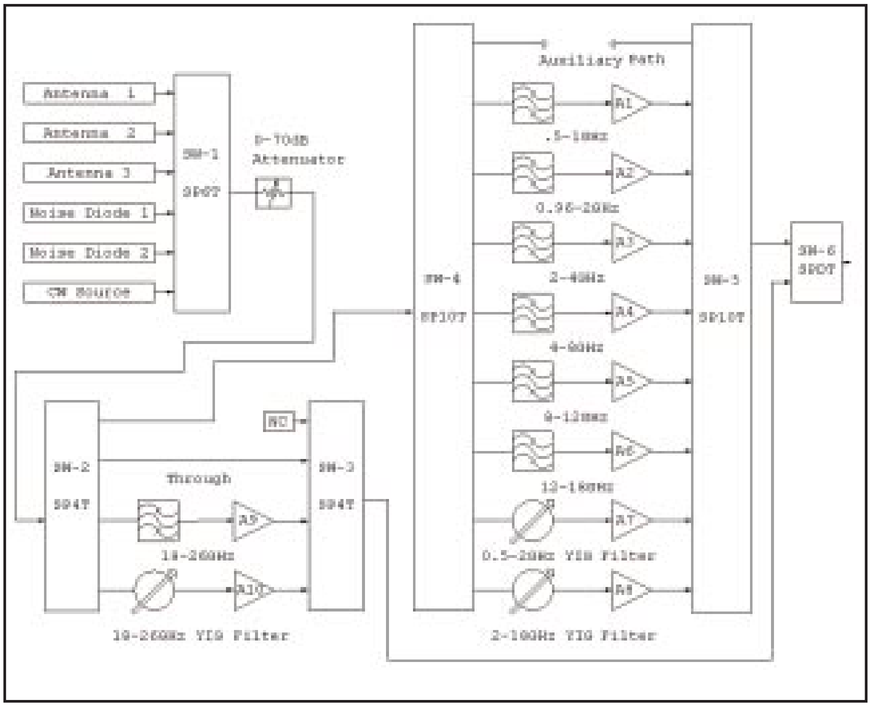

Figure 2. Block diagram of the ITS designed 0.5-26 GHz preselector.

part, divided up into individual channels which are assigned to individual users, the channel analyzer is used to examine the transmissions within these channels. This analyzer is extremely quick at categorizing various parameters of a signal within a channel as well as processing many channels per second to provide accurate statistics. This collection of instruments was chosen to meet the measurement needs of today and the future.

Preselection is the processes of selecting the signal (or a portion of the signal) for measurement, from an environment of multiple signals, and can be used to enhance the measurement system's sensitivity and dynamic range. The block diagram of the 0.5-26.5 GHz Preselector (High Frequency Preselector) is shown in Figure 2. On-board noise diodes and a port for a CW signal are available to calibrate the measurement paths. A stepped attenuator is used to prevent front-end overload and increase the measurement range of the system. Bandpass filtering with amplification is used to optimize sensitivity, selectivity and the dynamic range of the measurement system. A noise figure as low as 3.5 dB was achieved with noise figures under 10 dB available for all frequencies under 18 GHz, providing for a very sensitive measurement system. To handle signals with large amplitude excursions, the dynamic range was kept above 94 dB, rising to 108 dB for some frequencies.

A 0.1-1000 MHz Preselector (Low Frequency Preselector) was designed with similar goals as the 0.5-26.5 GHz Preselector except that it contains some additional functionality. The lower frequency filtering and amplification stages provide noise figures under 10 dB reaching as low as 3.6 dB. In addition to RF preselection, this unit provides some intelligence to the system through the use of a single board computer (SBC) which can accept commands from a controlling computer to set its own and the other preselector's configuration. The SBC is responsible for keeping the tunable filters tracking the measuring instrument while automatically compensating for changing temperature effects and tracking hysteresis to improve the quality and accuracy of future measurements.

Overall, the RF and Measurement team has created a new generation measurement system that will improve the quality of measurements, increase the speed at which information can be gathered, and add new measurement capability, while providing growth potential to meet the future needs of spectrum management.

Recent Publications:

"RF and Measurement System Requirements," http://www.its.bldrdoc.gov/home/programs/rsms-4/rf_meas_sys_req_v4.pdf

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RSMS-4 Design and Development — Software

Outputs

- System Requirements Document (http://www.its.bldrdoc.gov/home/programs/rsms-4/software_sys_req.pdf).
- Use-case Statement that describes how the software will operate from the user standpoint.
- Architectural design that documents the overall structure of the software.
- Data acquisition and analysis software.

The fourth generation of the Radio Spectrum Measurement System (RSMS-4) will critically depend on powerful new data acquisition and processing software to meet the greatly expanded system capabilities (see figure). The new software encompasses many of the strong features of previous generations, as well as incorporating several new features that improve on the current system and allow for substantial future growth.

Major goals in the development of the new software are the ability to easily expand measurement and analysis capabilities and to modify the equipment configuration in the field.

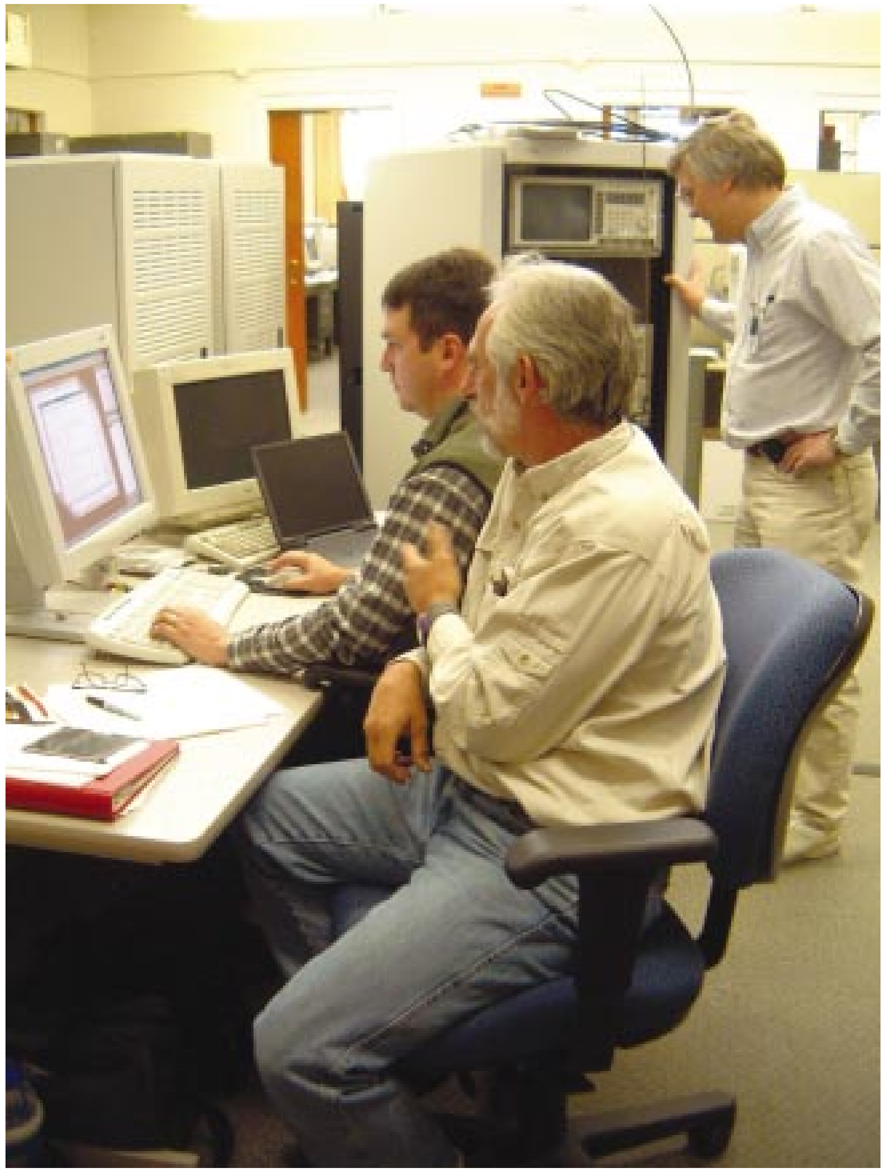
The ability to modify and expand is accomplished by taking a highly modular approach, using an object-oriented (OO) design technique. The software contains a relatively static core program that utilizes various dynamic measurement and instrument modules. By establishing well-defined interfaces and encapsulating the code into dynamic link libraries (DLLs), new measurement techniques can be added without modifying or re-compiling the core program. By establishing command/query interfaces and encapsulating into DLLs, it is also possible to add new models of equipment without the need to change existing measurement code modules. While this requires the use of functional features common to each general category of equipment, the ability to use specialized attributes is also possible by tailoring specialty measurements to make use of specific models.

Hardware flexibility is also enhanced because it is possible to use a variety of instrument models for the same type of measurement via a well-established interface to the general command/query modules. Also integral to the capability for flexible hardware configurations is the ability of the user to dynamically designate the hardware configuration — from the fully equipped measurement vehicle to an abbreviated “suitcase” system. The user also can designate the manual control of some devices and automated control of others.

A script language that gives the user a means to build custom routines for specialized signal measurements provides flexibility in the field. The scripting module utilizes a standard editor, which allows the user to enter specifically defined command text that is interpreted for execution on the targeted instruments. The language is generic for the different generic instrument types (e.g., spectrum analyzer, digital oscilloscope, etc.), and is interpreted in relation to the specific instrument model targeted for execution.

Other features of the new software include:
1) flexible file structures,
2) incorporation of calibrations into the data file,
3) remote measurement/control capabilities,
4) scheduling of measurements,
5) re-measurement capabilities, and
6) high speed signal digitization.

The output data-file format accommodates changes to stored information by adding version markers; these identify the structure of the data and allow backward compatibility despite change. Each module containing the data is responsible for packaging during data writes, parsing the information (according to the version marker) during reads, and documenting the data structure by writing the format for each version to an ASCII file. This allows future format modifications without having to change the core code module. The new file structure adds calibration information into the data files, along with system configuration, measurement parameters, and instrument settings.



To meet the requirements for expanded capabilities, ITS engineers are developing software for the 4th generation Radio Spectrum Measurement System (photograph by F.H. Sanders).

The setup and execution of RSMS-4 measurement procedures can be remotely controlled and monitored through the Internet. This minimizes field time for highly skilled employees, permits more opportunistic measurements and improves data quality, and allows the acquired data to be promptly processed in an optimal work environment.

While previous RSMS generations had the capability for sequential, automated execution of measurements, the 4th generation has the added features of a scheduler. This provides for triggering of measurement routines by external events, repetition and prioritization of a predetermined schedule of planned measurements, and scheduled automation of diagnostic, re-adjustment and calibration procedures.

Because system configuration, measurement parameters, and instrument settings are stored as a part of each data file and linked to the specific measurement routines, it is now possible for system operators to examine measured data and request re-measurement of that data under the same system conditions.

Also incorporated into the new software is the improved capability for digitization of signals in wideband predetection format. This significantly improves the capabilities for software signal processing in ways that are not possible through traditional analog means — for example, very sharp filtering techniques or determination of signal modulation characteristics. Previously, most signal measurements merely extracted the signal magnitude information. With digitization of the raw predetection signal, all of the signal information is retained, allowing the same signal to be processed in many different ways.

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Spectrum Compatibility Measurements

Outputs

- Interference threshold measurements on a variety of Federal Government radar systems.
- Data reports for other US agencies and international forums on results of the interference measurements.

A significant percentage of spectrum between 400 MHz and 18 GHz is allocated for the use of radar systems on a primary basis. Radar receivers are noise-limited in their performance (i.e., radar receivers are designed to be highly sensitive to listen for faint echoes from small, distant, target objects), and external noise sources that exceed critical levels will degrade radar receiver performance. Therefore the bands within which radars operate must be kept as radio-quiet as possible. In recent years spectrum managers and design engineers have experienced pressure to find technical methods by which radar receivers might share spectrum with communication systems. If such proposals are ever to be implemented, it will be necessary to understand precisely the noise levels at which radar receivers begin to exhibit measurably degraded performance. The introduction of new systems into radar bands should result in cumulative noise effects that would stay below the critical interference thresholds of radar receivers.

Within NTIA, the Office of Spectrum Management (OSM) has worked with ITS for the past two years to determine the critical interference levels at which a variety of radar systems experience degraded performance. Some analyses have been theoretical, but a large body of tests and measurements have been performed to verify and enhance the theoretical knowledge.

In FY 2002, OSM and ITS engineers continued this series of measurements in collaboration with other Federal Agencies that included the Coast Guard, the Federal Aviation Administration (FAA) and the National Weather Service (NWS). Radars that were subjected to measurements included maritime surface search and navigation systems, long range air traffic control radars, airport surveillance radars, and a widely deployed model of weather surveillance radar.

At each radar installation, equipment was installed for the generation of a variety of interference modulation types. Analog interference included noise, continuous wave, and a variety of pulsed RF signals. Digital data-type signals included binary and quadrature phase-shift keyed (BPSK and QPSK), and gated QPSK (replicating time division multiple access, or TDMA). All types of interference were normally injected into the radar receivers at their RF input ports via hardline connections. Interference levels were varied by the test personnel to determine levels at which interference occurred.

For each type of interference, radar test targets were injected at controlled levels. Target levels were set close to radar receiver noise, but were kept high enough to provide a high probability of detection in the absence of interference. Baseline probability of detection was recorded in the absence of interference. Interference levels were then gradually increased while target detection probability was monitored.

At the end of each series of measurements, curves were generated showing probability of detection of radar targets as a function of interference level. These curves showed the thresholds at which radar performance began to show observable degradation.

The results of the measurements have been used in US Administration Contributions to the International Telecommunication Union — Radiocommunication Sector Working Party 8B (ITU-R WP 8B). It is anticipated that this work will ultimately result in accurate determinations of interference thresholds for most types of radar in all bands in which sharing with other services is being proposed.

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NTIA engineers from ITS and OSM set up equipment for injection of interference signals into an air traffic control radar (photograph by F.H. Sanders).

Spectral Assessment of Government Systems

Outputs

- Land mobile radio usage measurements in Denver and New York City.
- Maritime radar emission spectrum measurements.

The US Government operates a large number of radio systems, and advances in technology continue to drive the development of new radio systems. In recent years, alternatives to conventional analog FM land mobile radio (LMR) systems have become available. But planning for upgraded networks cannot be accomplished until requirements can be set for the traffic capacity that must be built into the new systems. In FY 2002, ITS performed measurements of traffic levels and message length statistics on existing LMR networks in selected bands in Denver, CO and New York City.

The measurements were designed to show overall usage levels on a channel-by-channel basis in these cities. Since the goal was to establish overall usage across the metropolitan areas, multiple measurement locations were required in each city. The measurement systems were suitcase versions of the NTIA/ITS Radio Spectrum Measurement System, running ITS-developed software.

The measurements were technically challenging for several reasons. One problem was to identify locations in the heart of each city with large radio horizons (Figures 1a and 1b) that were free of local transmitters that would overload the measurement systems. Another problem was to establish measurement rates that were high enough to revisit each channel every second, but not so high as to cause uncalibrated measurements. A test series of measurements was performed in Denver, and a full series of measurements was performed in New York.

Figure 1a. View of downtown Manhattan from one of the New York City LMR measurement sites (photograph by F.H. Sanders).

Figure 1b. View of midtown Manhattan from one of the New York City LMR measurement sites (photograph by F.H. Sanders).

Measurements were performed at three sites in each city for a period of two weeks, running 24 hours per day. The resulting data volumes approached 100 GB for each city. ITS developed new analysis techniques to cope with the volume and provide channel usage and message length statistics. Figure 2 shows an example data output from this measurement series.

In FY 2002 ITS began a detailed study of the behavior of spurious emission spectra produced by radar transmitters. Those emission levels are regulated by the NTIA Radar Spectrum Engineering Criteria (RSEC), but the measured power level of these emissions depends upon the bandwidth in which they are measured. Until recently, measurement bandwidths have been specified to be set equal to the inverse of the radar pulse widths (1/t), but some radar pulse widths are so narrow that no measurement equipment is available with sufficiently wide bandwidth. Thus it is important to understand the exact dependence of radar spurious levels as a function of measurement bandwidth. To begin the study, ITS bought a commercial radar and installed it north of Boulder. The measurement series began in late FY 2002. Results of the measurements will be used in FY 2003 for an NTIA Report and at least one US Contribution for the International Telecommunication Union — Radiocommunication Sector, Working Party 8B (ITU-R WP 8B). The data are needed so that NTIA can provide guidance to domestic and international personnel who are tasked with measuring radar emissions and comparing them to emission masks such as the RSEC.

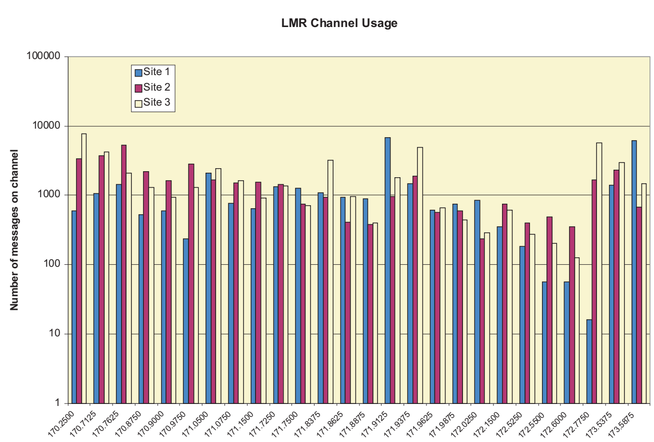

Figure 2. Data output showing land mobile radio channel usage at three selected sites in New York City.

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Ultrawideband Regulatory Activities

Outputs

- Comments provided to NTIA on UWB regulatory proposals.
- Comments on proposed new ITU-R study questions regarding UWB devices.
- Measurement advice to entrepreneurs developing UWB devices.
- Emission measurements of Part 15 devices.

In May 2000, the Federal Communications Commission (FCC) released a notice of proposed rulemaking (NPRM) on ultrawideband (UWB) systems, asking for a wide range of information on UWB systems, interference from UWB systems, and proposals for how they should be regulated. At that time, there was a wide range of technical opinion about how UWB systems interacted with traditional radio systems, and how they should be regulated. In FY 2000 and FY 2001, ITS staff made extensive measurements to characterize UWB device emissions. In addition, ITS made extensive measurements of UWB interference to various types of global positioning system (GPS) receivers. This work was summarized in NTIA Reports 01-383, 01-384, and 01-389. Subsequently, NTIA/OSM engineers 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.

Throughout and following the period of measurement and analysis, NTIA and the FCC were closely considering what regulations and numerical regulatory limits would be appropriate for the use of UWB devices. Intensive negotiations generated extensive draft documentation on many contentious and elusive issues, including allowable emission levels in specific frequency bands and special regulations for GPS bands, aimed at creating a new section of Part 15 of the FCC rules. ITS monitored and reviewed this documentation on a daily basis. ITS technical experts provided comments on many aspects of these negotiations, especially with respect to measurement procedures and the changing units of regulatory limits. It was often useful for ITS to comment on a range of topics such as interpreting the results of our laboratory and field measurements. In addition to some 80+ sets of comments sent by ITS to NTIA in FY 2002, many thorough reviews of the document changes resulted in no required comments.

In February 2002, the FCC released a first report and order (FR&O) on UWB device rules. This FR&O included rule-making that followed many of the NTIA recommendations and allowable emission levels (see Figure 1 below). A recommended major change from earlier FCC Part 15 procedures included the adoption of root mean square (RMS) weighting and well-defined integration times and measurement conditions. Such details were particularly important because of the wide range in numerical answers that result from seemingly small details like detector weighting functions. The FR&O stated that the initial regulations would be reviewed in 6-12 months and possibly adjusted according to information that becomes available in the intervening time.

While many observers applauded the new UWB rules, others stated that they were either much too permissive or much too restrictive. One application in particular, ground penetrating radars (GPRs), is subjected to much more stringent regulation under the new rules. This seems strange to some, because

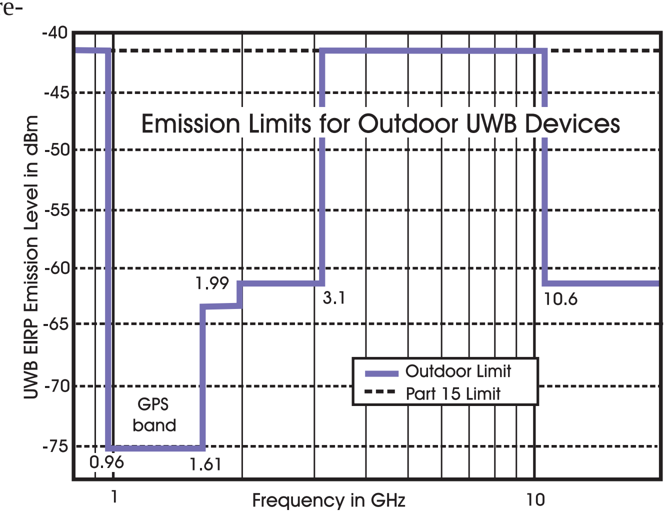

Figure 1. Emission limits for outdoor UWB devices, based on FCC first report and order on UWB device rules.

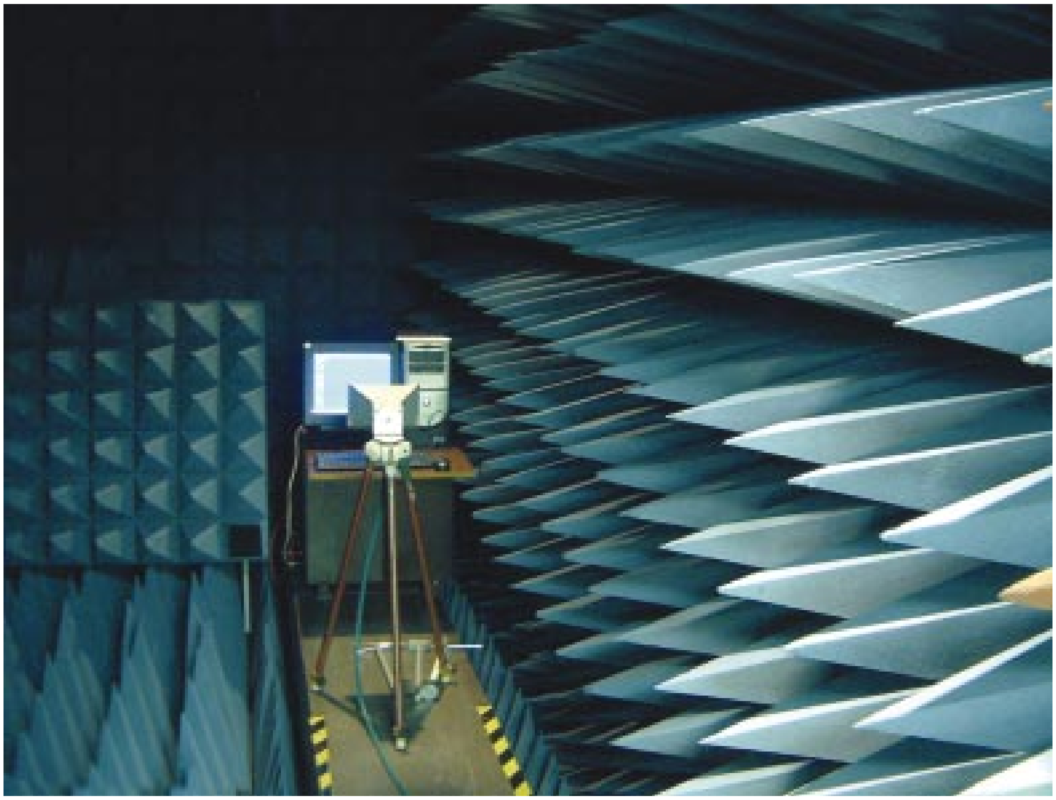

Figure 2. Emissions produced by a personal computer are measured in a NIST anechoic chamber with an ITS measurement system (photograph by F.H. Sanders).

GPRs arguably have the longest history of use of all UWB devices, with apparently few instances of interference. However, many share frequency bands with particularly critical safety and defense systems.

Paralleling U.S. activity in regulation of UWB systems, the International Telecommunication Union — Radiocommunication Sector (ITU-R) has also begun a study program on UWB devices. ITS commented on proposed new ITU-R study questions, which will become a part of ITU-R Study Group 1/8 activities.

Following the release of the FCC UWB regulations, ITS has continued to serve a tutorial and advisory role. Entrepreneurs are developing new UWB devices and are attempting to measure them according to the techniques described in the FR&O. Requests have come from as far away as Germany, where a 24-GHz short-range automotive radar was being characterized according to the new UWB criteria. In this case, peculiar measurement results were traced to inadequate (sub-Nyquist) digital sampling rates in the measurement instrumentation. ITS has investigated the feasibility of making some of the low level measurements required for some frequencies for UWB devices. ITS and other agencies have continued research in areas related to the deployment of UWB devices. ITS has made measurements of the emissions from other Part 15 devices, such as computers, to see how the emissions from such devices compare with UWB emissions (see Figure 2 above). In addition, ITS continues to make a limited number of measurements of environment noise background, part of a “reality check” on interference models that assume kT as the applicable noise background for many radio systems. ITS has also conferred with other Federal Agencies concerning background noise measurements.

It is expected that ITS will continue an involvement in UWB measurement and regulatory activities in the coming year, particularly as new UWB devices appear on the market, and as needed to react to changes proposed in the scheduled 6-12 month FCC review of the UWB rules.

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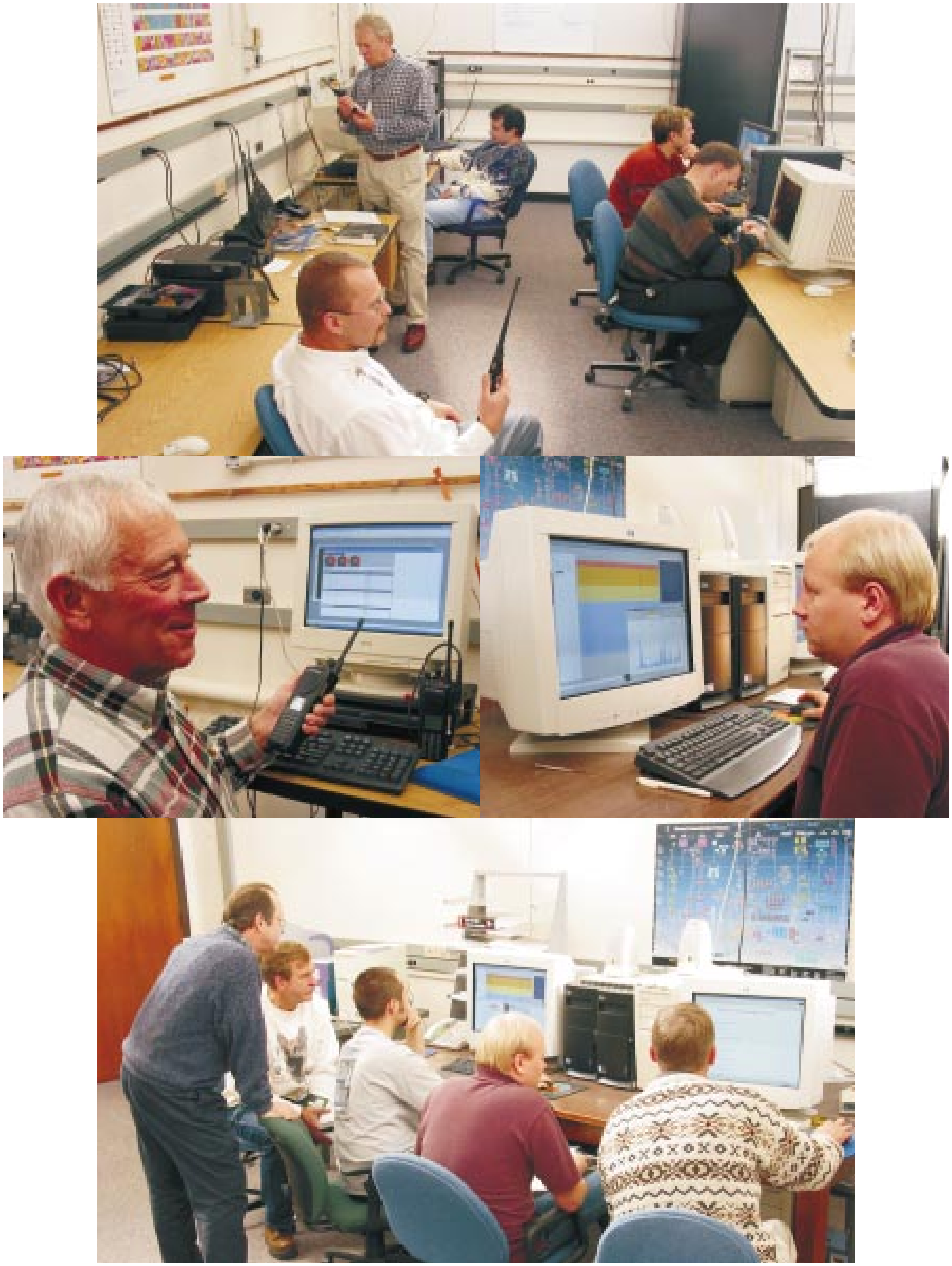


The new Interoperability Research Laboratory (IRL), developed during FY 2002 to respond to the needs of the Justice/Public Safety/Homeland Security community, is used for basic wireless interoperability testing, investigations of information systems and networking technologies, and assessments of hybrid (wireline/wireless) communication products and services (photographs by S. Wolf).

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

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.

Emergency Telecommunications Service (ETS) A two-prong approach addresses ETS. The Institute develops and verifies ETS Recommendations for ITU-T Study Group 9. Computer simulation, laboratory studies, security analyses, and traffic engineering are used to support Critical Infrastructure Protection initiatives related to broadband cable television networks. A second project provides ETS expertise relating to Network Survivability for Technical Subcommittee T1A1. These two projects are funded by the National Communications System (NCS).

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

Justice/Public Safety/Homeland Security Telecommunications Interoperability Standards The Institute conducts a technical program aimed at facilitating effective telecommunications interoperability and information-sharing among dissimilar wireless and information technology systems of local, state, and Federal government agencies. The main thrust is the development of interoperability standards. The NCS, Public Safety Wireless Network (PSWN), and NIST's Office of Law Enforcement Standards (a Technology Center of the National Institute of Justice) fund the program.

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

Voice Over Packet The Institute develops technical contributions related to Internet Protocol (IP) telephony gateways and their supporting infrastructure for the TIA TR41 Standards Formulating Group. Work is conducted to ensure that user interfaces being developed for IP telephony satisfy national security and emergency preparedness communications requirements. This project is funded by NCS.

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.

The wireless industry made projections on how they expected the rollout of technology to progress, as shown in Tables 1 and 2. Both the number of users and the types of services (beyond just voice communications) are increasing, with more emphasis on Internet-type uses. These new services require greater bandwidths (and more radio spectrum).

In order to predict wireless signal coverage more accurately, ITS and other research organizations are developing and evaluating propagation models that are more responsive to the needs of cellular and private land mobile radio service providers. A common model used by system planners is the ITS Irregular Terrain Model (ITM), also known as the Longley-Rice model. While a good predictor in irregular terrain, it does not have the capability to utilize land-use, land-cover databases to predict losses due to man-made objects. 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.

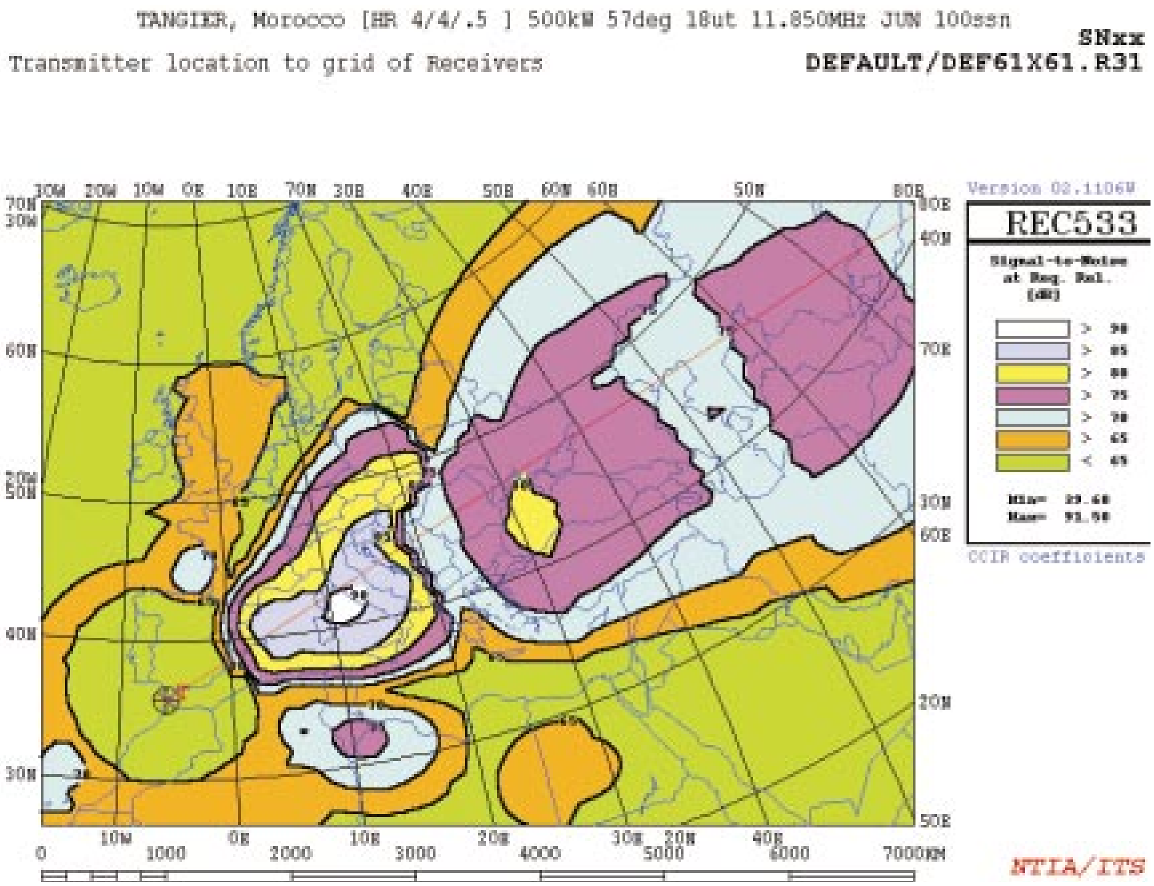
Table 1. Growth in Subscriber Penetration for Wireless Services

	1998	2000	2002
Wireless service subscriber penetration in the U.S.	24%	35%	42%

Table 2. Growth in Subscribers (North America) by Wireless Service Technology

Technology	1998	2000	2002
Advanced mobile phone service (AMPS), analog	53 million	42 million	24 million
Time Division Multiple Access (TDMA), digital	10 million	27 million	44 million
Code Division Multiple Access (CDMA), digital	8 million	27 million	52 million
GSM, a TDMA standard developed in Europe with worldwide use	4 million	10 million	20 million

Radio propagation predictions made using land-use, land-cover databases should estimate signal losses due to objects on a propagation path more accurately than predictions calculated without knowledge of the obstacles. The improved predictions 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. ITS is evaluating the incorporation of land-use, land-cover databases into the ITM propagation prediction model to provide better estimations of signal loss. Although better databases are now available for land-use, land-cover descriptions, the signal loss associated with the various land-use, land-cover categories is not well known, nor is the loss versus frequency well known. 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.



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

Another effort supported by ITS is the international development of propagation prediction models that can be used by spectrum managers and system planners of both land mobile, terrestrial broadcast, maritime mobile and certain applicable fixed (e.g., point-to-multipoint) services. As these services are becoming more similar in terms of RF equipment characteristics, it is appropriate to use the same propagation model for planning and coordination of these services.

The ITU-R Study Group 3 on Radio Propagation 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 the ITU Study Group 3 Working Party 3L. This study group deals with 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 web site:

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 website of the U.S. Department of Commerce NTIA/ITS)

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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Emergency Telecommunications Service (ETS)

Outputs

- Technical contributions to ANSI Working Group T1A1.2.
- Technical contributions to ITU-T Study Group 9.
- Letter report to NCS on NS/EP Communications over Metropolitan Area Networks (MANs).

In the aftermath of the recent terrorist attacks, the Federal Government has refocused its interests on priority treatment of 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) within the United States. ETS is envisioned as a GETS-like service that will be available internationally and will encompass virtually all wireless and wireline communications networks. Types of traffic to be carried include voice, video, database access, text messaging, email, file transfer protocol (FTP), and web-based services.

The ETS effort at ITS encompasses several projects including Packet-Switched Networks and Network Survivability. For 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.

For the first project, Packet-Switched Networks, the Institute develops and verifies ETS Recommendations for International Telecommunication Union — Telecommunication Standardization Sector (ITU-T) Study Group 9 (integrated broadband cable and television networks). 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.

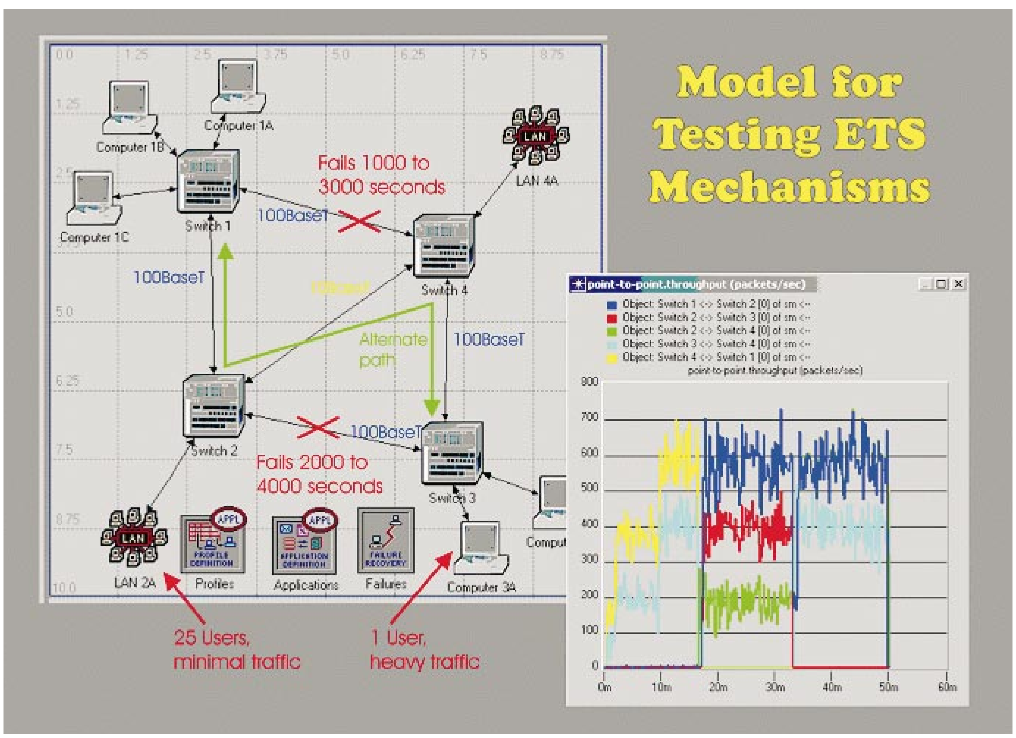

Figure 1. Simulation for testing ETS protocols.

The second project, Network Survivability and Restoral, provides ETS expertise relating to Network Survivability for ANSI-accredited Technical Subcommittee T1A1 (performance, reliability, and signal processing). Within this project, ITS serves as co-editor of a new T1 Technical Report: "Overview of Standards in Support of Emergency Telecommunications Service (ETS)."

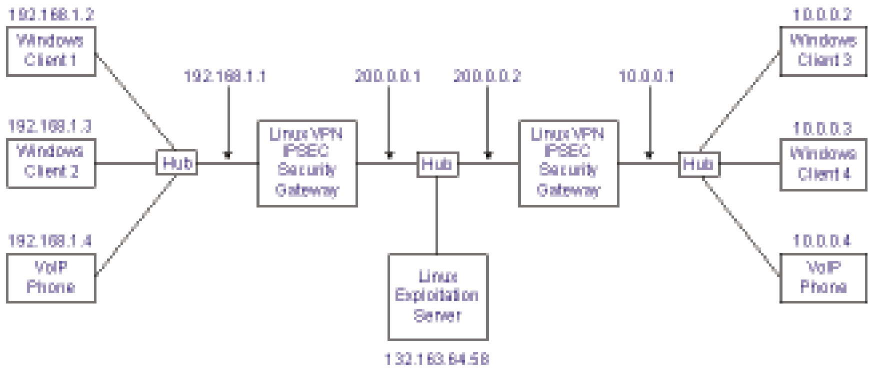

Figure 2. Laboratory setup for testing security and ETS protocols.

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 Working Group T1A1.2 (network survivability performance), national security and emergency preparedness (NS/EP), and the nation. While modeling and simulation are powerful tools for the assessment of threats and mitigation techniques, the simulations need to be well grounded in the physical measurement of important parameters. One of the goals of the project has been to produce baseline models for reference network architectures that can be used both in standards development and in future network research by ITS and others. Figure 1 shows one such reference model developed to test proposed ETS mechanisms.

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 are currently in production worldwide. One goal of this project is to identify where additions or changes might be needed to support 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.

Another important activity underway at ITS is a series of tests utilizing GETS over IPCablecom networks. The evolution of GETS from a PSTN-only service to one that will interoperate over the wireless, IPCablecom, and Next Generation Networks (NGN) is one of the goals of NCS.

Determining the security needs of ETS in IPCablecom networks is another goal of this effort. Figure 2 shows a laboratory setup to test proposed ETS mechanisms over virtual private networks (VPNs) and through firewalls. The setup is currently used to test the performance of Videoconferencing and Voice over IP (Internet protocol) over SIP (session initiation protocol). 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.

During FY 2002, ITS presented numerous technical and editorial contributions to T1A1.2 and ITU-T Study Group 9. Some of these were included in the new T1 ETS Technical Report mentioned above. In FY 2003, ITS will continue to participate in the development and standardization of ETS in T1A1, the IETF, and ITU-T Study Group 9. The projects will address technologies in the Next Generation Network and interactions with the IPCablecom networks. This work on ETS must of necessity be conducted with the help of representatives from network providers, cable television equipment manufacturers, and NCS. Additionally, the work in FY 2003 will focus on survivability and security in the NGN ETS as well as GETS in the IPCablecom networks.

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Networking Technology

Outputs

- Definition of structured planning process for telecommunication and information technology networks.
- Suggestions for types of tools to assist in network design and administration.
- Handbook for telecommunication and information technology network planning (will be available in 2003 on ITS programs webpage http://www.its.bldrdoc.gov/home/projects.html)

The Institute has a long history of performing telecommunication planning and assessment studies for other organizations, but the complexity of today's telecommunication and information technology (hereafter "telecom and 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 project has defined a structured planning process for such studies, examined many tools that can be used in conducting such studies, and identified those tools most likely to provide the greatest benefits. Last year's Technical Progress Report showed the use of these tools in discovering the topology of a network, the loads on segments of the network, and simulating the migration of the topology and loads to a new topology. Efforts in FY 2002 focused on two of the most important aspects of network design and administration: Network Management and Network Security.

Network Management

Network management can be defined as the ability to control the activities required in managing a network from a single point on that network. This point can be at several locations, thus allowing management staff to quickly perform functions from many locations on the network. Good network management can help any organization achieve its goals of availability and performance. Poor network management will not only *not* help an organization reach its goals but may also contribute to the problems which prevent the achievement of those goals.

A logical approach to network management is to break down the management function into its component parts and ensure that each part can be performed efficiently using tools and trained personnel. The International Organization for Standardization (ISO) defines five types of network management functions:

1. *Fault management* refers to detecting, isolating, reporting, diagnosing, and correcting faults on the network. A variety of tools exist to meet these fault management requirements, including monitoring tools, polling tools, alarming tools, report generation tools, and protocol analyzers.

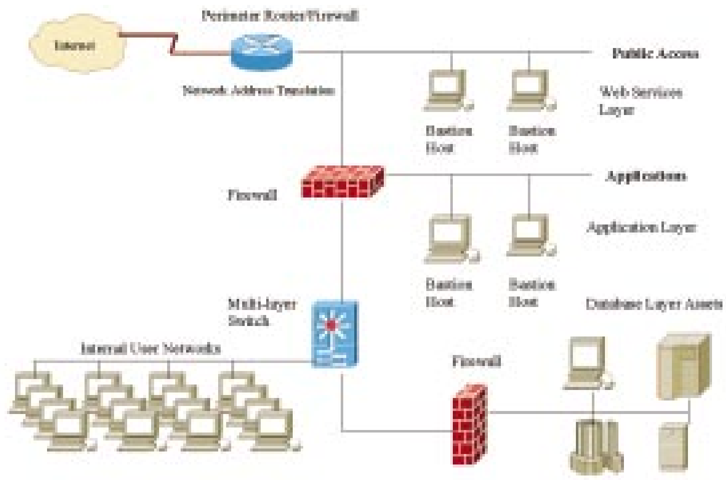
2. *Performance management* is the ability to measure network behavior and effectiveness. This includes protocol performance, application performance, response times across the network, and the reachability of network components. Tools that monitor and measure performance include network analyzers, RMON monitors, and tools that utilize built-in capabilities of many network devices.

3. *Security management* protects network components and interconnections from unauthorized access, unauthorized use, and other damage. This function maintains audit logs, records logins and logouts, and records attempts by users to change their level of authorization. Tools for security management include firewall, intrusion detection systems, perimeter routers, and virtual private networks.

4. *Configuration management* allows the manager to control the configuration of the network and manage the network assets in a logical, systematic, and organized manner. Configuration tools allow the network manager to keep track of operating system configurations and local configurations of devices as well as changes to devices.

5. *Accounting management* allows the administrators to collect statistical information on network usage and load on a component, user, or group level. This facilitates usage-based billing of network customers and can be an aid in detecting abuse of network resources. Another practical reason for accounting management is to track network load levels so that future capacity planning can be undertaken with more confidence in the predicted levels of growth.

Network Security



A layered secure network topology.

Every organization has a mission. In this "information age," as individuals and organizations use information technology systems to process information and further their mission, security management is critical in protecting each organization's assets, and thus its mission, from damage. In recent years and especially since September 11, 2001, security has become a major concern of network designers and administrators. The cost of lost data and time, as well as the potential damage to an organization's image and stability, requires that the network administrator or designer place a very high emphasis on network security. To ensure that a comprehensive, detailed, relevant, and effective security management system is developed, it is important to start by creating a procedure for its creation that covers all aspects of security planning and implementation. This procedure will provide a baseline that organizations can reference when the network security is regularly re-evaluated. A logical approach to security management follows the steps listed below:

1. Define clear principles and practices for securing the IT system.
2. Define an IT security framework for implementing the security management system.
3. Identify overall security requirements.
4. Identify existing assets to be secured.
5. Identify the security risks and consequences of failure of these assets.
6. Analyze security trade-offs and costs for required security level for these assets.
7. Develop a security plan.
8. Develop a security policy.
9. Document procedures and controls for implementing the security plan and policy.
10. Implement the policy through adequate training and resource allocation.
11. Integrate the policy with the organization's overall security management system.
12. Review and reassess the security management system periodically or as the network or security requirements change.

Security considerations have a major impact on network topology and the experience of the network designer is critical in this effort. When designing a network, the designer must consider trade-offs of cost with the level of performance and security provided. Since this is the case, there are many ways that a network solution and design can be implemented. A basic secure network design assumes that the organization's assets will be broken down into three layers of access and sensitivity. This configuration is shown in the figure. The three layers are:

Layer 1 - Public access layer. This layer allows public access to those services and data that the security plan permits. The security policy and risk assessment dictate how that access is achieved, who is permitted access, and how the assets are managed. Data and services at this layer have the lowest sensitivity and the lowest level of security.

Layer 2 - Application layer. This layer supports the services in layer 1 without allowing direct access to the services by the requesting user. This protects the application assets from unauthorized access or modification. Services in layer 1 are permitted to access the applications in layer 2 via a bastion host and firewall. Data and services at this layer have moderate sensitivity and a moderate level of security.

Layer 3 - Database layer. This layer supports database requirements of applications operating in layer 2. These assets are considered very sensitive and must be given the greatest level of security. Direct access to this layer by users is prohibited or at least severely restricted.

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Justice/Public Safety/Homeland Security Telecommunications Interoperability Standards

Outputs

- Voice and data encryption standards for Project 25 digital radios.
- XML data element dictionary.
- TIA Telecommunications Systems Bulletins for testing Project 25 radios.

ITS is conducting a technical program aimed at providing effective interoperability and information sharing among dissimilar wireless telecommunications and information technology (IT) systems within the justice/public safety/homeland security community. The key to the program is the identification and/or development of interoperability standards to allow local, State, and Federal agencies to exchange information, without requiring substantial changes to internal systems or procedures. The ITS program is sponsored by two Federal agencies and one Federal program: National Communications System (NCS), National Institute of Justice (NIJ) (through its Advanced Generation of Interoperability for Law Enforcement (AGILE) Program), and Public Safety Wireless Network (PSWN) program (jointly sponsored by the Departments of Justice and Treasury). The tripartite ITS program is summarized below.

National Communications System Support

The Institute is assisting NCS's Technology and Programs Division in developing a comprehensive series of interoperability standards for digital land mobile radio (LMR) for public safety applications. Next generation LMR standards are being developed by the Federal Government, in conjunction with industry and local and State governments, within a group called Association of Public-Safety Communications Officials/National Association of State Telecommunications Directors/Federal (APCO/NASTD/FED) Project 25. This project consists of three phases. Phase 1, which has been completed, included the development of a comprehensive set of standards for 12.5-kHz digital LMRs. Phase 2, in progress, is developing a set of interoperability standards for narrowband (6.25 kHz) digital LMRs; standards defining TDMA radios with an equivalent 6.25 kHz/channel efficiency are also being developed. ITS efforts have mainly supported Phase 2. Phase 3 (also referred to as "Project 34") has also begun, and is focused on the development of standards for wideband mobile data applications.

NCS, Federal law enforcement agencies, and the National Security Agency, with assistance from ITS, are participating in the development of these standards, and are taking the lead in the development of related Information System Security (INFOSEC) standards. An ITS representative chairs the Project 25 Encryption Task Group and works closely with its members in developing Project 25 INFOSEC standards. ITS participates on the Telecommunications Industry Association (TIA) TR 8 Encryption Committee to ensure that TIA standards meet Government requirements. ITS also participates in other TIA TR 8 Committees and Project 25 task groups as necessary to ensure that the total suite of Project 25 LMR interoperability standards meets Federal requirements, and to continually assess Project 25's impact on Federal agencies. An ITS engineer represents NCS on the Project 25 Steering Committee. To date ITS has contributed to the development of standards for the encryption of voice and data sent over the Project 25 Common Air Interface, a standardized key fill interface for Project 25 equipment, and for the over-the-air-rekeying of Project 25 radios.

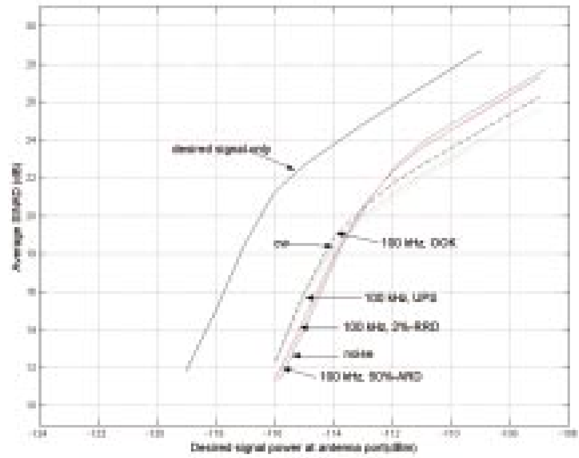
NIJ's AGILE Program Support

As the Department of Justice's science and technology arm for assisting State and local agencies, NIJ addresses wireless telecommunications and IT interoperability issues. In particular, NIJ's AGILE program has facilitated the efforts of the practitioners in the justice/public safety/homeland security community to coordinate and share information. The long-term thrust involves assistance toward standardization of interoperability approaches. The AGILE program continues to provide specialized technical support to help users define their requirements, and then assists the practitioners to address and satisfy those functional needs. This is done by recommending standards that most aptly specify the context of a nationwide information sharing framework. The second thrust of the AGILE Program provides technical investigation and laboratory evaluation of interim interoperability products, services, and techniques to allow agencies to work better now while longer term standardization efforts are developed. ITS performs the AGILE standardization and evaluation activities under the auspices of NIST's Office of Law Enforcement Standards (OLES), one of NIJ's technology centers.

During FY 2002, considerable progress was made in the AGILE Program regarding standardization of IT applications by teaming with the Global Justice Information Network Advisory Committee (Global). Global, as the Group of Groups, represents all practitioners in the Justice community (e.g., law enforcement, courts, corrections, prosecutors, defense, etc.; see http://it.ojp.gov/global/index.html). ITS worked with Global's Infrastructure/Standards Working Group to develop a standard approach for XML (eXtensible Markup Language) implementation, along with a data element dictionary that can provide common "words" for a common "language" to be used by the justice/public safety/homeland security community. In addition, ITS helped design and develop a web-based Justice Standards Registry for Information Sharing to allow practitioners to list and discuss their interoperability standards, standards projects, and concepts that may benefit others (see http://it.ojp.gov/jsr/public/index.jsp). An Interoperability Research Laboratory (p. 69) was established at ITS to accommodate testing and evaluation of interim interoperability products and proposed ideas.

Public Safety Wireless Network (PSWN) Support

ITS provides technical support to the TIA TR8 (Project 25) Committee to develop Project 25 Standard documents. Specifically, ITS has had the responsibility for developing procedures to test the interoperability of radio systems engaged in conventional voice, over-the-air re-keying of encryption, trunking, and data applications. The procedures are TIA Telecommunications Systems Bulletins (TSB) and guide TSB users on the set-up and conduct of functional tests to assure that two Project 25 devices are interoperable. In addition, through AGILE and PSWN, ITS provides support to the ISSI Task Group of TR8 in the development of the Inter-RF Sub-System Interface (ISSI) standard for Project 25. This standard is needed to link the radio networks of cooperating jurisdictions and to link local radio systems to a nationwide network, such as proposed by the Treasury/Justice Integrated Wireless Network.



Susceptibility of an analog land mobile radio to various ultrawideband devices.

ITS developed and conducted tests to measure the performance of Public Safety radio receivers with ultrawideband interference. The information resulting from the tests is important as practitioners are expected to use land mobile radios in their vehicles or carry handheld radios while they also make use of ultra wide band equipment in support of their missions. Thus, the levels that cause interference to the radios are important to the community. The graph above shows the susceptibility of an analog land mobile radio to various, typical ultrawideband devices. The desired signal is an analog FM signal at the antenna port of the radio. The interference signals are the signals that cause the desired signal reception to degrade by 3 dB.

Recent Publications

TIA/EIA TSB-102.CABB Project 25 Interoperability Test Procedures: Over-The-Air-Rekeying (OTAR), Feb. 14, 2002.

Draft version TIA/EIA TSB-102.CABx Project 25 Interoperability Test Procedures Voice Operation in Trunked Systems, Sep. 2, 2002.

Presentation to Congressional, Federal, and State/local representatives: Invited paper on Emerging Technology Solutions at the NTIA/PSWN Public Safety Communications Interoperability Summit.

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Outputs

- Demonstration of advanced radio technology and infrastructure along the Midwest passenger rail corridor, in support of the Federal Railroad Administration's high-speed rail pilot program.

Amtrak station at Niles, Michigan (image courtesy of G.E. Transportation Systems).

The incremental train control system (ITCS) is a radio-based signaling system designed by G.E. Transportation Systems whose purpose is to facilitate high-speed passenger rail transportation along the Midwest rail corridor between Chicago and Detroit. The current ITCS demonstration system "overlays" on an existing legacy track signaling system of approximately 70 miles in length. It provides enforcement of signal indications and civil speed limits, as well as advanced start of highway crossing gates, in a high-speed rail environment. The overlay design supplies system redundancy, so that in the event of data communication failure between ITCS components, passenger safety is not compromised, as train control will revert to the legacy signaling infrastructure.

At higher track speeds, the status of highway crossings and signal lights must be made known to the locomotive at further distances from the crossing and signals, as compared to traditional track speeds, and highway crossing gates must be activated when the locomotive is further distant from each crossing. Monitoring and notification over these greater distances is accomplished by radio frequency (RF) data links.

ITCS monitors the status of "wayside" devices (signal lights, highway crossing gates, etc.) via an RF data link, and relays these statuses to the locomotive via a second RF data link. A computer onboard the locomotive evaluates the status information from these devices in conjunction with local sensory information (speed, GPS location, etc.) and other pertinent data (track profile, computed braking distances based on track profile, and so forth), and then determines permissible locomotive actions, so as to facilitate efficient high-speed rail travel.

During the course of this pilot program, operational system anomalies, believed attributable to radio propagation, have been experienced on a

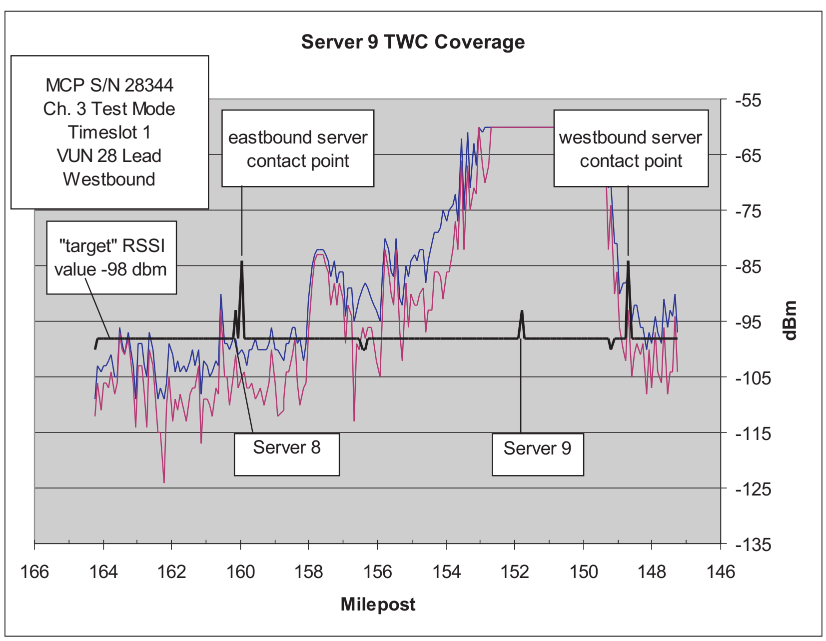

Figure 1. Measured signal strength – Server 9; Amtrak locomotive at track speeds.

number of occasions. While these anomalies have always resulted in restrictive "fail-safe" modes of operation, with ITCS functioning exactly as it should under these degraded conditions, these anomalies have resulted in sub-optimum transit time performance of passenger trains traversing the territory. Consequently, the Federal Railroad Administration (FRA) asked the Institute to provide technical representation to the ITCS program on their behalf.

Empirical evidence collected thus far suggests that log-normal shadowing phenomena is deleteriously affecting the propagation of the 900-MHz RF data link signals. Figure 1 shows typical receiver response curves (average and minimum received power levels) as measured by G.E. Transportation Systems.

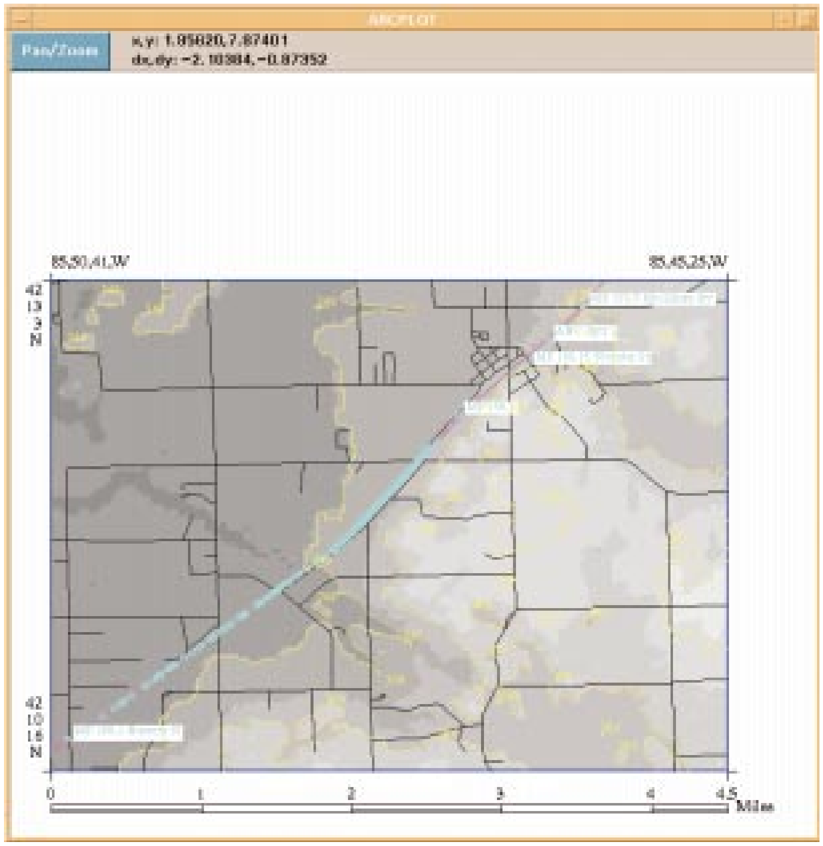

Figure 2. Successfully received ITCS data packets; Hy-Rail vehicle at 5 mph.

What this plot shows is that on eastbound moves (although this measurement was actually taken traveling westbound), the signal strength would not have been sufficient to allow the locomotive's ITCS equipment to have acquired the signal from wayside server 9 by the time milepost marker MP 160 had been reached. Even though MP 160 is still in server 8 territory, having acquired server 9 by this time ensures that an RF data link is established and that advance gate crossing activations and other critical actions can be triggered just as soon as the locomotive would enter server 9 territory at MP 156.

Further investigations by the Institute determined representative areas of successful data communication. Figure 2 shows the locations of successfully received ITCS packets over a portion of the same track territory, indicated by the turquoise-colored dots on the (magenta-colored) tracks. It is to be noted that this data was collected in a single pass while driving along trackside in an ITCS-equipped Hy-Rail vehicle, at speeds of about 5 mph, as opposed to a number of data sets collected at typical (faster) locomotive speeds, as was done in Figure 1.

What is apparent is that near MP 160 (lower-left corner) and west, successful packet reception in this fringe area appears to be less reliable than further east, a region more centrally located to the track section. During this data collection activity, the Institute noted that the tree line was on the same order of height as the 900-MHz antennas, a very likely cause of the shadowing phenomena being experienced. The Institute is currently exploring whether apposite solutions could be as simple as raising the heights of wayside antennas, or whether an entirely new approach to system design and/or deployment of the underlying infrastructure may be more appropriate.

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Voice over IP

Outputs

- Report to IEEE conference regarding VoIP degradation over 802.11 networks under Bluetooth interference.
- Standards contributions (ITU, TR-41.1) detailing the behavior of Government Emergency Telecommunications System (GETS) calls over VoIP based systems.

Advances in quality of service (QOS) and greater market availability have resulted in increased utilization of Voice over IP (VoIP) on enterprise networks. VoIP technology offers substantial benefits including 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, interference problems within the wireless channel can substantially degrade the QOS of a VoIP system. This effect is of particular concern in Wi-Fi systems, which share the same spectral allocation as Bluetooth (IEEE 802.15) devices.

In order to evaluate some of the effects of radio interference on VoIP transmission over wireless channels, ITS has investigated the degradation of estimated mean opinion scores (MOS) in VoIP transmissions over Wi-Fi channels with nearby Bluetooth interferers. This experiment simulated the effects of multiple active Bluetooth piconets (small networks of devices connected in an ad hoc fashion using Bluetooth technology) operating in close proximity to VoIP-encoded Wi-Fi transmissions at various signal to noise ratios (SNR).

In this experiment, standardized Harvard phonetically balanced sentences were transmitted using an H.323-based VoIP system. The packet telephony devices used the G.723.1 codec at a bit rate of 5.3 Kbps. The information was carried over a Wi-Fi channel at 11 Mbps, where the transmitter and receiver were in close proximity to as many as four independent Bluetooth piconets that were sending large files using FTP. Forty sentences were transmitted during each experimental iteration, and the audio signal transmitted was compared with the audio signal received. Estimates of MOS were derived using the perceptual evaluation of speech quality (PESQ) algorithm (ITU-P.862) and packet loss was measured using a software-based protocol analyzer.

The experimental results were analyzed over multiple planes. The percentage of packets dropped versus the number of Bluetooth piconet interferers was investigated, as well as the estimated MOS compared to number of piconets. Both of these comparisons were made for three different SNR values. A third comparison, shown in Figure 1, indicates the degradation of MOS with increasing packet loss percentages. The target MOS for toll quality telephony (and VoIP systems) is 4, so these results indicate that

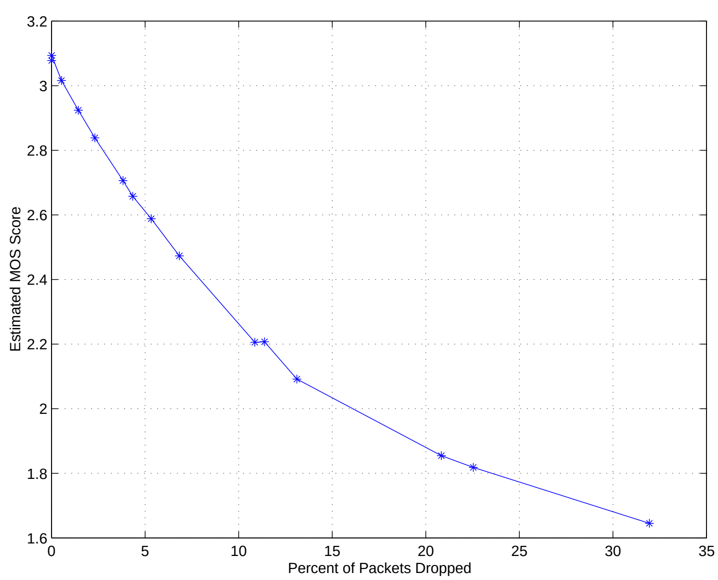

Figure 1. Mean opinion score (MOS) versus dropped packets in Wi-Fi transported VoIP.

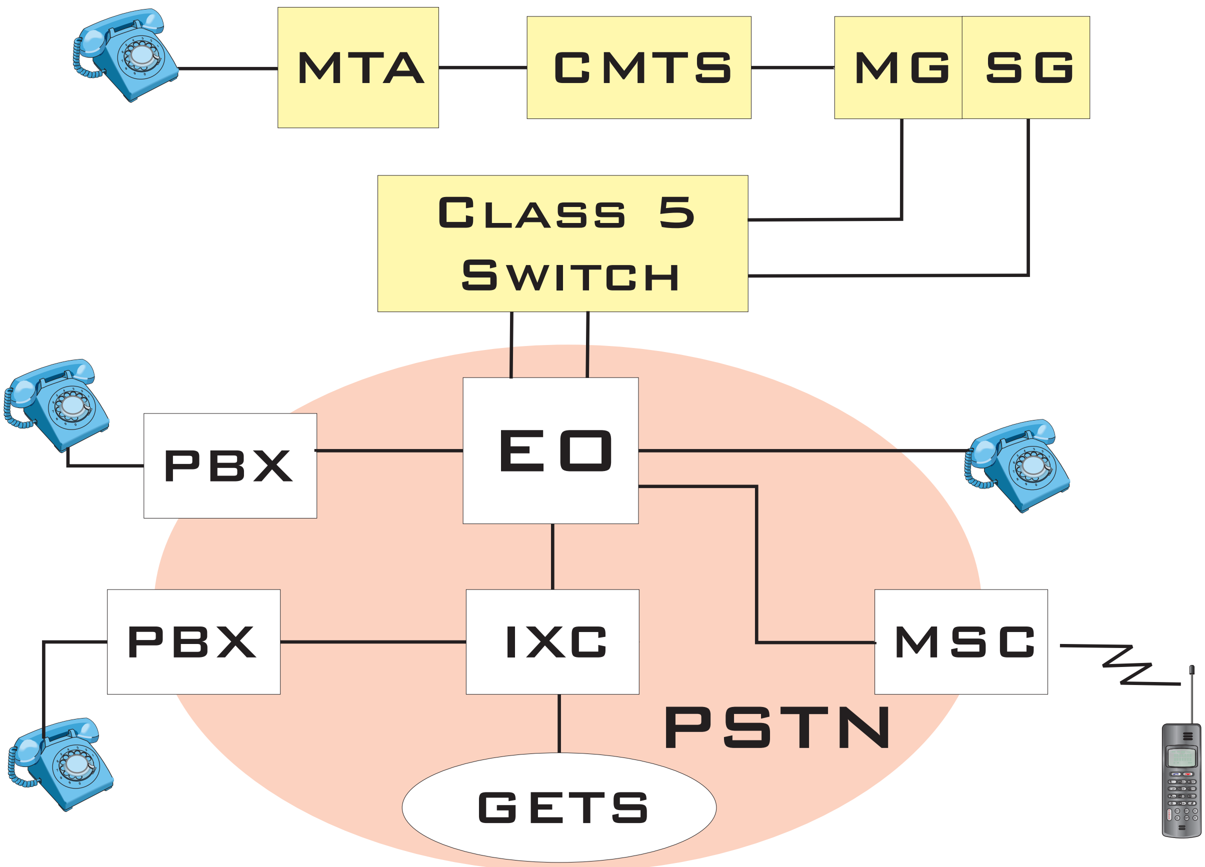

Figure 2. Test setup for GETS calling over VoIP-based media.

low percentages of packet loss due to radio interference can severely degrade the intelligibility of these systems.

Recognizing the growing availability of VoIP-based packet telephony, as well as a heightened awareness of government emergency communications, ITS has also embarked on a series of investigations regarding the capabilities of current VoIP signaling implementations for this process. During emergencies, the public switched telephone network (PSTN) may encounter congestion, precluding emergency calls from getting through. Even government emergency telecommunications service (GETS) calls, which enjoy enhanced priority, may be impossible to place using normal telephone connections. However, VoIP-based enterprise networks might be used to route calls around the congested area, through gateways into non-congested portions of the PSTN. In order to test the viability of using alternative VoIP-based media to make such calls, experimental GETS call placements over existing alternative systems like the one diagrammed in Figure 2 are being made. Here, the enterprise network includes a cable modem system with a media terminal adaptor (MTA) and a cable modem termination system (CMTS) as well as media and signaling gateways (MG and SG). The calls may be terminated through a variety of equipment including local phone and private branch exchange (PBX) equipment as well as cellular telephones and long-distance PBX (e.g., through an interexchange carrier or IXC). This is an ongoing effort, in connection with other ITS projects studying the emergency telecommunications service (ETS).

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To introduce the new 3-D fly-through analysis of the Communication Systems Planning Tool (CSPT), Institute staff took the 3-D propagation prediction software on the road. Shown is the exhibition booth for the U.S. Department of Commerce, NTIA/ITS, at MILCOM 2002 in California, October 2002 (photograph by C.J. Behm).

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 work 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 work 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 has been one of ITS' greatest strengths for many years. 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.

The **Wireless Networks Research Center** (WNRC), opened in May 2001, has been home to four projects in its first year. ITS engineers have been able to assist other Federal agencies with emerging technologies in 2.5G and 3G wireless communications. The WNRC was designed to accommodate studies of emerging technologies and PCS, analysis of wireless protocols, and studies of wireless network effects such as congestion and capabilities such as priority access. (See page 75 for more information about the WNRC.)

Areas of Emphasis

ENGINEERING

PCS Applications The Institute helps the Telecommunications Industry Association (TIA) committee TR46.2.1 develop an inter-PCS interference model and handbook. ITS also serves as editor for this committee. The project is funded by NTIA.

Cellular and PCS Network Measurements Analysis of commercial wireless networks is achieved by collecting network protocol messages and physical RF link measurements. To help develop a better understanding of the loading of commercial wireless networks, ITS has conducted a series of IS-95 network code channel occupancy measurements. This work is funded by multiple Department of Defense agencies

Wireless Network Analysis and Forecasting Wireless communication links are used to extend wired networks to solve the first mile/last mile connectivity problem. The Institute is actively investigating wireless networks and services expected to be used in the future, including the interference between wireless network technologies, such as that between 802.11b and Bluetooth. This work is funded by multiple DoD agencies.

ANALYSIS

Telecommunications Analysis (TA) 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.

Geographic Information System Applications The Institute has developed a menu-driven propagation model using geographic information system (GIS) formats. In addition, ITS has developed a 3-D fly-through capability. This work was funded by the Dept. of Defense and ARINC.

MODELING

Propagation Model Development & Comparisons The Institute develops enhancements to existing propagation models. This research includes examination of various related databases, such as terrain, and how they interact with the models. Models are also examined using sets of measured data. Some of the technical products from this effort are presented on behalf of the U.S. at the ITU-R. This project is funded by NTIA.

PCS Applications

Outputs

- Technical contributions to an industry-developed inter-PCS interference standard for predicting, identifying, and alleviating interference related problems.
- Interference models for the PCS technologies currently in use, as well as proposed third generation (3G) systems.

Personal Communications Services (PCS) is widely used for mobile voice and data communications and is becoming an important resource for implementing emergency telecommunication services following a natural or man-made disaster. Several factors contribute to diminished channel capacity of a wireless network. A major limiting factor of channel capacity is co-channel interference for channels in the same technology. Another stress on channel capacity occurs from multiple, independent, non-interoperable systems that service the same geographical area, often using the same frequency bands and infrastructure (base station sites and towers). In addition, natural and man-made disasters can damage the terrestrial 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. National security/emergency preparedness (NS/EP) planners and network operators must understand these interference effects to operate effectively in an overloaded environment.

ITS contributes to understanding inter-PCS interference by participating in the Telecommunications Industry Association (TIA) committee TR46.2 (Mobile & Personal Communications 1800-Network Interfaces). Through this committee, ITS helps develop the Technical Service Bulletin "Licensed Band PCS Interference." This bulletin is a first step in characterizing the interfering environment caused by large numbers of active users and competing technologies.

However, this work 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. Information from simulations or simulators fed by these models can be used to develop methods to alleviate existing interference problems and even avoid future interference problems. 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 (Rusyn 2002, see **Recent Publication** on next page). The model covers system-specific interference modeling to determine co-channel interference from both immediate and adjacent cells.

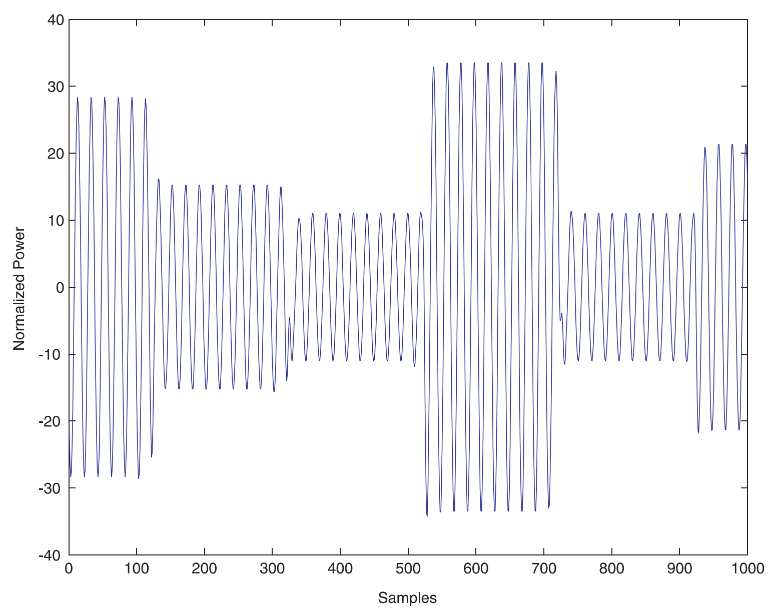

Figure 1. The output of the ITS models can be used in either software- or hardware-based simulations.

The output of the physical model is a sampled modulated signal which is the composite of the signals transmitted from all sources identified in a specified scenario. Software- and hardware-based simulations can use the sampled signal from the model to evaluate system designs (see Figure 1). 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.

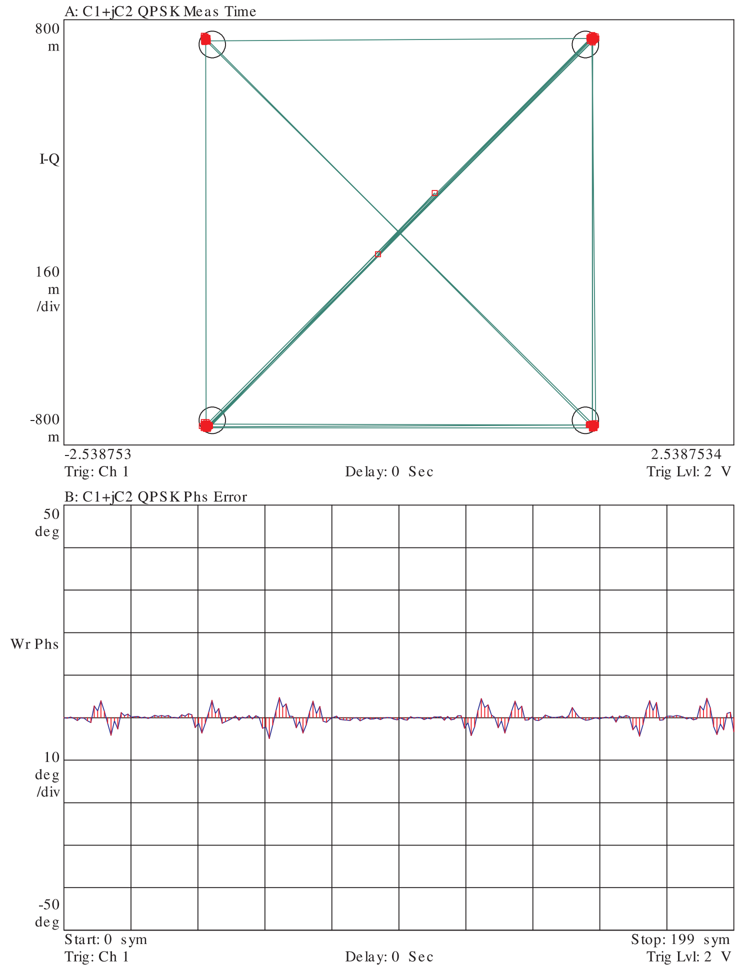

Figure 2. The ITS model can show properties of a PCS signal such as the phase error shown here.

The ANSI 95-B model is the first in a series of models that will include third generation (3G) systems. 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. The series of ITS models will include cdma2000 and W-CDMA. All of the new models are being developed such that the output data from the models will be compatible with the output data from the other models in the series; this will allow users to characterize potential problems between the different technologies as the 3G systems are implemented as well as characterizing interference problems with the existing PCS networks (see Figure 2).

Recent Publication

T.L. Rusyn, "Co-channel interference modeling of the ANSI/TIA/EIA-95-B Code Division Multiple Access cellular system," in *Proc. 2002 IEEE EMC Symposium*, Minneapolis, MN, Aug. 2002.

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Cellular and PCS Network Measurements

Outputs

- Network discovery.
- Wireless network capacity and interference measurements.
- Hostile environment characterization.

The Federal Government is relying more heavily on commercial wireless infrastructure to satisfy its communications needs. Consequently, government services are increasingly dependent on commercial wireless infrastructure. In times of national emergency it is imperative to maintain a continuity of government service over these infrastructures so that critical government services are not interrupted. Therefore, it is crucial that the government have an understanding of the commercial networks that it is relying on.

In contrast to wired networks, wireless networks exhibit an ephemeral and dynamic relationship between services and resources. At each transaction, the measurable RF and network parameters will change depending on the demands of that particular transaction. It is essential to investigate both of these domains, radio and network, in order to understand the network behavior, since simple RF power measurements alone are inadequate.

Analysis of commercial wireless networks is achieved by collecting network protocol messages and physical RF link measurements. Both types of data are needed to identify wireless network characteristics such as usage patterns, channel resource allocation and network topology. This multifaceted viewpoint is necessary since many wireless network architectures rely on spread spectrum techniques to increase user density. Without this real time information about the air interface and the network interface, parameters like channel occupancy would not be obtainable. For instance, in IS-95 networks, the paging channel must be decoded to gain access to the Walsh code domain which is required to measure traffic channel activity. A similar problem exists in GSM networks, where frequency hopping sequences and time slot allocations from control channels are needed to identify user activity. These kinds of measurements are not possible without examining the integral connection between network protocols and radio resources. These tools are used to identify the intricacies of wireless infrastructure topologies in real time.

To help develop a better understanding of the loading of commercial wireless networks, ITS has conducted a series of IS-95 network code channel occupancy measurements. The code domain correlation strength data was collected over several time regimes. Both continuous and discrete measurements were made during potential busy hours and busy daytime periods. A statistical analysis of the IS-95 base station code channel occupancy was then conducted. Results of the analysis are shown in Figures 1 and 2, which show the channel occupancy and channel idle time distributions, respectively. The data in Figure 1 are suggestive of a lognormal distribution. Previous investigators have found that call holding distributions exhibit a lognormal

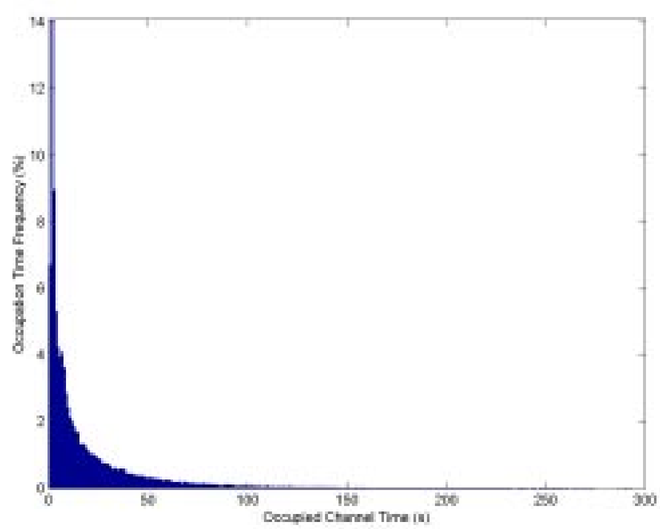

Figure 1. Occupied channel time distribution (discrete case).

characteristic.* This contrasts with the exponential distribution observed in wireline systems.

The second distribution, Figure 2, examines the time between successive uses of a code channel. Essentially, this is a look at the call arrival model, and shows that it too represents the lognormal distribution. In contrast to the occupancy, or channel holding-time model in the previous figure, this result was unexpected since previous investigators had found an exponential distribution for this statistic.* The discrepancy might be due to the abstracted nature of code power measurements versus true user occupancy data.

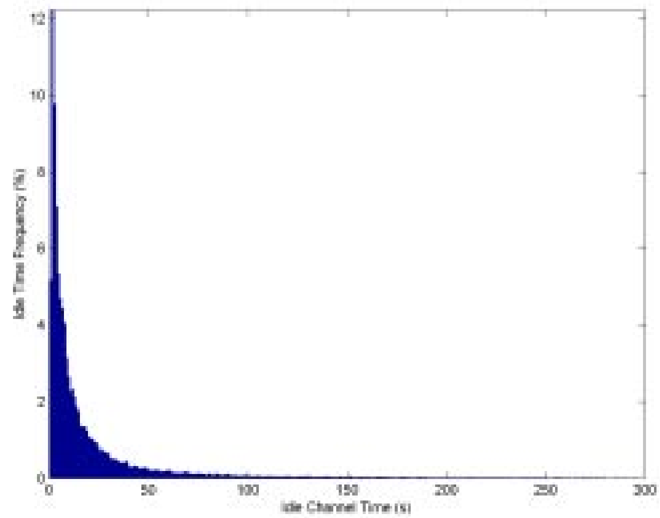

Figure 2. Unoccupied channel time distribution (discrete case).

Since there is very little public domain information available about real time cellular/PCS usage, this work will help in the development of usage pattern models for both commercial and government users. This kind of data has added benefit to Federal network planners in that it is an independent evaluation of commercial providers of government communication services.

Figure 3. Wireless phones used in cellular and PCS network measurements in the ITS Wireless Networks Research Center (photograph by S. Wolf).

ITS has also investigated issues relating to GSM interference. ITS has conducted a series of experiments that explore the behavior of GSM handsets in hostile environments. Such an interference environment would be expected to materialize in times of national emergency. Experiments attempted to identify user recognizable and measurable manifestations of system congestion or other manmade sources of interference. These tests were designed to help quickly identify network overload and vulnerabilities.

* C. Jedrzychi and V.C. M.Leung, “Probability of channel holding time in cellular telephony systems,” in *Proc. 46th IEEE Vehicular Technology Conference, Mobile Technology for the Human Race*, Volume 2, 1996, pp 247-251.

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Wireless Network Analysis and Forecasting

Outputs

- Wireless ad hoc network research.
- Forecasting of future wireless technologies.
- Studies of WPAN to WLAN interference.

Wireless communication links are used to extend 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, which is more expensive to upgrade and whose inherent limitations restrict user mobility. Wi-Fi (wireless fidelity) 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 communication 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 posess the unique features of mobility and self association. Peer to peer communications, such as those defined in the 802.11 standard and Bluetooth, only partially take advantage of the self association characteristic of wireless communication. 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.

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 IEEE 802.16, 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

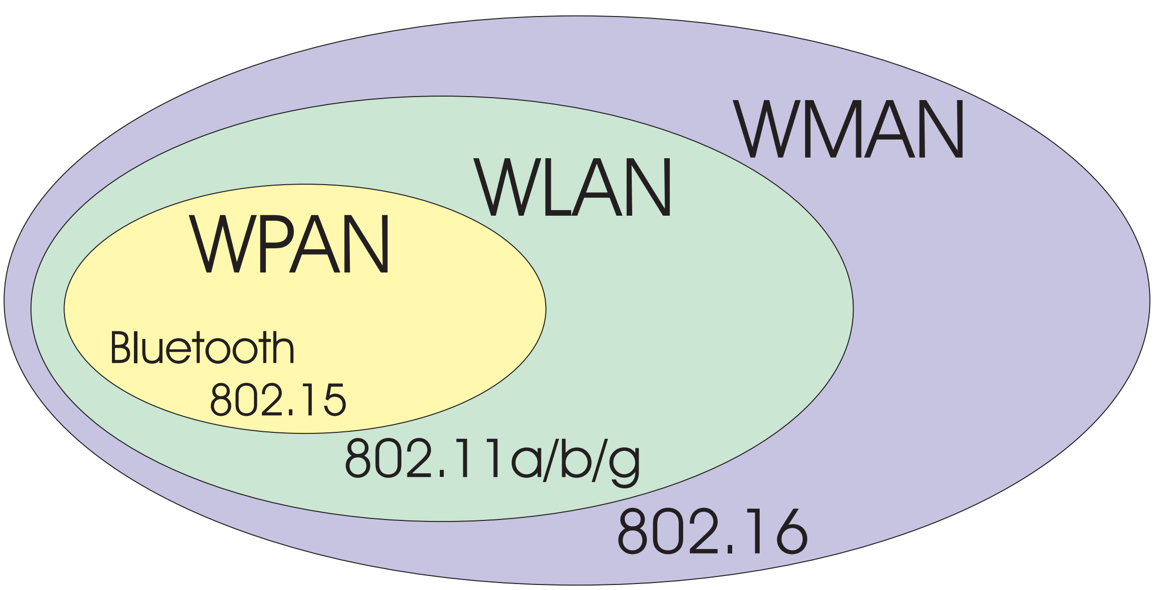

Figure 1. Hierarchical connectivity between wireless network standards

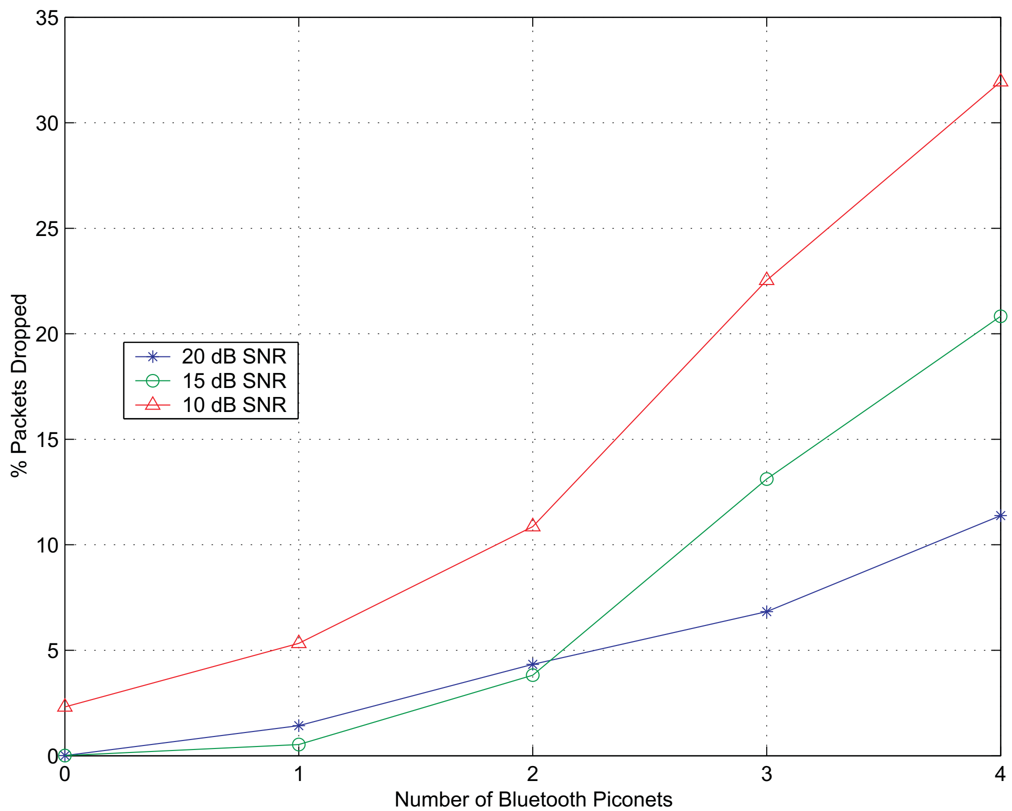

Figure 2. Percent packets dropped vs. active Bluetooth piconets.

piconets (small networks of devices) in the unlicenced 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. A hierarchical connectivity diagram of these networks is shown in Figure 1.

Another area of research centers on the interference between wireless network technologies. The Wi-Fi (IEEE 802.11b) and Bluetooth wireless networking technologies are widely available and are increasingly used in field applications when government data infrastructures do not exist. Unfortunately, interference between these networks can create vulnerabilities for government emergency services, particularly when these networks are used as ad hoc data infrastructures. Wi-Fi operates in the unlicenced 2.4 GHz band, uses direct sequence spread spectrum (DSSS), and supports data rates of up to 11 Mbps. It is typically deployed in networks ranging up to 100 meters in airports, homes and businesses. Bluetooth, which is also in the 2.4 GHz band, uses frequency hop spread spectrum (FHSS), supports data rates up to 1 Mbps, and typically operates in piconets of up to 10 meter range. Bluetooth piconets are used as wireless data cables to connect peripherals such as printers to PDAs or to connect headsets to handsets. Although these networks are designed for somewhat different applications, they are often found in the same area, and consequently may interfere with each other. ITS has been exploring the interference between these wireless networks by conducting a series of measurements. Figure 2 above shows the percentage of dropped Wi-Fi packets versus the number of active Bluetooth piconets. As the figure indicates, there is increasing packet loss on the Wi-Fi link as the number of piconets increases and the Wi-Fi link power decreases.

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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, and radar systems, personal communications services (PCS), and local multipoint distribution systems (LMDS).
- Standardized models and methods of system analysis for comparing competing designs for proposed telecommunication services.

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 One-km Base Elevation) data for the entire world; the US Census data for 2000, 1997 update, and 1990; and Federal Communications Commission (FCC) databases. For more information on available programs see the Tools and Facilities section (pp. 74-75) or call the contact listed below.

TA Services is currently assisting broadcast television providers with their transition to digital

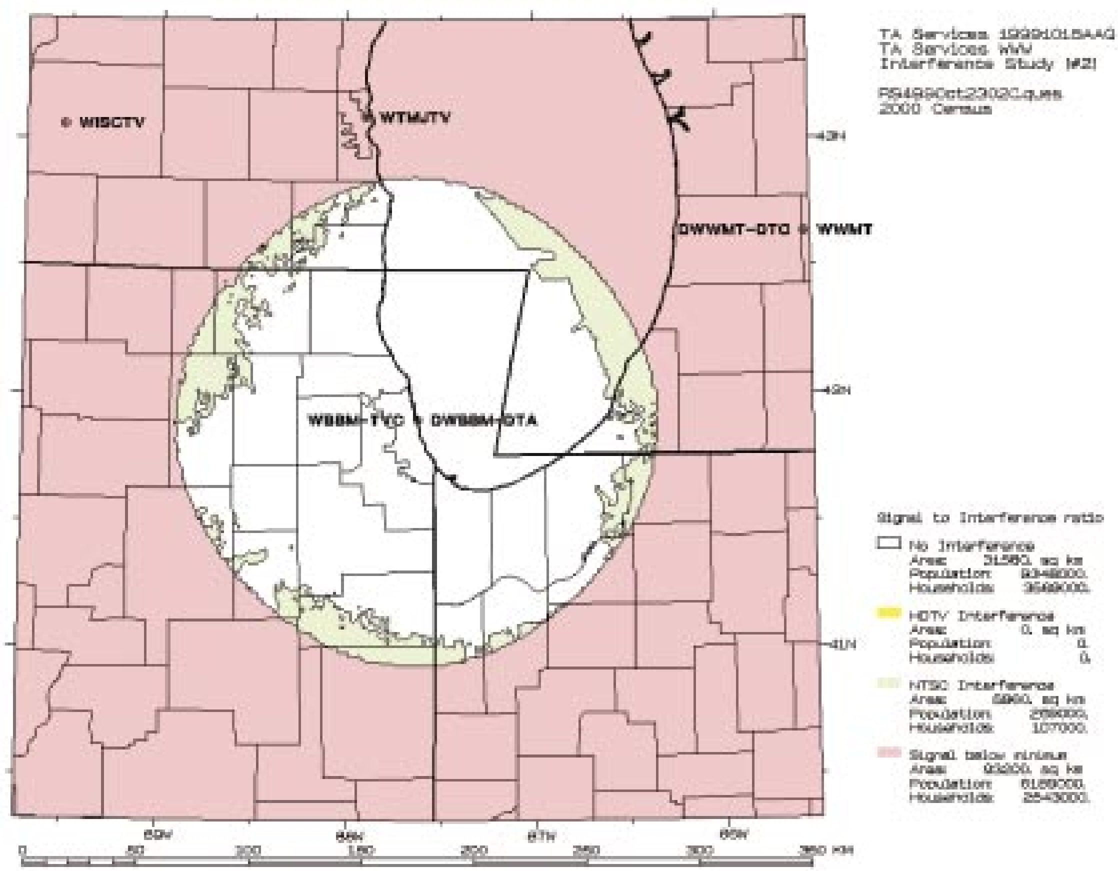

Figure 1. Interference analysis for proposed digital station in Chicago.

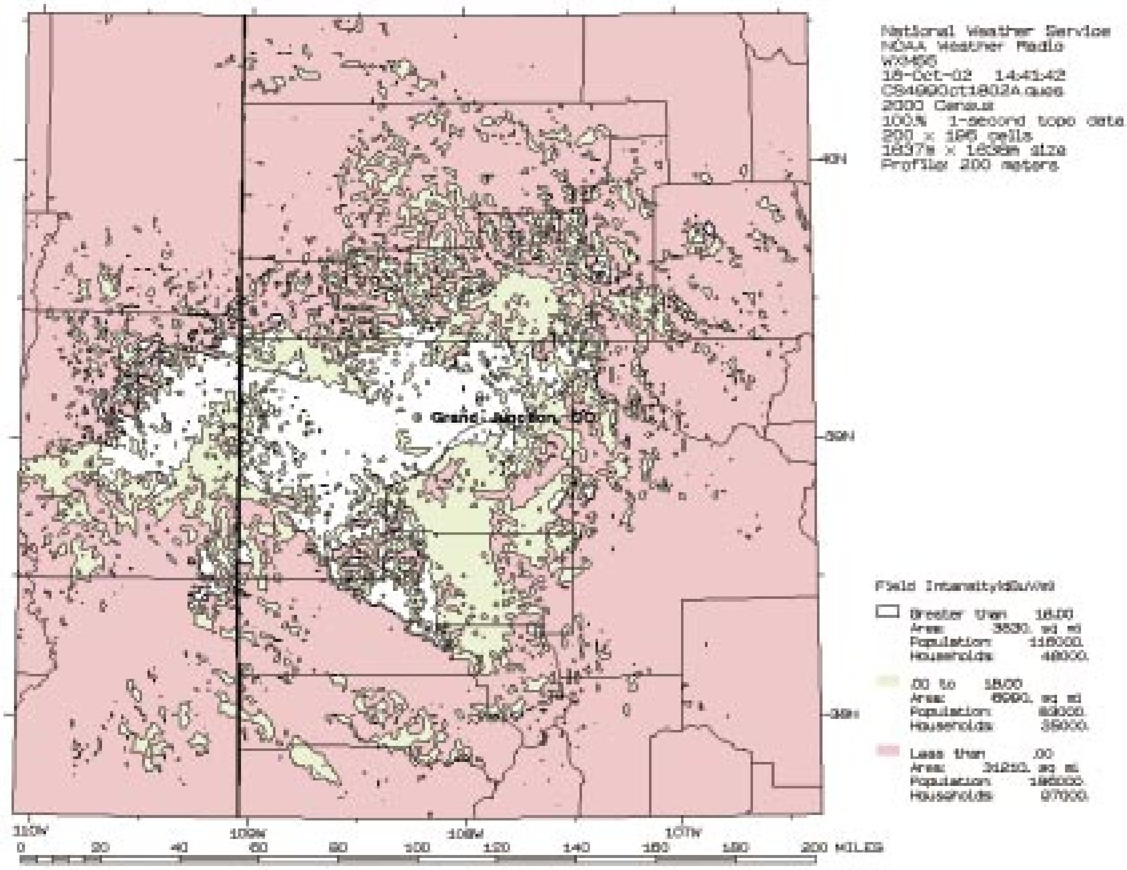

Figure 2. NWS stations coverage for Grand Junction, Colorado.

television (DTV) by providing a model for use in advanced television analysis (high-definition television, advanced television, and digital television). This model allows the user to create scenarios of desired and undesired station mixes. The model maintains a catalog of television stations and advanced television stations updated weekly from the FCC from which these scenarios are made. Results of analyses show those areas of new interference and the population and number of households within those areas. Figure 1 shows the result of a study done analyzing the predicted interference to a proposed digital TV station in Chicago, Illinois. 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 a plot similar to that shown in Figure 1, 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.

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. Recently the whole NWS database was recalculated using the 1-arc-second terrain database. Figure 2 shows the recalculated coverage for Grand Junction, Colorado.

All models in TA Services and their outputs can be accessed via a network browser.

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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.
- Interference and overlap coverages of multiple transmitters.
- 2.5-D or full 3-D coverage predictions with interfaces to 3-D visualization tools.

ITS maintains 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 becoming more commonly available at affordable prices and include such data as terrain, satellite photo imagery, roads, communications infrastructure, building locations and footprints, land type and use, water bodies, streams, population densities and many others. These are maintained in commonly used relational database management systems (RDBMS) which can be connected to a GIS. The Institute has modified and distributed this tool to several groups with modifications tailored to a specific application. These groups include government agencies, private cellular companies, paging system providers, public and private television systems, private consultants and transportation companies such as the railroads of the United States.

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 stereo photographs 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.

A graphical description of CSPT is shown in Figure 1. The output shows an analysis area of Dupont Circle in Washington, DC, made from an imported digital elevation model and image at 1 meter resolution. The image shows the coverage of a transmitter placed in the center of Dupont Circle.

The general flow of CSPT is as follows. The user defines an area within which a study will be performed. This analysis area can be defined

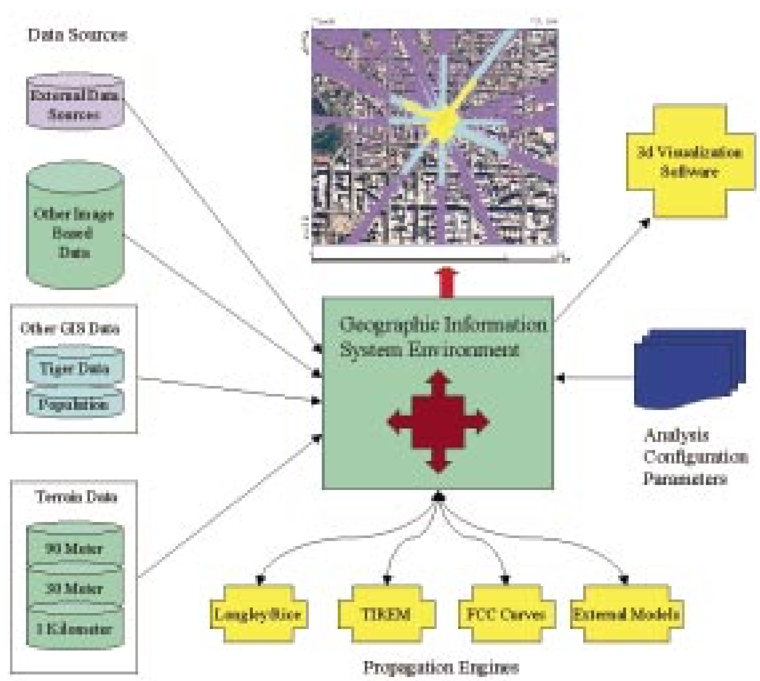

Figure 1. Overview of the CSPT model.

graphically by zooming into a map of the world or of the U.S. or by defining the latitude and longitude of the boundaries of the desired area. The user then imports desired GIS information such as political boundaries, roads, rivers, special imagery, or application specific GIS data. 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.

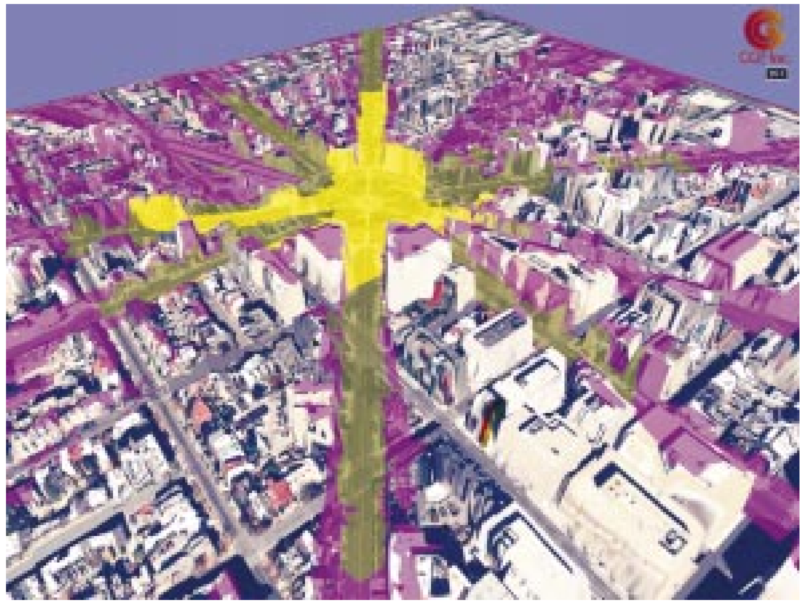

Figure 2. CSPT fly-through analysis showing Dupont Circle in 2.5-D.

The CSPT software can be configured to produce propagation predictions in 2.5-D or full 3-D. A 2.5-D prediction includes the calculation of signal strength at the surface of the analysis area but not above the surface. A full 3-D propagation prediction includes all of the space from the surface to a user specified altitude. This data can then be exported from CSPT into one of two additional tools that permit the user to view the combined imagery and propagation prediction. The first tool, shown in Figure 2, allows the user to fly into the 2.5-D analysis area and view not only the terrain and buildings but also the propagation prediction draped over the image. The second tool, shown in Figure 3, allows the user to fully manipulate the area of interest and the 3-D propagation cloud. This tool is useful only in relatively small regions since the amount of data is extremely high, but it allows for the most visually appealing and accurate results possible.

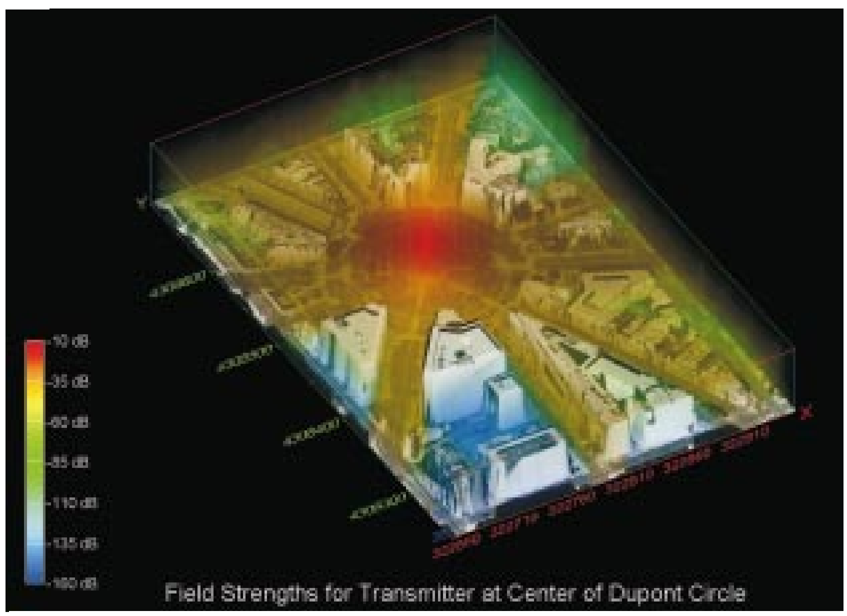

Figure 3. Same area of coverage shown in Figure 2, in full 3-D.

CSPT is available on a UNIX or Windows® NT platform. 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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Propagation Model Development & Comparisons

Outputs

- Comparison of algorithms used in ITM and TIREM models.
- Comparison of ITM and TIREM models to various measurement datasets.

ITS' work on propagation model development in FY 2002 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. Progress in each area for FY2002 is described below.

ITM & TIREM Intercomparison

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

ITM is an empirical model: its "deterministic" results are modified by comparisons to measured data to account for parameters that the model does not control. The set of measured data consists of over a dozen datasets containing more than 41,000 measurements, which span the frequency range from 20 to 10,000 MHz. Many different 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 to perform 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 still propagation scenarios not contained in this database.

In FY 2001, ITS began a project to describe and compare the algorithms used in ITM and TIREM.

*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).

This work continued through FY 2002. Specifically, the algorithms for the line-of-sight (LOS), diffraction, and troposcatter regions are being examined, in addition to how each model utilizes an effective antenna height for these calculations. The final report will contain a summary of the results. It 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.

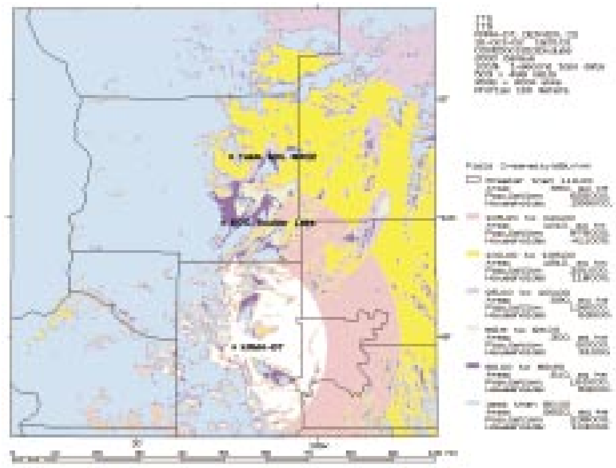
ITM & TIREM Harmonization

During FY 2000, a study was launched to compare ITM v1.2.2 and TIREM v3.14 predictions to several measured radio propagation datasets. The major goals of this work, which continued throughout FY 2002, are to improve the predictive accuracies of ITM and TIREM, and to reduce or eliminate, where possible, differences between these two models' predictions for circuits with equivalent input values, all while preserving the increased predictive accuracies.

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. However, examination of the results for individual paths revealed large differences in the detailed comparisons of the predictions for a given model (TIREM) between the two studies. Furthermore, there was evidence from the data that both the measurements and the 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.

ITS has proposed a mechanism for the data correlation and tested it on several datasets. Results show substantial correlation in the data and the statistics are affected by this correlation. This data 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 antenna 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.

It is necessary to eliminate this correlation. As our model, the measurements on one path are considered to be independent of measurements taken on another path. The excess loss relative to free space predicted by ITM was compared to the measured data, and the difference was 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. These results will aid the harmonization effort for the two propagation prediction models.



Example of the use of ITM to predict electric field strength for a proposed digital television broadcast antenna on Lookout Mountain near Golden, CO. The predictions were made using USGS 1" terrain data.

Effective Antenna Height Study

ITM uses effective antenna heights throughout most of the program (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. 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, the structural antenna heights above ground level, and the distances to the horizon from each of the antennas.

ITM was used to examine propagation paths found 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. Propagation loss predictions were made for most propagation paths in the database. The predicted value of propagation loss was compared with the measured value 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 a number of different behavior characteristics related to the internal computation of effective antenna height being investigated. This investigation 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 can be reduced, but in just as many cases large deviation occurs. That is, many cases exist where 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.

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Audio-video research laboratories at ITS (photographs by Stephen Wolf).

Telecommunications Theory

The Institute is involved in research in both wireless and wireline telecommunications. The rapid growth of telecommunications in the last 50 years has caused crowding in the radio spectrum. New technology requires a new understanding of the behavior of radio waves in all parts of the radio spectrum. The Institute studies all frequencies in use, extending our understanding of how radio signal propagation is affected by the earth's surface, the atmosphere, and the ionosphere.

This work is resulting in new propagation models for the broadband signals used in new radio systems. The Institute's historical involvement in radio-wave research and propagation prediction development provides a substantial knowledge base for the development of state-of-the-art telecommunication systems. In another research area, the Institute develops perception-based quality measures for multimedia services.

ITS transfers all of these concepts and technology to both public and private users, where knowledge is transformed into new products and new opportunities.

Areas of Emphasis

Adaptive 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.

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.

Radio Channel Effects on Networks
The Institute, a recognized leader in radio channel measurement and modeling, is involved in research to assess the effects of the wireless communication channel on communications system 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.

Wireless Propagation Research
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 wireless (3G). Projects are funded by NTIA and DoD.

Advanced Antenna Testbed

Outputs

- Analysis of some proposed antenna array comparison data.
- 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 (WLAN's) 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 arrays used for MIMO testing at the NIST open area test site (photograph by P. Papazian).

A recent ATB application is a 16-element multiple input, multiple output (MIMO), experiment conducted in FY 2001. Two 16-element MIMO arrays were fabricated and tested and then deployed at the NIST open area test site, as shown in Figures 1 and 2. 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 (Papazian et al. 2002, see **Recent Publications** below).

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*

ρ = *signal to noise ratio*

H = *complex transmission matrix*

H^+ = *hermetian transpose of* H

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. 67, for more information about the ATB.)

Figure 2. Dipole antenna elements used by MIMO array (photograph by P. Papazian).

Recent Publications

P. Wilson, P. Papazian, and Y. Lo, "A comparison of 1920 MHz mobile channel diversity gain using horizontal and vertical arrays," *IEEE Trans. on Communications*, vol. 49, no. 12, pp. 2068-2070, Dec. 2001.

P. Papazian, M. Gans, Y. Lo, and R. Dalke, "Capacity measurements for a 16x16 BLAST array over a conducting ground plane," in *Proc. IEEE Fall VTC 2002*, Vancouver, B.C., Canada, Sep. 2002.

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Audio Quality Research

Outputs

- Technical publications documenting new research results.
- Subjective measurements and objective estimates 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 transmitted as data packets, thus sharing channel capacity (e.g., 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 bit-rate, delay, or complexity of digital speech and audio coding and transmission. The ultimate result of such progress is 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 subjects' opinions of the speech or audio quality of various coding and transmission systems. Subjects provide their opinions through electronic forms, an example of which appears in Figure 1 above.

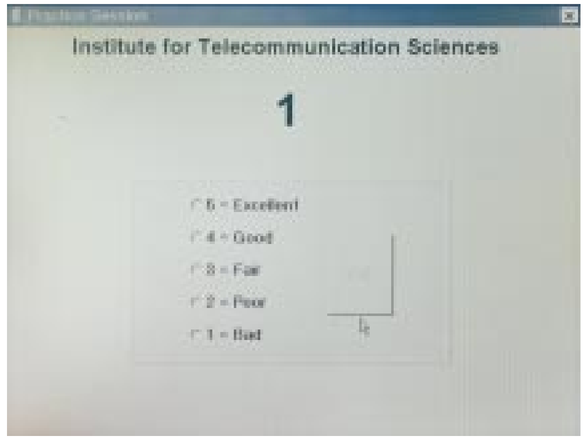

Figure 1. Example electronic response form used in subjective testing.

The Program has developed, verified, and patented tools for the objective estimation of telephone bandwidth speech quality. An example screen from one ITS-developed software tool is shown in Figure 2.

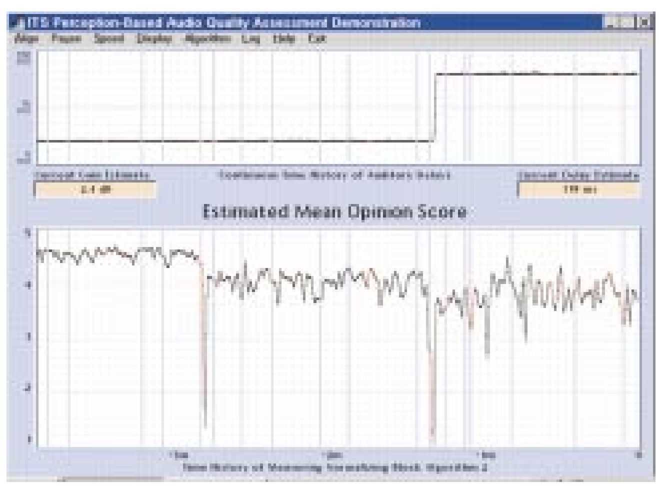

Figure 2. Example screen from ITS-developed software tool for objective estimation of perceived speech quality.

Throughout FY 2002, Audio Quality Research Program staff continued to apply and support such tools. Staff applied software tools, equipment and expertise in experiments aimed at finding relationships between the quality of speech delivered by VoIP systems and underlying network conditions.

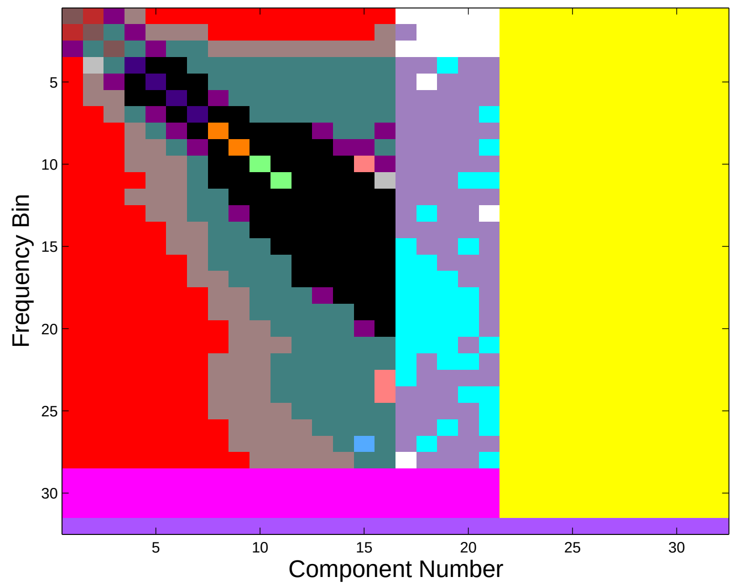

Figure 3. Example quantizer map for coding technique under study: audio signal has been decomposed into 1024 components, each component has been assigned to one of 19 quantizers indicated by one of 19 different colors.

Program staff also investigated several potential new innovations in speech and audio coding. In one investigation, the concepts of linear algebra were applied to time-frequency representations in order to generate novel decompositions of audio signals. These new decompositions display some desirable quantization properties and may ultimately lead to more efficient speech or audio coding schemes. Figure 3 uses 19 different colors to show how each of the 1024 different signal components in the decomposition can be linked to one of 19 fixed quantizers. The result is nearly optimal quantization of all 1024 signal components.

The Audio Quality Research Program recently responded to a specific inquiry regarding the use of speech and audio coding algorithms for signals other than those they were designed for. For example, if a speech coding algorithm is given the sounds of laughter, or the sounds of a train, how badly will it distort each of these sounds? To answer the broader question in a concrete way, Program staff generated over 700 sound files and a set of tables linking to those files. Through these tables, a user can select example sounds and coders and hear first hand what a typical result might sound like.

Also in FY 2002, the Audio Quality Research Program staff performed significant upgrades to the ITS Audio-Visual Laboratories. An ad-hoc network of digital interconnections was replaced with a single unified digital audio infrastructure based on a 16 by 16 digital audio routing switcher. The Audio Quality Research Program continued to transfer technology to industry, Government, and academia throughout FY 2002. 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, “Estimation of system gain and bias using noisy observations with known noise power ratio,” NTIA Report 02-395, Sep. 2002.

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

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

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

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Effects of Radio Channel on Networking Performance

Outputs

- Quantitative analysis of effects of radio channel on network performance.
- Bit, frame, and packet error wait time statistics.

The Institute is a recognized leader in radio channel measurement and modeling. Such knowledge is essential in the development of new, spectrally efficient radios which will operate in radio channels degraded by multipath, man-made noise, and interference. This is especially true for the mobile radio channel whose degradations vary with time. For example, development of new adaptive equalizers for modern, wide-bandwidth mobile radios would not be possible without radio channel measurement and modeling.

Systems using mobile radios to access the Internet are proliferating. IEEE 802.11 “Wi-Fi” wireless local area network (WLAN) and personal communications services (PCS) general packet radio service (GPRS) are but two examples. To reach their fullest potential these systems must reach large numbers of people and have correspondingly high bandwidth efficiencies per unit area, i.e., spectrum efficiency. In the past, enormous gains in spectrum efficiency have been found through advances in cellular frequency reuse and multiple access methodologies. In the future, equally significant gains may be found in novel queuing, routing, and retransmission algorithms.

These gains are unlikely to be realized without knowledge of the radio channel obtained through radio channel measurement and modeling. Currently, the Institute is promoting the use of this knowledge in two ways. First, it is conducting a comprehensive literature search to determine the scope of the effects of the mobile radio channel on networking tasks. Thus far, the literature search indicates that networking tasks are as sensitive to second-order statistics such as the distribution of wait time between packet errors as they are to the commonly studied first-order statistics such as packet error rate. Second, the Institute is developing methods for extracting these statistics from radio channel measurements and models.

The Gaussian Wide Sense Stationary Uncorrelated Scattering channel presented by Hufford* is often used to model the mobile radio channel. This model describes archetypal regions, i.e., urban and in-building regions, with statistically varying direct-path and multipath components. The multipath component is composed of an exponentially decaying continuum of indirect paths characterized by strength (relative to the direct component) and time constant parameters. Figure 1 shows a single realization or “snapshot” of the impulse response amplitude from an urban mobile radio channel where the strength and time constants are -5 dB and 0.5 microseconds, respectively.

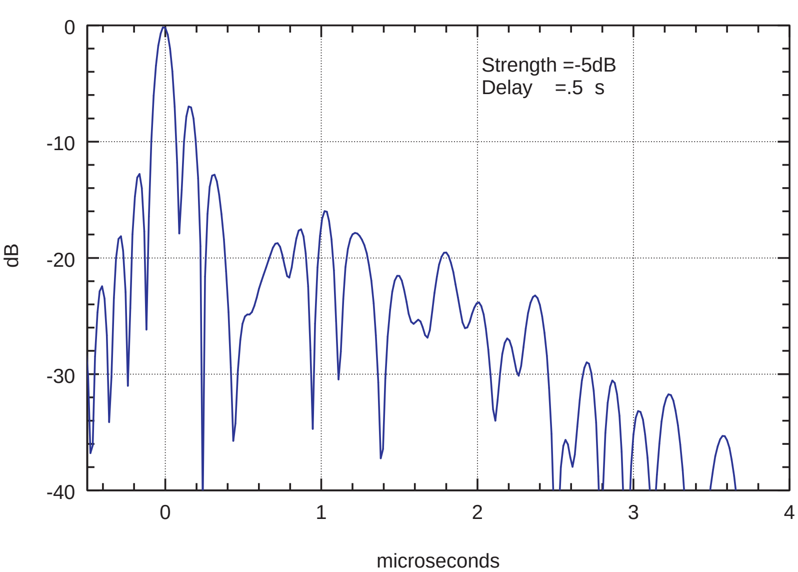

Figure 1. Radio channel impulse response amplitude.

*G. Hufford, “A characterization of the multipath in the HDTV channel,” *IEEE Trans. on Broadcasting*, vol. 38, no. 4, pp. 252-255, Dec. 1992.

It was theorized that independent and identically distributed bits transmitted over this channel would result in exponentially distributed wait times between bit errors. This hypothesis is confirmed by simulations. As an example, Figure 2 shows the complementary cumulative distribution of the wait times between bit errors which were determined from simulations of a binary phase shift keyed (BPSK) signal transmitted at 6 million bits per second at a 0.0043 bit error rate.

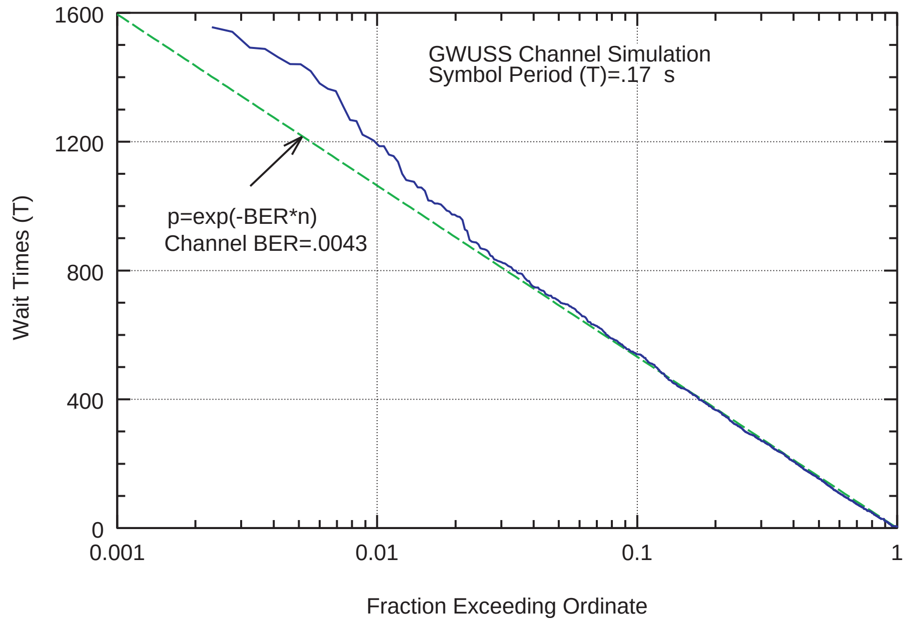

Figure 2. Complementary cumulative distribution function of bit error wait times for radio channel depicted in Figure 1.

The distribution is plotted on a log-linear graph where an exponentially distributed random variable is displayed as a negatively sloped line. The ordinate is the wait time between bit errors in units of symbol periods. The abscissa is the fraction of time the ordinate is exceeded. The mean wait time is the inverse of the bit error rate or 232.5 symbol periods. The graph shows that the wait time between bit errors exceeds 1071, 535, and 161 symbol periods for 1, 10, and 50 percent of the time, respectively.

Packet wait times are also exponentially distributed. For the above example, a packet 207 bytes long, 20 of which are error correction bytes capable of correcting 10 byte errors, would be transmitted at a rate of 3623 packets per second. The corresponding byte and packet error rates are 0.034 and 0.1, respectively. The mean wait time between packet errors is the inverse of the packet error rate or 10 packet periods. Wait time between packet errors exceeds 46, 23, and 7 packet periods for 1, 10, and 50 percent of the time, respectively.

Results such as these are immediately useful to network designers. For example, since the packet error rate is high, the network designer may ask for a lower BER, drop queued packets from this link first when switches are congested, reroute packets away from this link if possible, or deny retransmission of packets from this link.

Ultimately, results such as these will benefit the public and private sectors by facilitating the integration of new wireless links into existing legacy networks, reducing the proliferation of redundant wireless network protocols, and decreasing the pressure for additional spectrum by using existing allocations more efficiently. These benefits will become more meaningful as the convergence of voice and data as well as fixed and mobile users onto the Internet continues.

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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.

Digital video systems are creating many new telecommunication services and industries (e.g., direct broadcast satellite, digital television, high definition television, video teleconferencing, telemedicine, e-commerce) that are becoming an essential part of the U.S. and world economy. Objective metrics for measuring the performance of these systems are required 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 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 developed a new measurement paradigm that is based upon extraction and comparison of low bandwidth perception-based features that can be easily communicated across the telecommunications network. This new measurement paradigm has received three U.S. patents, been adopted as an ANSI standard, and is being used by organizations worldwide. Figure 1 demonstrates the ability of the ITS measurements to perform continuous in-service quality monitoring. This graph shows an example time history of single stimulus continuous quality evaluation (SSCQE) data from an MPEG-2 test and corresponding quality predictions from a 10 kbit/s reduced reference quality monitoring system (i.e., the extracted features have 10 kbit/s of total bandwidth). A 100 on the scale is excellent quality while a 0 is bad quality. During FY 2002, two SSCQE experiments were conducted and this subjective data was used to optimize the ITS metrics for an automatic quality monitoring of MPEG-2 digital television systems.

Also during FY 2002, ITS completed development of a UNIX-based and Windows®-based automated video quality measurement (VQM) tool. This VQM tool can be downloaded from the Video Quality Research home page given below. Version 2.0 of the VQM software includes detailed documentation of the technical algorithms, a user's manual, and test video sequences to verify proper software installation. The VQM software performs all necessary processing steps on the sampled input and output video streams, including:

1. Calibration. A video system may introduce spatial shifts of the picture (both horizontal and vertical), a reduction of the picture area (valid region), changes in gain (i.e., contrast) and offset (i.e., brightness), and temporal shifts of the video stream (i.e., video delay). The process of estimating and removing these four items from the destination

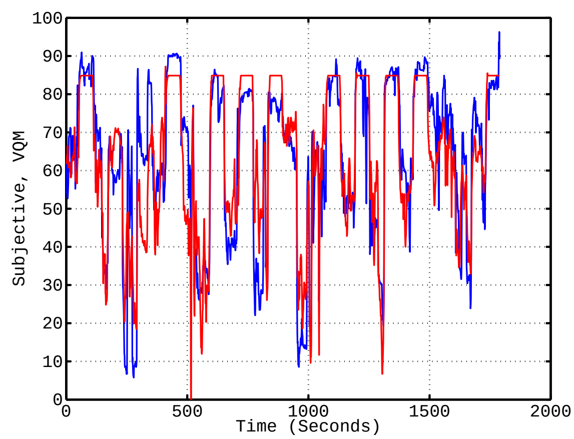

Figure 1. SSCQE subjective data (blue) and corresponding objective quality predictions (red).

video stream is referred to as calibration or normalization. Many deployed video systems have been observed to have poor system calibration. If not properly accounted for, this can create erroneous results with very poor correlation to subjective quality ratings.

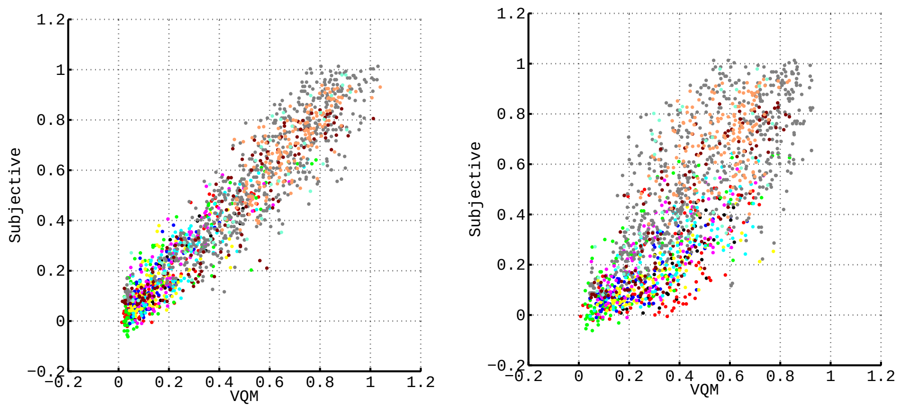

Figure 2. Performance of two video quality mappings: General Purpose – left, PSNR– right.

2. Feature Extraction. The input and output video streams are divided into spatial-temporal (S-T) regions from which features, or summary statistics, are extracted that quantify the perceptual aspects of video quality. Two types of features are extracted from the luminance signal Y: features based on spatial gradients and features based on temporal gradients. Features derived from spatial gradients are used to characterize perceptual distortions of edges and detail, while features derived from temporal gradients quantify distortions in the flow of motion. Some coding and transmission impairments create special color impairments (e.g., a colored error block, localized color shifts). A useful feature to quantify these types of impairments is based on the mean two-dimensional chrominance vector (Cb, Cr) computed over each S-T region.

3. Distance Measures. The perceptual impairment at each S-T region is calculated using functions that model visual masking of the spatial and temporal impairments. Loss and gain are normally examined separately, since they produce fundamentally different effects on quality perception (e.g., loss of spatial detail due to blurring and gain of spatial noise due to blocking). Of the many comparison functions that have been evaluated, two forms have consistently produced the best correlation to subjective ratings. These visual masking functions imply that impairment perception is inversely proportional to the amount of localized spatial or temporal activity that is present.

4. Quality Mapping. A video quality mapping, or model, is a particular algorithm that is used to combine a set of distance measures into an overall estimate of quality. The quality mapping can depend upon many things, including the type of subjective experiment and video application. Currently, fifteen subjective data sets that span a very wide range of scenes and video systems are used as truth data for the development and testing of objective video quality mappings. The VQM software that is available for download implements five different quality mappings. Figure 2 gives the performance of two of these quality mappings: a "General Purpose" mapping using ITS-developed metrics and a traditional Peak Signal to Noise Ratio (PSNR) mapping. Eleven data sets are shown where each data set is plotted in a different color. The Y-axis is the actual subjective score while the X-axis is the quality mapping. The data has been scaled such that "0" is mapped to no perceived impairment and "1" is mapped to nominally maximum perceived impairment. The correlation coefficients for the left and right scatter plots are 0.95 and 0.78, respectively.

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

Recent Publications:

S. Wolf and M. Pinson, "Video quality measurement techniques," NTIA Report 02-392, Jun. 2002

M. Pinson and S. Wolf, "Video quality measurement user's manual," NTIA Handbook 02-01, Feb. 2002.

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Wireless Propagation Research

Outputs

- Survey and implementation of data analysis and modeling techniques for multipath channel estimation.
- Methods for the prediction and measurement of wireless indoor radio channel characteristics.
- Assessment of geometric optics approximation for indoor ray-trace models.

The Institute has been involved in research efforts related to wireless communication applications and theory. More specifically, ITS develops models and measurement systems to estimate propagation characteristics of various multipath environments. The objectives of these efforts are to support new wireless technology development and help U.S. industry compete in the worldwide telecommunications marketplace. In the past, a majority of the wireless research has been related to the outdoor propagation environment. Recently, with the emergence of new indoor wireless local area networks and wireless local campus networks, the research has been extended to indoor scenarios.

ITS is able to measure and model the transfer function of a wide variety of wireless radio links. The data is nondeterministic and there is significant complexity in reducing that data into a concise set of metrics with limited ambiguity. Signal attenuation is a performance metric that can be expressed statistically and straightforwardly. However, time-dispersion parameters that reflect the bandwidth limitation imposed by the channel are not so clear cut. Historically, researchers have used RMS (root mean square) delay spread as a dispersion metric because of the derived correlation with bit error ratio (BER) for channels with Gaussian, wide-sense stationary, uncorrelated-scattering characteristics. There are a number of adverse wireless radio environments, however, where the frequency-domain statistics are dynamic over small distances and the justification for using rms delay spread is compromised.

Over the course of the last year an extensive literature search was conducted on characterization for wireless channels. The resulting article database provided numerous processing and modeling techniques for consideration. Those procedures were incorporated into a channel characterization toolbox for MATLAB, which has proved to be a useful tool for system evaluation, data comparison, statistical analyses, model development, presentation of results, and distribution of data.

In an attempt to understand antenna polarization and directivity effects indoors, impulse response measurements were acquired in a number of scenarios (e.g., in-room, in-corridor, obstructed line-of-site) employing different types of antennas. An effective method of presentation for this data is shown in Figure 1. The left plot shows time dispersion versus excess loss; this provides a clear comparison between different channels and demonstrates a correlation between the two metrics. The right plot is the cumulative distribution function of maximum delay on Gaussian paper, which provides an intuitive view of the distribution for that random variable.

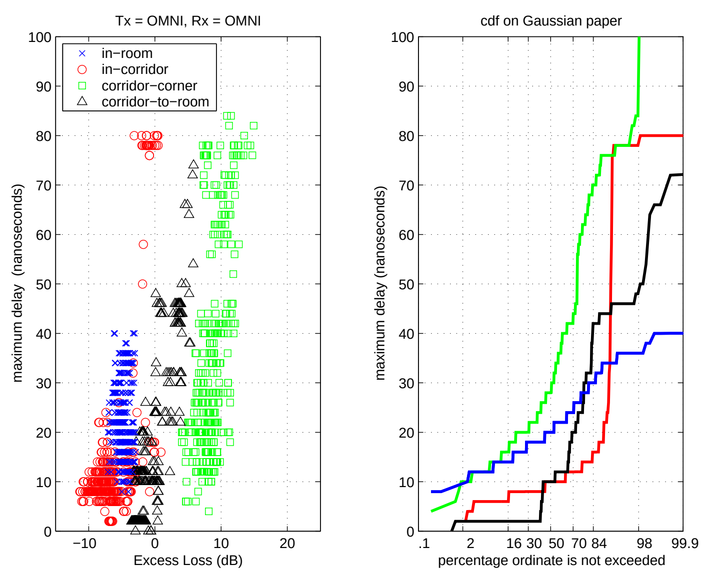

Figure 1. Maximum delay versus excess loss from four canonical indoor scenarios measured with linearly polarized omnidirectional receive and transmit antennas.

Figure 2 statistically demonstrates the different effects of the channels in the frequency domain.

The Institute has developed a geometric optics (or ray-tracing) model for calculating the field strength and impulse response of an indoor radio propagation channel, characterizing an anechoic chamber, and analyzing the coupling mechanisms between rooms. In an attempt to assess the validity of the ray-trace model, we have investigated the accuracy of some of the inherent assumptions. Using the exact Sommerfeld formulation for a source above a dielectric half space, a thorough investigation into the geometric optics (GO) approximation was performed. This study demonstrated discrepancies associated with surface-wave and near-field effects and the use of plane-wave Fresnel reflection coefficients, as is common in ray-trace models. Figure 3 shows fields from an elementary horizontal dipole close to a dielectric surface calculated from the GO approximation (with and without the Norton surface-wave term added) and numerical evaluation of Sommerfeld's formulation. A discernable pseudo-lateral wave phenomenon was identified that produces an interference pattern in the Sommerfeld solution with respect to the GO plus Norton term approximation at relatively high frequencies when the source and observation points are near the surface.

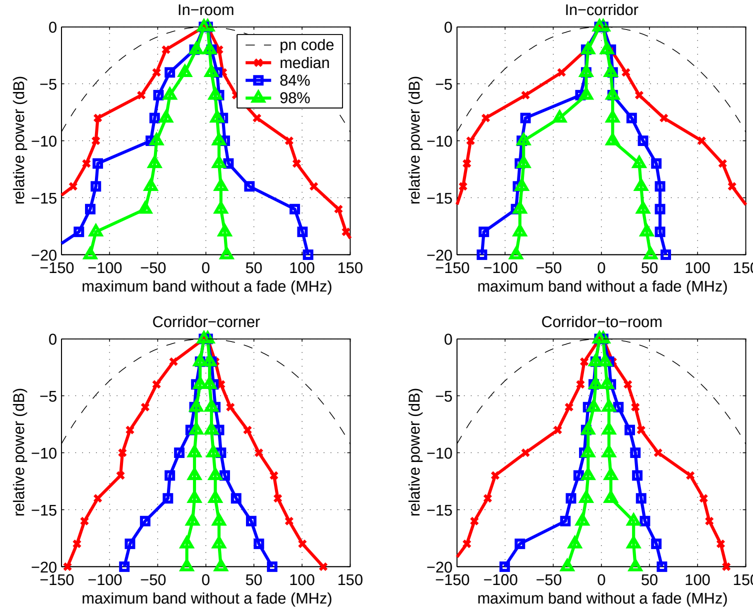

Figure 2. Channel bandwidth statistics from four canonical indoor scenarios measured with linearly polarized omnidirectional receive and directional transmit antennas.

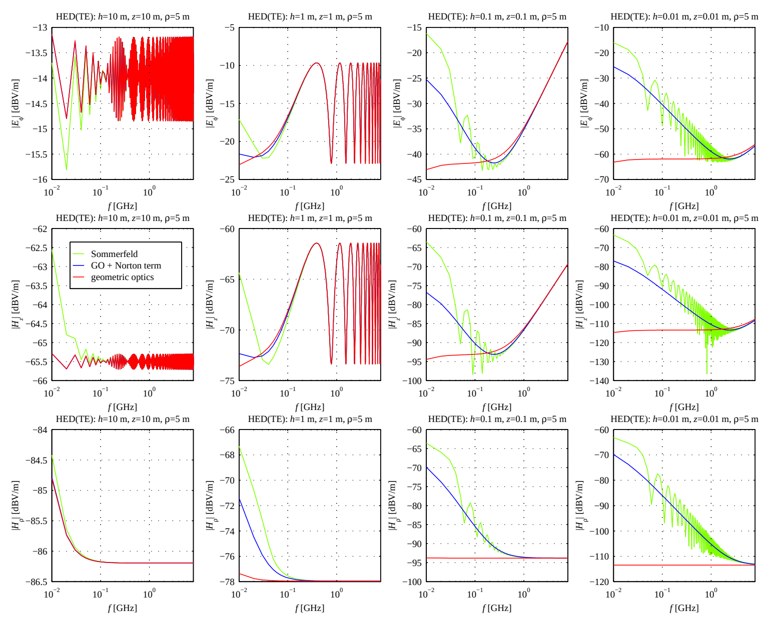

Figure 3. Near-surface effects on field strength of an elementary horizontal electric dipole above a concrete half space.

Recent Publication

M.G. Cotton, E.F. Kuester, and C.L. Holloway, "An investigation into the geometric optics approximation for indoor propagation models," *Radio Science*, vol. 37, no. 4, pp. 1-1 – 1-22, Jul.-Aug. 2002.

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Cooperative Research with Industry

Outputs

- PC software that measures the quality of audio and video signals that have been transmitted through a telecommunications system.
- Tools for measuring the quality of digital video and speech transmission through next generation Internet and Internet 2 technologies.
- Measurements to validate the theoretical capacity of the Bell Labs Layered Space-Time (BLAST) antenna system.

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. For a number of years ITS has participated 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 Atlantic Mobile Systems
- Bell South Enterprises
- Industrial Technology, Inc.
- Integrator Corporation
- Intel Corporation
- Lehman Chambers
- Lucent Digital Radio
- Lucent Technologies
- Motorola Inc.
- East Carolina University's Brody School of Medicine.
- General Electric Company
- GTE Laboratories Inc.
- Hewlett-Packard Company (HP)
- 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 audio and video signals is available on ITS' web site.
- ITS conducted cooperative research with the University of Pennsylvania to investigate the relationships between application-level performance (e.g., the video quality that is perceived by end-users of a video system) and the next generation Internet (NGI) and Internet 2 (I2) network performance parameters. By determining these Quality of Service (QoS) relationships and disseminating the results to industry, network providers will be able to design better NGI/I2 networks and services. In addition, end-users of NGI/I2 networks and services will benefit since they will have an objective means of measuring QoS from competing network providers. Updated software was completed and delivered this year.
- Lucent Technologies, Bell Laboratories, and ITS completed cooperative research to measure the transmission coefficient matrix associated with two 16-element arrays located above a ground plane. The purpose of this experiment was to validate the theoretical capacity of the

Testing the BLAST antenna system above a ground plane (photograph by P.B. Papazian).

Bell Labs Layered Space-Time (BLAST) antenna system. The BLAST system has the potential to greatly increase the capacity of wireless communications systems.

- East Carolina University's Brody School of Medicine and ITS began cooperative research and development in the area of quality assessment of digital video and audio for telemedicine applications. Traditional techniques for assessing analog video and audio quality are inadequate for accurately quantifying digital audio and video quality due to the adaptive processing of signals by codecs. Therefore, newer digital techniques developed by ITS must be employed for this assessment. A set of video test scenes were processed this year.

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

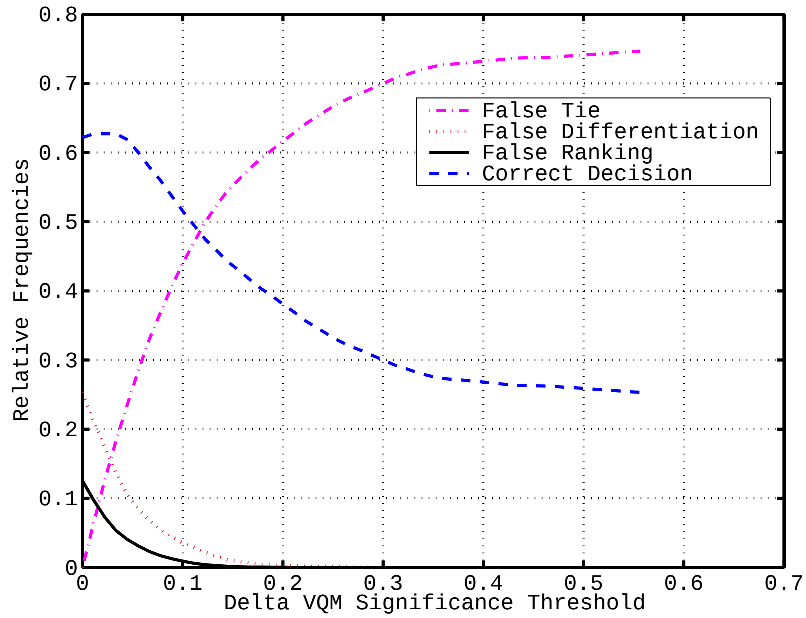
Outputs

- 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 have been 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 technical work is centered in two permanent organs: the Telecommunication Standardization Sector (ITU-T), and the Radiocommunication Sector (ITU-R). The ITU-T develops international standards (Recommendations) addressing technical, operating, and tariff questions relating to all aspects of wireline telecommunications. The technical work of ITU-T is conducted in thirteen Study Groups whose responsibilities are distinguished on the basis of particular technical specialties and standards development needs. ITU-T Recommendations have a strong impact on both the evolution of U.S. telecommunications infrastructures and the competitiveness of U.S. telecommunications equipment and services in international trade.

ITS has played a strong role in ITU-T standardization work for many years. The Institute's technical 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 specific telecommunication requirements and selecting products that effectively meet them. In prior work, ITS participants have led ITU-T and related U.S. standards committees in defining the basic principles and framework that underpin a user-oriented approach to telecommunications quality assessment; developed a set of generic, user-oriented quality measures for data transfer and call processing functions; and applied those generic measures in deriving specific performance parameters and measurement methods for X.25-based packet switching, frame relay, narrowband and broadband integrated services digital network (ISDN), and asynchronous transfer mode (ATM) technologies. This work has produced over a dozen ITU-T Recommendations and related U.S. industry standards and has strongly influenced both the theory and practice of digital network performance description. In recent years, ITS participants have been working to extend the performance description principles and framework to integrated IP and telephony networks, and to develop objective, perception-based quality metrics for voice, video, and multimedia services.

In FY 2002, the Institute's ITU-T leadership was focused in two 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), ATM, wave division multiplexing (WDM), and 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. During 2002, 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



ITS-developed framework can be used to evaluate the power and limitations of proposed objective video quality metrics.

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 2002, ITS led negotiations resulting in final ITU-T approval of two new Recommendations (Y.1541, Y.1221) that specify standard Quality of Service (QoS) Classes and Traffic Contracts for IP-based networks that offer assured-quality services. Y.1541 is the first ITU-T Recommendation to specifically define performance objectives for IP-based networks. Y.1221 complements Y.1541 by defining standard parameters for characterizing and limiting offered traffic. These related Recommendations will be important in defining service level agreements (SLAs) among independent network operators that wish to cooperate in providing assured-quality IP packet flows. In related work, ITS motivated T1 and ITU-T efforts to define IP network QoS signaling standards that will facilitate such cooperation. In pursuing that goal, ITS instigated and participated in a highly successful Committee T1 “Summit” on Signaling for Voice over IP (VoIP) and contributed to several ITU-T documents that specify generic IP network QoS signaling requirements.

In the video quality area, ITS spearheaded T1A1 activities leading to Committee T1 approval of five new Technical Reports defining objective video quality metrics (VQMs). The first (TR 72) specifies a set of “meta-metrics” that can be used to evaluate the resolving power and accuracy of proposed objective VQMs. ITS presented TR 72 to ITU-T SG 9 in 2002, and that group expects to approve a new ITU-T Recommendation based on TR 72 in 2003. The new Recommendation will assist SG 9 and the VQEG in assessing objective VQMs proposed for standardization, possibly enabling ITU-T to recommend a single, optimized VQM for a wide range of quality assessment needs.

The figure illustrates an ITS-developed framework, defined in TR 72 and its counterpart draft ITU Recommendation, for evaluating the power and limitations of particular VQMs in replicating the subjective video quality assessments of human viewer panels. The figure plots the relative frequencies of various outcomes that can occur when the VQM ranking of a pair of video signals (A,B) is compared with the subjective viewer panel ranking for the same two signals (the latter ranking assumed to be “true” by definition). Four possible outcomes of such a comparison are distinguished: false ranking (the VQM ranks A better than B, while the viewers rank B better than A); false tie (the VQM fails to recognize a difference the human viewers see); false differentiation (the VQM reports a difference human viewers do not see); and the desired outcome, correct decision (the VQM ranking agrees with the subjective ranking). The abscissa in all cases is the Delta VQM Significance Threshold, i.e., the smallest difference between VQM values that the VQM algorithm declares to be valid. This framework is useful in comparing the performance of alternative VQMs, and can be used to optimize a particular VQM by choosing the Significance Threshold that minimizes a user-specified cost function.

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Support to Private Sector Telecommunications Activities:

ITU-R Standards Activities

Outputs

- Approval by Working Party 8B of NTIA methodology for radar spurious emission measurements in WP 8B as ITU-R Draft New Recommendation.
- Conference at ITS Boulder laboratory for WP 8B International Radar Correspondence Group to consider radar spurious emission measurements.
- Contribution for WP 8B describing how dynamic frequency sharing (DFS) techniques can allow use of radar spectrum bands by wireless communication systems.
- Contributions for WP 8B describing results of signal interference tests in maritime, air traffic control, and weather surveillance radars.

In Study Group 8 (SG 8) of the International Telecommunication Union — Radiocommunication Sector (ITU-R), a number of proposals have been made by non-U.S. Administrations to introduce communication systems into bands that have heretofore been allocated to radiolocation ("radar") use on a primary basis. The U.S. Administration has made an enormous investment in the development and deployment of radars in these bands, including thousands of military and civil systems that play critical roles in national defense, transportation, and atmospheric and space science. Therefore, it is essential to the U.S. Administration that new systems proposed for spectrum sharing with radars be shown to be electromagnetically compatible with existing and future radar operations. To this end, ITS engineers have actively and critically supported the U.S. Administration in ITU-R SG 8, particularly in Working Party 8B (WP 8B).

The RSMS transmits radar signals during demonstration of U.S. spectrum measurement techniques for the ITU-R Radar Correspondence Group in Boulder (photograph by F.H. Sanders).

Meeting of ITU-R Working Party 8B in Geneva, Switzerland (photograph by F.H. Sanders).

In FY 2002, ITS engineers addressed the problem of dynamic frequency selection (DFS) and wrote a Contribution for WP 8B on the topic. DFS is a proposed methodology in which wireless communication systems share spectrum with radars by detecting radar signals and then avoiding those frequencies for data transmission. This approach has never been implemented and presents a number of difficult, unsolved problems. These include developing a methodology for identifying radar signals and determination of the amount of time that must be allocated for detection of radar signals. The Contribution written by ITS engineers and co-authored by NTIA Office of Spectrum Management (OSM) engineers was the first and so far the only attempt made by any Administration to develop a practical DFS approach that solves these problems. The Contribution represents both a workable solution and a challenge to other Administrations to develop a better approach, if such exists.

ITS engineers have played a key role in WP 8B development of techniques for measuring radar emission spectra, and have developed world-recognized expertise in this difficult field. In August 2002, ITS hosted a meeting of the WP 8B Radar Correspondence Group (RCG) in Boulder for the purpose of discussing an ITS WP 8B Contribution that describes such techniques. At the meeting, ITS engineers demonstrated the use of these techniques for measuring radar emissions. The U.S. Contribution was subsequently approved as a Draft New Recommendation by WP 8B.

ITS and OSM performed a complicated series of radar interference measurements in 2002 to determine levels at which interference caused observable degradation in radar receiver performance. Utilizing these measurements, ITS authors jointly authored several WP 8B Contributions with OSM engineers. These papers challenged the thresholds at which existing documentation indicated that such interference effects should be observable in a variety of radar types. Radars that were tested included maritime surface search radars, air traffic control radars, and a weather surveillance radar. ITS engineers also supported the U.S. Administration with critiques of Contributions from other Administrations in Working Parties 8B, 8D, and 8F.

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An ITS engineer (lower left) demonstrates ITS radar target and interference generation equipment (right) to sponsors in the United Kingdom during joint UK/US radar interference measurements. The equipment was shipped to the UK as a suitcase test and measurement system (photograph by F.H. Sanders).

ITS Tools and Facilities

Advanced Antenna Testbed

The advanced antenna testbed (ATB) is a multi-channel test facility based on ITS digital sampling channel probe technology (see “Advanced Antenna Testbed,” pp. 50-51). 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 or Real Time

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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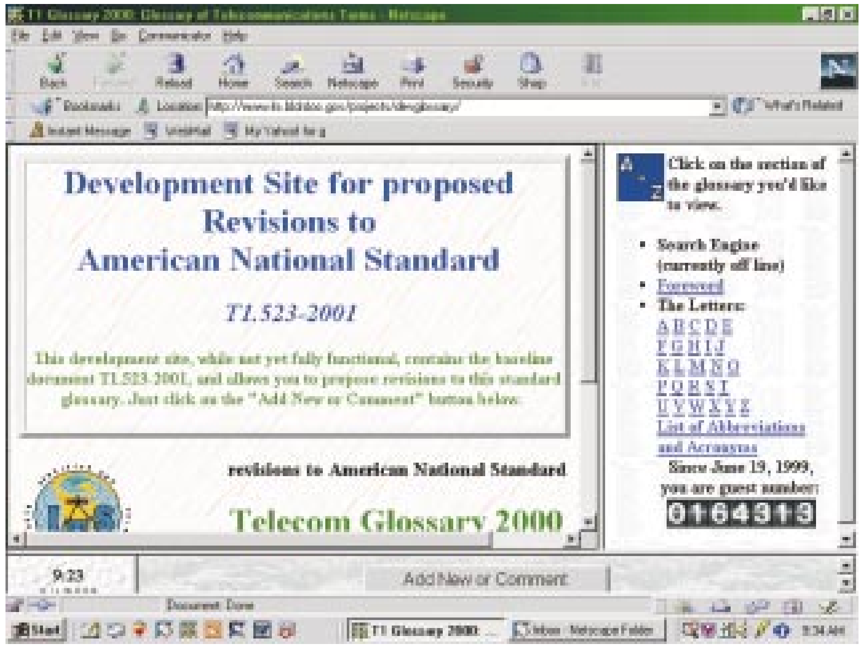
Audio-Visual Laboratories

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.

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. One laboratory system offers the ability to record and playback video streams that conform with International Telecommunication Union, Radiocommunication Sector (ITU-R) Recommendation BT.601 and synchronized digital audio streams to and from a high-speed workstation with over 1 TB of hard disk storage. Video processing is performed in the digital environment using several high-performance video workstations. These workstations are supported by storage peripherals that include a 12-GB 4mm tape drive, an 8-GB 8mm tape drive, and a 40-GB digital linear tape drive. Analog audio mixing, filtering, and equalizing equipment is available, and the most intensive audio processing is done in the digital domain on PC platforms. An array of digital audio and video encoders and decoders are available as well. Analog and digital audio and video routing switches and patch-panels allow for nearly arbitrary interconnections between the various pieces of equipment in these laboratories.

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. Finally, the labs feature an array of audio and video signal generators and analyzers to support laboratory measurement and calibration activities.



Opening page of the Development Web Site for Proposed Revisions to ANS T1.523-2001, Telecom Glossary 2000.

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 two separate 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) T1.801.03-1996 and other more recently developed 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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Development Site for Proposed Revisions to *Telecom Glossary 2000*

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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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 can characterize the communication channel over a shorter period of time. Historically the DSCP has been employed extensively for channel characterization of cellular and personal communications services (PCS). ITS has recently 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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Interoperability Research Laboratory

The Institute's Interoperability Research Laboratory (IRL) was developed during fiscal year 2002 to respond to the needs of the Justice/Public Safety/ Homeland Security community. It was established to confront both wireless telecommunications interoperability problems and difficulties associated with information sharing between local, state, and Federal government systems using different information technologies (and implementations). As a result, it is designed to accommodate a wide variety of uses.

The IRL is being used for basic wireless interoperability testing, e.g., between Project 25 radios produced by different manufacturers. It is also used to investigate current or emerging information systems and networking technologies, such as eXtensible Markup Language (XML) implementation approaches and intrusion detection systems. In addition, hybrid (wireline/wireless) communication products and services are assessed, e.g., radio frequency/ Internet Protocol repeaters.

The IRL works closely with other ITS laboratories to ensure that appropriate performance standards and testing techniques are chosen and properly applied for specialized engineering areas. For example, audio experts are consulted for voice quality tests.

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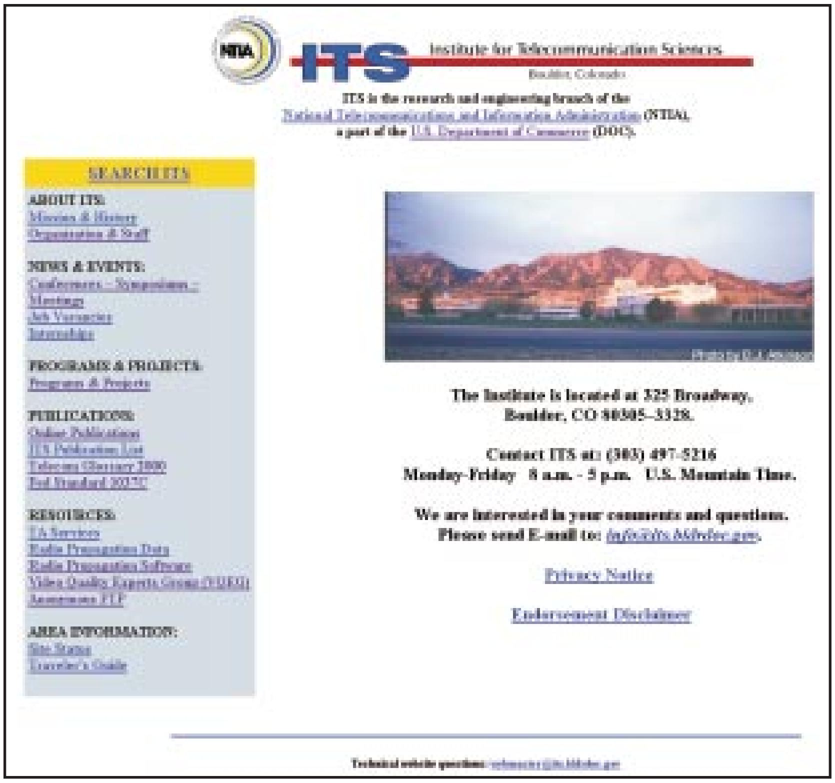
ITS Internet Services

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



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

- 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 Communication Performance Measurements

ITS maintains a test capability for determining the performance of land-mobile radio systems that comply with the Telecommunications Industry Association's TIA-102 and TIA-603 series of specifications.

The measurement capabilities include the usual TIA-603 type of measurements for analog systems, such as receiver sensitivity, adjacent-channel, and cochannel interference. In addition, with TIA-102 (Project 25) capable test equipment, various aspects of the link control format information, such as network access code, talk group identification, emergency bit, and message opcode, can be viewed. Demodulated speech samples can also be collected for an assessment of audio clarity by ITS' audio laboratory.

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 analog FM systems. Other applications may be possible, for example, routine performance measurements. This capability is available on a first-come, first-served basis by both NTIA and other agencies.

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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. During the past year ITS 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 Systems

ITS has designed, constructed, and currently operates a number of automated spectrum measurement systems. The third generation Radio Spectrum Measurement System (RSMS-3), ITS' primary sytem, is a vehicularly mounted, self-contained facility for measurements between 1 MHz and 24 GHz. A fourth generation RSMS (RSMS-4) has been designed and is currently being built. RSMS-4 capabilities will exceed those of RSMS-3, to better meet spectrum measurement challenges of the 21st Century. Development of hardware, software, and a vehicular platform for RSMS-4 progressed substantially in FY 2002 and completion is expected in FY 2003.

ITS also has available a number of suitcase-deployable systems called Compact Radio Spectrum Measurement Systems (CRSMS's). In FY 2002, CRSMS's were used to couple interference into a variety of radars at locations across the U.S.

All RSMS and CRSMS facilities incorporate a combination of commercial off-the-shelf hardware, hardware custom-designed by ITS, and control software written by ITS. Both the RSMS-3 and the RSMS-4 are RF-shielded, and each incorporates multiple 30-ft masts; on-board power generators; air conditioners; a complement of full-height equipment racks; and storage space. CRSMS capabilities utilize the same software but typically include only as much hardware as is required for any given measurement task. Local arrangements are made for CRSMS shelter and power.

All RSMS and CRSMS measurements rely extensively upon computer control of measurements. These systems can be operated in fully automatic, semi-automatic, and fully manual modes. Mobile radios; fixed communication links; radars; personal communication systems; earth station uplinks; industrial, scientific, and medical devices; broadcast signals; and special-purpose transmitter system emissions can be measured. For a detailed description of the RSMS, go to ITS on-line publications (http://www.its.bldrdoc.gov/pub/pubs.html) and download applicable appendices from any RSMS measurement report (e.g., Appendix A of NTIA Report 97-334).

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RFIMS Laboratory

The Radio Frequency Interference Monitoring System (RFIMS) Laboratory is used to provide support to the Federal Aviation Administration’s (FAA) RFIMS program. Under the RFIMS program, ITS personnel analyzed FAA requirements and developed an automated, custom-designed radio frequency measurement system; integrated and tested a prototype mobile system; and integrated, tested and delivered eleven mobile systems. The lab contains a measurement system that is identical to the measurement system found within RFIMS vehicles. The lab is capable of reproducing the same measurement scenarios that can be created with the mobile systems, including measurements of spectrum signature, radar prf, and spectragraph, among others. In the RFIMS lab, ITS engineers develop and test measurement concepts that will become part of the RFIMS. Newly created software is tested for both functionality and user friendliness. If trouble reports are received from the deployed systems, the lab is used to recreate the situation, analyze the causes, and implement a viable solution. The lab is available to ITS engineers, all nine FAA regions, FAA headquarters and the FAA Technical Center to support the use and future development of the RFIMS.

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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. An example of these needs is the requirement to determine the thresholds at which various types of interference are manifested as observable interference effects in a variety of radar receivers.

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 radar and 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 now 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 and the original signal from which it was derived.

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Table Mountain Radio Quiet Zone

This unique facility (one of only two in the nation) is controlled by public law to keep the lowest possible levels of unwanted radio frequency energy within the test area. This allows research concerned with low signal levels, such as from deep space, extraterrestrial low-signal satellites, or very sensitive receiver techniques, to be conducted without the interference found in most areas of the nation. As the use of electronic systems (e.g., garage door openers, computers, citizen band radios, cellular telephones, arc welders, and microwave ovens), the number of radio and television stations, and new uses for the radio frequency spectrum increase, the average level of electromagnetic energy across the spectrum will also increase. This is important to companies that develop sensitive radio receivers and signal-processing equipment, since the equipment is often saturated by the background signal level. This facility is available for use by private parties on a reimbursable basis.

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Telecommunications Analysis Services

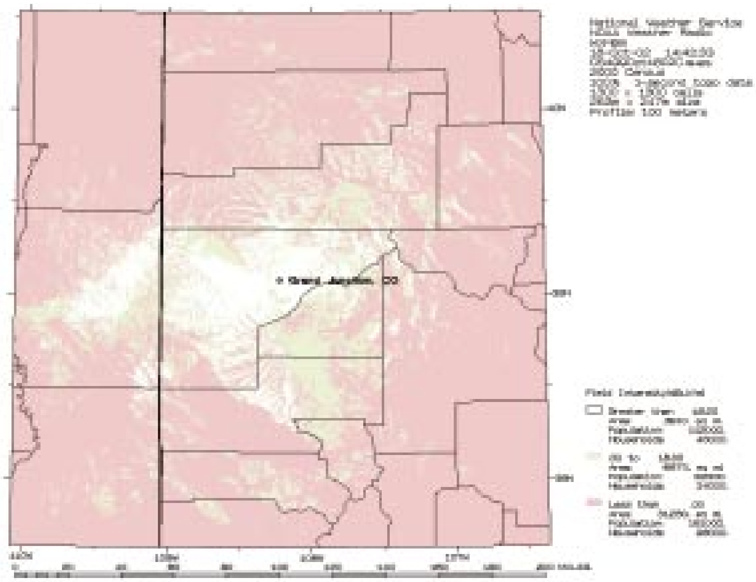
Telecommunications Analysis Services (TA Services) provides the latest engineering models and research data developed by ITS to industry and other Government agencies via a web-based interface (http://flattop.its.bldrdoc.gov). Designed to be both user-friendly and efficient, it offers a broad range of 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 which 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 receive signal levels along radials that are spaced at user-defined intervals of bearing around the transmitter. The program lists the contours of signal coverage of the transmitter along each radial and lists distances to user-specified contours for each radial. Either the FCC broadcast rules or the ITS Irregular Terrain Model can be chosen

for calculations.

CSPM – Determines the system performance of mobile and broadcast systems in detailed output plots of signal intensity, as shown in the figure. Plotted outputs can be faxed to the user, plotted on clear plastic for overlaying on geopolitical maps, or downloaded to the user site (in HPGL, GIF, or TARGA format). This program uses the ITS Irregular Terrain Model in a point-to-point mode, or other user-chosen algorithms for path loss calculation.

HDTV – Allows the user to analyze interference scenarios for proposed digital television (DTV) stations. The model contains current FCC and MSTV allotment tables and maintains the catalogs created by all 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.



Example of a CSPM output using highest resolution terrain data.

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.

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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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ITS engineer checking for correct voltages on the ITS digital sampling channel probe. (photograph by F.H. Sanders).

ITS Projects in FY 2002

NTIA Projects

Audio Quality Research. Identify and respond to selected open questions surrounding quality issues in digital speech and audio compression and transmission, especially Internet transmission of compressed audio. Contribute results enabling lower rate audio coding at higher quality levels, more robust transmission of audio over lossy and noisy channels, and more accurate objective and subjective estimation of perceived audio quality. Deliverables include technical publications, algorithms, software, an upgraded laboratory, and technical presentations and laboratory demonstrations as requested.
Project Leader: Stephen D. Voran (303) 497-3839
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Broadband Wireless Research. Collect broadband radio-wave propagation data between 100 MHz and 100 GHz, to promote the use of HF radio spectrum and new signal processing methods to increase spectrum utilization and channel capacity, as well as the development of new wideband wireless data services. Deliverables include two data sets and a report.
Project Leader: Peter B. Papazian (303) 497-5369
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Broadband Wireless Standards. Develop technical means to improve predictions of signal coverage and interference for 3G wireless services through support to ITU-R (e.g., SG 3/Working Parties 3K, 3J, 3M, and 3L) and to Public Safety community interests in TIA TR-8 (Project 25); enhance or refine propagation-related models as needed; develop evaluations of and recommendations for spectrum optimization techniques.
Project Leader: Paul M. McKenna (303) 497-3474
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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 problems in laboratory or field environments and use the results to refine the generic framework.
Project Leader: Randall S. Bloomfield (303) 497-5489
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Network Performance. Provide objective, expert leadership and key technical contributions in ITU-T and related U.S. industry committees responsible for developing telecommunication network performance and resource management standards.
Project Leader: Neal B. Seitz (303) 497-3106
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Networking Technology. Continue the development of networking technology methodologies and tools to address network management and network security/protection issues. Deliverables include a report.
Project Leader: Val Pietrasiewicz (303) 497-5132
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Policy Support. Provide engineering and technical support to NTIA in telecommunications policy development. Provide support in various technical analyses including broadband wireless access, 3rd generation wireless systems, privacy issues, information technology advances, and critical informal protection.
Project Leader: Val M. O’Day (303) 497-3484
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Propagation Model Support. Provide propagation model support to NTIA’s Office of Spectrum Management (OSM) in order to improve the agreement of the two primary radio prediction models maintained by the U.S. Government to measured data and to each model.
Project Leader: Paul M. McKenna (303) 497-3474
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RSMS Development. Develop new spectrum measurement capabilities for the existing Radio Spectrum Measurement System (RSMS), including digital signal processing capabilities, follow-on data acquisition software to operate with a new generation of spectrum analyzers, upgraded RF front-end designs, a new radar-signal direction-finding system, acquisition and integration of a digitizer and a digital oscilloscope, and miscellaneous new measurement capabilities.
Project Leader: Frank Sanders (303) 497-5727
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RSMS 4th Generation Development. Specify, design, and implement the state-of-the-art radio spectrum measurement system. The development will consist of three parallel tracks: (1) vehicle with alternative deployment options; (2) RF instrumentation and measurement methods; (3) software for measurement control and data analysis.
Project Leaders: (1) John Ewan (303) 497-3059
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(2) Brent Bedford (303) 497-5288
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(3) J. Randy Hoffman (303) 497-3582
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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: Frank H. Sanders (303) 497-5727
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Support for U.S. Administration in ITU-R and CEPT-5G. Support NTIA's Office of Spectrum Management (OSM) with critical support for international activities at the International Telecommunications Union — Radiocommunication Sector (ITU-R). Activities include writing a required Contribution and supporting an existing Preliminary Draft New Recommendation.
Project Leader: Frank H. Sanders (303) 497-5727
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Third Generation Wireless. Develop accurate attenuation, frequency selective fading, noise, and interference radio channel models for proposed 3G 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
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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 report and contributions to a handbook to be used by network planners and field personnel.
Project Leader: Timothy J. Riley (303) 497-5735
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UWB Support. Provide NTIA's Office of Spectrum Management (OSM) with consultative and analysis support regarding measurements of ultrawideband (UWB) signals. Activities include review of UWB documents including the draft FCC Report and Order, assistance with definitions of UWB characteristics, calculations of peak and average power from amplitude probability distributions, and various other questions and analyses.
Project Leader: William Kissick (303) 497-7410
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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

Central Intelligence Agency

Analysis of RF Threat to Telecommunications Infrastructure. Analyze the effects of high power RF fields on critical elements of the military and civilian telecommunications infrastructure.
Project Leader: John J. Lemmon (303) 497-3414
e-mail jlemmon@its.bldrdoc.gov

Department of Commerce

Systems Engineering and Technical Assistance. As a follow-on to the Telecommunications Assessment performed previously, provide engineering services and technical assistance, consistent with current DOC priorities, to assist the Digital Department as it strives to provide more effective and efficient service to the offices and bureaus of DOC.
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

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

Radio Propagation Measurements. Conduct field measurements to define the radio propagation environment at two sites in Denver, Colorado. The results will be used to help the Defense Technology Analysis Office (DTAO) develop and validate propagation models.
Project Leader: Peter Papazian (303) 497-5369
e-mail ppapazian@its.bldrdoc.gov

Department of Justice

Land Mobile Radio Usage Statistics and Engineering Studies. Assist DOJ's Wireless Management Office's high-level system design efforts aimed at planning the Justice Wireless Network 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. Provide support to the FAA's RFIMS program, including providing changes and enhancements to the RFIMS, servicing ITS-designed and ITS-built components, and providing training in measurement techniques using the RFIMS.
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 continuing support for the implementation of a nationwide differential Global Positioning System (DGPS) radio beacon service, to provide a nationwide navigation and positioning signal.
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 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

Digital Land Mobile Radio Standards Development. Assist NCS in developing a comprehensive set of interoperability standards for digital land mobile radio to support law enforcement, public safety, and other critical NS/EP operations. Serve as NCS representative on the Project 25 steering committee and the TIA TR 8 committee, lead the Encryption Task Group, provide systems engineering support to other Task Groups, develop 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 Survivability and Restoral. Reduce vulnerabilities and enhance restoral capabilities in public telecommunication networks by spearheading the development of network reliability standards in various 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 Recommendation of Emergency Telecommunications Service (ETS) capabilities in ITU-T Study Group 9, by developing and/or verifying ETS mechanisms. Apply computer simulation, laboratory studies, security analyses, and/or traffic engineering to assist NCS in support of various Critical Infrastructure Protection (CIP) initiatives related to broadband cable television networks.
Project Leader: Arthur A. Webster (303) 497-3567
e-mail awebster@its.bldrdoc.gov

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

Voice Over Packet and Strategic Interoperability. Assist NCS and its member organizations in defining, promoting, and implementing telecommunication technology enhancements supporting NS/EP and critical infrastructure protection (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. In support of the wireless intelligent network (WIN) implementation of Priority Access Service, continue participation in the Standards Requirements Document (SRD) development and associated support of NCS in the TR 45.2.5 standards development process; provide assistance to NCS in developing priority access for wideband code division multiple access (CDMA); assist NCS in extending GETS-like priority access capabilities to wireless and broadband infrastructures, selected international services, and IP-based networks; continue to refine instrumentation and methods for wireless network discovery; and continue real world testing to characterize the behavior of PCS/cellular networks and identify vulnerabilities.
Project Leader: Christopher J. Behm (303) 497-3640
e-mail cbehm@its.bldrdoc.gov

National Institute of Standards and Technology

OLES Communication Standards. Provide engineering support, scientific analysis, technical liaison, and test design and implementation to allow the Office of Law Enforcement Standards (OLES) and the National Institute of Justice to play a key role in the development and validation of interoperability standards for the justice and public safety communities, and other communication system products, supporting telecommunications and information technology (IT) needs. Provide technical assessments and evaluations of products and services that may provide interim solutions for various interoperability scenarios. Deliverables include standards, reports, guides, guidelines, handbooks, white papers, and other products as requested.
Project Leader: Val J. Pietrasiewicz (303) 497-5132
e-mail valp@its.bldrdoc.gov

U.S. Air Force

Air Force Cellular Analysis. Provide technical support (analysis and evaluation) to the Air Force Information Warfare Center/Electronic Warfare Squadron (AFIWC/EWS). Analyze and model existing and future commercial cellular communication systems, identifying operational limitations and vulnerabilities to jamming.
Project Leader: Christopher Redding (303) 497-3104
e-mail credding@its.bldrdoc.gov

Cooperative Research and Development Agreements (CRADAs)

American Automobile Manufacturers Association

Incident Field Strength Measurements in Highway Environments (Phase 2). Perform field strength measurements in roadway environments in the vicinity of selected high-power radio transmitters, mainly radars. Deliverables include a final report to the sponsor.
Project Leader: Frank H. Sanders (303) 497-5727
e-mail fsanders@its.bldrdoc.gov

Participants at the ITS-sponsored International Symposium on Advanced Radio Technologies (ISART), held in March 2002, mingle during one of the session breaks (photograph by E. Gray).

ITS engineer giving a presentation at the NLANR/Internet 2 Joint Techs Workshop, held in Boulder in Jul.-Aug. 2002, and co-sponsored by NIST, NOAA, NTIA/ITS, and NCAR (photograph by E. Gray).

ITS Outputs in FY 2002

NTIA Publications

R.J. Achatz and R.A. Dalke, "Man-made noise power measurements at VHF and UHF frequencies," NTIA Report 02-390, Dec. 2001.

> Man-made noise generated by automotive ignition, power distribution and transmission, industrial equipment, consumer products, and lighting systems degrades the performance of radio systems. Man-made noise models, derived from measurements made in the 1970s, may be inaccurate due to changes in these technologies. For example, recent man-made noise measurements performed by ITS in the 136 to 138 MHz meteorological satellite band indicated that man-made noise power in residential areas is lower than predictions by these models. However, these same measurements indicated that man-made noise in business areas has not changed. UHF man-made noise has not been comprehensively measured and modeled. This report describes UHF man-made noise measurements conducted in the Denver, CO metropolitan area in 1999. Measurement data is analyzed and results are compared to other measurements and models. These results showed that 402.5 MHz UHF noise levels in business areas were high enough to adversely affect communication system performance some of the time.

J.J. Lemmon, "Wireless link statistical bit error model," NTIA Report 02-394, Jun. 2002.

> A bit error model that enables simulations of the digital error performance of wireless communication links has been developed. The model development has been based on error sequences derived from waveform simulations of wireless link performance with various modems operating under varying propagation, noise, and interference conditions. Values of the model parameters are obtained by analyzing the distributions of the lengths of error bursts and error gaps (error-free intervals). Mathematical expressions have been derived for the means and variances of the error burst and error gap distributions of the model as functions of the model parameters. Constraining the means and variances to the values obtained from waveform simulations uniquely determines values of the model parameters corresponding to a given set of link conditions. Examples of error burst and error gap distributions obtained from waveform simulations are compared with those generated by the model for a land mobile radio system and a wireless local area network. The simulated and model distributions are quite similar; however, the model runs tens of thousands of times faster than the corresponding waveform simulations, enabling rapid determination of link performance.

J.J. Lemmon and R.A. Dalke, "Analysis of the RF threat to telecommunications switching stations and cellular base stations," NTIA Report 02-391, Feb. 2002.

> The objective of this report is to assess the vulnerability of telecommunications switching stations and cellular base stations to high power electromagnetic radiation generated by an RF device. Analyses, measurements, and simulations of indoor propagation and the penetration of electromagnetic fields into structures indicate that typical buildings provide little, if any, protection for telecommunications switching stations from high power electromagnetic fields. The front end electronics of cellular base stations are also vulnerable to damage from high intensity RF fields via front door coupling through the receive antennas. Tools to provide estimates of power densities inside of structures and the received power levels in cellular base stations are developed in this report. More quantitative predictions of field strengths inside structures require detailed analyses on a case-by-case basis. The techniques to carry out such analyses are currently available and are briefly discussed.

M. Pinson and S. Wolf, "Video quality measurement user's manual," NTIA Handbook 02-01, Feb. 2002.

> The purpose of this handbook is to provide a user's manual for the video quality metric (VQM) tool. The VQM software tool performs automated batch processing of video files. Program VQM runs under the UNIX operating system and uses a control file to specify the exact video quality measurement procedures that are to be performed. All results are emailed to the user.

Program VQM compares the video sequence that has been processed by the video system under test to the original video sequence through two main steps. First, program VQM calibrates the processed video sequence to remove systematic differences between the original and processed, such as spatial and temporal shifts. Second, program VQM estimates and reports the perceived quality of the processed video using one of five video quality models. Quality estimates are reported on a scale of zero to one, where zero means that no impairment is visible and one means that the video clip has reached the maximum impairment level.

F.H. Sanders, "Measurements of pulsed co-channel interference in a 4-GHz digital Earth station receiver," NTIA Report 02-393, May 2002.

Pulsed signals in Earth station receiver spectrum bands have traditionally occurred due to unwanted emissions from adjacent-band transmitters such as radars and altimeters. Analog Earth station receivers sometimes experience interference from such emissions. The trend toward increasing use of digital receivers, coupled with a possible future increase in pulsed signals, have raised the question of the circumstances under which pulsed emissions may cause interference to such receivers. This report documents the results of measurements in which a variety of co-channel pulsed signals were injected into the radio frequency (RF) front-end of an operational, television receive-only (TVRO) digital Earth station. The results identified the susceptibility of the Earth station to pulsed interference as a function of pulse characteristics that included pulse width, pulse repetition rate (both constant and jittered), and peak amplitude. The results indicate that digital Earth station receivers may be vulnerable to interference that creates either a contiguous block of symbol errors or a long series of symbol errors. Interference with lower pulse repetition rates, pulse widths, and duty cycles may also produce effects; in those cases results show the interference amplitude may be increased by as much as 50 dB above the carrier level before significant interference occurs. Quantitative interference thresholds are provided for the performance of electromagnetic compatibility analyses between pulsed interference sources and digital Earth station receivers. Examples of such analyses are provided.

S. Voran, "Estimation of system gain and bias using noisy observations with known noise power ratio," NTIA Report 02-395, Sep. 2002.

The identification of linear systems from input and output observations is an important and well-studied topic. When both the input and output observations are noisy, the resulting problem is sometimes called the "errors in variables" problem. Existing work on this problem deals with the identification of multivariate systems and thus results in algorithms that are necessarily somewhat complex and often involve iteration. In this report we treat an important special case of the problem: estimation of a system bias and a system gain from noisy observations of system input and output. In addition, we invoke an input-output noise power ration constraint. This constraint can also be interpreted as a parameter that moves the problem in a continuous fashion between two limiting cases, each of which is a conventional least-squares problem. We do not model the input signal, and we place minimal restrictions on the input and output observation noises. We develop five different low-complexity closed-form solutions to the problem. The final two are the most satisfying and we explore these further through simulations. Our original motivation for working on this problem came from the need to calibrate objective and subjective estimates of perceived video or speech quality. We expect that our solutions may also find applications in remote sensing, active noise reduction, echo cancellation, channel estimation, and channel equalization.

J. Wepman, "Software defined radio comes of age," NTIA Spectrum News, vol.3, issue 1, Fall 2001.

No abstract available.

S. Wolf and M. Pinson, "Video quality measurement techniques," NTIA Report 02-392, Jun. 2002.

Objective metrics for measuring digital video performance are required by Government and industry for specification of system performance requirements, comparison of competing service offerings, service level agreements, network maintenance, and optimization of the use of limited network resources such as transmission bandwidth. To be accurate, digital video quality measurements must be based on the perceived quality of the actual video being received by the users of the digital video system rather than the measured quality of traditional video test signals (e.g., color bar). This is because the performance of digital video systems is variable and depends upon the dynamic characteristics of both the original video (e.g., spatial detail, motion) and the digital transmission system (e.g., bit rate, error rate). The goal of this report is to provide a complete description of the ITS video quality metric (VQM) algorithms and techniques. The ITS automated objective measurement algorithms provide close approximations to the overall quality impressions, or mean opinion scores, of digital video impairments that have been graded by panels of viewers.

Outside Publications

Articles in Conference Proceedings

B. Archambeault, C. Holloway, and P. McKenna, "Measurements and simulation of a semi-anechoic room using field mapping as an indication of chamber quality," in *Proc. 2002 IEEE Intl. Symposium on EMC,* Minneapolis, MN, Aug. 2002, pp. 947-951.

In this paper we discuss the use of a field mapping approach for determining chamber quality. Both measurements and simulation results are used to illustrate this approach.

R.A. Dalke, "A model for predicting RF interference due to randomly distributed UWB sources," in *Proc. 2002 Wireless Conference,* Calgary, Jul. 2002.

This paper presents a statistical model that can be used to estimate RF interference due to randomly distributed UWB sources. The essential assumption is that the devices are uniformly distributed over the geographical area surrounding the victim receiver. The model can be used to predict interference power for both terrestrial and airborne victim receivers. Interference power is calculated in terms of the average transmitted power and transmitter gain at the RF frequency of interest, the density of the transmitters, the average azimuthal receiver gain and the average propagation gain over the area surrounding the victim receiver. Example calculations employing commonly used radio propagation models are given in the paper.

J.J. Lemmon, "Wireless link statistical bit error model," in *Proc. 2002 Wireless Conference,* Calgary, Jul. 2002.

A bit error model that enables simulations of the digital error performance of wireless communication links has been developed. The model development has been based on error sequences derived from waveform simulations of wireless link performance with various modems operating under varying propagation, noise, and interference conditions. Values of the model parameters are obtained by analyzing the distributions of the lengths of error bursts and error gaps (error-free intervals). Mathematical expressions have been derived for the means and variances of the error burst and error gap distributions of the model as functions of the model parameters. Constraining the means and variances to the values obtained from waveform simulations uniquely determines values of the model parameters corresponding to a given set of link conditions. Examples of error burst and error gap distributions obtained from waveform simulations are compared with those generated by the model for a land mobile radio system and a wireless local area network. The simulated and model distributions are quite similar; however, the model runs tens of thousands of times faster than the corresponding waveform simulations, enabling rapid determination of link performance.

P. Papazian, M. Gans, Y. Lo, and R. Dalke, "Capacity measurements for a 16x16 element BLAST array over a conducting ground plane," in *Proc. 2002 International Vehicular Technology Conference,* Vancouver, British Columbia, Sep. 2002.

This paper presents channel transfer function measurements using a 16x16 "Bell Laboratories Layered Space-Time (BLAST) antenna array and a wideband measurement system. The capacity of a BLAST system is computed using the H matrix, comprised of the complex transfer functions between each transmitter and receiver element. Measurements were made over a metallic ground plane allowing for comparison with an analytical calculation of the H matrix. Measurement data were then compared to theoretical results. Using this comparison it was determined how accurately H can be measured using a wideband system and hence how accurately the capacity of the BLAST system can be predicted. It was found that the predicted capacities, based on measurements using the 16x16 system, were within 5% of the theoretical calculations.

E. Quincy, “Victim receiver response to ultrawideband signals,” in *Proc. MILCOM 2001,* Washington, D.C., Oct. 2001.

A class of time-dithered ultrawideband (UWB) systems is modeled and simulated from an analytic description of the system. These simulated time waveforms and Fourier spectra results are analyzed to show the effect of a receiver's intermediate frequency (IF) bandwidth (BW) on peak and average power. The peak and average power curves provide the basis for establishing a normalized bandwidth correction factor (BWCF) curve and equation. The BWCF is used to estimate peak power over a range of BWs from average power measurements made in a 1 MHz BW. Peak and average power are computed and compared over BWs from 0.3 MHz to 100 MHz for both pre and post detection. The 50% dithered case is also compared to a non-dithered periodic system which exhibited constant power curves as a function of IF BW below the pulse repetition rate (PRR) of 10 MHz. All of the curves increased linearly in power with BW on log-log plots. Peak power increased more rapidly than average power above the PRR for all cases.

C. Redding & C. Taylor, “Priority access service in cellular and PCS networks,” in *Proc. MILCOM 2001,* Washington, D.C., Oct. 2001.

Wireless telephony can greatly assist National Security and Emergency Preparedness (NS/EP) personnel in providing emergency communications. With the widespread availability of wireless telephony, a cost effective means of communication is readily available to NS/EP users. However, due to the heavy traffic demand placed upon existing or surviving systems in the aftermath of a disaster, severe network congestion will result in high call blocking to NS/EP users when their services are needed the most. This need has resulted in the wireless intelligent network (WIN) implementation of a priority access service (PAS) development effort. The WIN implementation of PAS provides a means for NS/EP users to obtain priority access on the next available radio channel when network congestion is encountered.

T. Riley, “Modeling of licensed PCS self-interference,” in *Proc. MILCOM 2001,* Washington, D.C., Oct. 2001.

Self-interference in Personal Communications Services (PCS) systems is a real and acknowledged problem in both urban and rural areas. If left unresolved, it can impact the quality of service and system capacity. Self-interference is of particular interest to the commercial PCS industry, as more systems are being developed and implemented in already saturated areas. Since commercial PCS services are being considered for use in national security/emergency preparedness (NS/EP) situations, self-interference is becoming a concern of government and military agencies. A model of self-interference in PCS systems, which is applicable to other cellular, wireless technologies, has been developed by the Institute for Telecommunication Sciences (ITS). The developed methodology was applied to two existing PCS technologies: PCS 1900 (a narrowband time division multiple access (TDMA) system based on Global System for Mobile (GSM)), and IS-95-based code division multiple access; application to the remaining second-generation, as well as proposed second-and-a-half- and third-generation technologies, is currently under way. The system-specific models are used to produce output noise and interference waveforms suitable for implementation in a real-time hardware channel simulator, or as a component of higher-level software simulations and models. Example outputs are given for simulations of both technologies, with corresponding statistical analyses of the noise and interference waveform properties. The models are particularly well-suited for independent PCS system evaluation by other Federal agencies, system manufacturers, and service providers.

T. Rusyn, “Co-channel interference modeling of the ANSI/TIA/EIA-95B code division multiple access cellular system,” in *Proc. 2002 IEEE Intl. Symp. on EMC*, Minneapolis, MN, Aug. 2002.

Spectral efficiency is an essential component of existing and new technologies in Personal Communications Services (PCS). The growing demand for PCS has resulted in an increasingly crowded spectrum. Code division multiple access is one of the best methods for efficient use of the radio spectrum. Code division is used in some second generation PCS systems and is used or proposed for all third generation PCS systems. The capacity of code division cellular systems is limited primarily by interference caused by co-channel interferers and other channel interferers. This paper introduces an interference model of the ANSI/TIA/EIA-95-B cellular system which can be used to study the effects of co-channel interference and presents results of four preliminary simulation scenarios run using the output of the model.

R. Stafford and C. Behm, “Wireless network throughput measurements,” in *Proc. MILCOM 2001*, Washington, D.C., Oct. 2001.

In the current technological environment, real-time access to the Internet is becoming as important as access to a desktop computer was a decade ago. As cellular and PCS phones become more ubiquitous, the availability of mobile voice communications leads to a natural desire for mobile Internet access. This report details throughput studies performed on five different wireless data access technologies. These include one purely cellular technology, cellular digital packet data, which is carried on AMPS channels, and two PCS technologies, IS-95 and GSM. In addition a wireless mobile computing device (PDA) is examined, as well as a proprietary microcellular system.

All five technologies were tested in stationary modes and the cellular/PCS based systems were also tested in a mobile configuration at highway speeds. This study involved the use of the FTP service to investigate throughput at a user level as well as a study of packet by packet transfers. Measurements of a line modem are also given for comparison.

Journal Articles

M.G. Cotton, E.F. Kuester, and C.L. Holloway, “An investigation into the geometric optics approximation for indoor scenarios with a discussion on pseudolateral waves,” *Radio Science*, vol. 37, no. 4, pp. 1-1 – 1-22, Jul.-Aug. 2002.

In this study we investigated the geometric optics (GO) approximation to the fields of an infinitesimal electric dipole above a half plane for geometries typical of wireless indoor communications. This inspection was motivated by efforts to establish a ray trace model to characterize indoor radio propagation channels. Eight canonical geometries were examined to isolate near-surface and near-field effects that are not accounted for in the GO approximation. Common building materials and physical dimensions (i.e., antenna separation and height) as small as 1 cm were investigated for frequencies up to 8 GHz. Theoretical fields were calculated via numerical evaluation of Sommerfeld integrals and compared to corresponding GO approximations. As expected, near-field and near-surface (e.g., surface wave) mechanisms which invalidate GO were observed. Close to the surface, an interesting interference pattern in the frequency domain was identified. Mathematical manipulation showed that this so-called “pseudolateral wave” phenomenon was caused by adjacent fields in the two media propagating at different speeds. Next, we transformed the results to the time domain and used delay spread as a metric to quantify GO error. We also show that the pseudolateral wave manifests itself in the time domain as an additional pulse that arrives at a delay associated with the speed of a wave traveling in the lossy media.

C.L. Holloway, P.M. McKenna, R.A. Dalke, R.A. Perala, and C.L. Devor, Jr., “Time-domain modeling, characterization, and measurements of anechoic and semi-anechoic electromagnetic test chambers,” *IEEE Trans. on EMC,* v. 44, no. 1, pp. 102-118, Feb. 2002.

We present time-domain techniques for modeling, characterizing, and measuring anechoic and semi-anechoic chambers used for emission and immunity testing of digital devices. The finite difference time-domain (FDTD) approach is used to model and characterize these chambers. In the FDTD model presented here, we discuss methods used to eliminate the need to spatially resolve the fine detail of the absorbing structures; present a differential-operator approach for incorporating both frequency-dependent permittivity and permeability into the time domain; and discuss the effects of gaps and holes in ferrite-tile absorbers on both absorber and chamber performance. Comparisons of the FDTD chamber model with measured data for different chamber sizes are presented. Finally, we discuss and illustrate how time-domain techniques can be used to characterize chambers, predict performance, and diagnose problems with both absorbers and chambers. With time-domain and frequency-domain techniques, we show how the performance of chambers can be significantly altered with only small changes in the type of absorbing structure used, and we illustrate how undesirable modal field distributions can occur inside a chamber when a nonoptimal absorber is used.

J.J. Lemmon, “Wideband model of HF atmospheric radio noise,” *Radio Science,* vol. 36, no. 6, pp. 1385-1391, Nov.-Dec. 2001.

A model of the waveform generated by high-frequency atmospheric radio noise is presented. Cumulative probability distributions of the noise envelope are derived and shown to be in good agreement with a large database collected from a wide range of noise environments. The model includes correlations in the waveforms that simulate the burst structure of measured atmospheric noise. The bandwidth dependence of the voltage deviation parameter, which parameterizes the impulsiveness of the noise, shows behavior that is qualitatively similar to a limited amount of measured data.

P. Wilson, P. Papazian, M. Cotton, and Y. Lo, “A comparison of 1920-MHz mobile channel diversity gain using horizontal and vertical arrays,” *IEEE Trans. on Communications,* vol. 49, no. 12, pp. 2068-2070, Dec. 2001.

Diversity gain for a 1920-MHz suburban mobile channel was measured for various array orientations (horizontal and vertical), combining techniques, and bandwidths (19.6 kHz to 10.0 MHz). While horizontal array diversity gain was larger than for the vertical array, vertical array gain was still significant for narrower bandwidths.

Unpublished Presentations

N. DeMinco, “Modeling antennas on automotive vehicles at VHF and lower frequencies,” presented at IEEE Antennas and Propagation Society meeting, San Antonio, TX, Jun. 20, 2002.

E. Haakinson, “Emerging technology solutions,” presented at the NTIA/PSWN Current and Emerging Solutions to Public Safety Communications Interoperability Summit, Jun. 2002, Washington DC.

J.R. Hoffman and M. Cotton, “Measurements to determine potential interference to GPS receivers from ultrawideband transmission systems,” presented at the International Symposium on Advanced Radio Technologies (ISART), Boulder, CO, Mar. 2002.

J. Lemmon, “Vulnerability of telecommunications infrastructure to high power RF fields,” presented at the 2001 Department of Energy Wireless Working Group, Las Vegas, NV, Nov. 27-29, 2001.

R. Matheson, “Spectrum management aspects of the wireless Internet,” tutorial presented at NLANR/Internet2 Joint Techs Workshop, Boulder, CO, Jul. 28, 2002.

P. McKenna, “A comparison of radio propagation predictions and measurements at VHF and UHF using univariate and multivariate normal statistics,” presented at ISART, Boulder, CO, Mar. 2002.

F.H. Sanders, “Bandwidth-limited measurements of ultrawideband device emissions,” presented at ISART, Boulder, CO, Mar. 2002.

R. Stafford, “Wireless network discovery,” presented at ISART, Boulder, CO, Mar. 2002.

S. Voran, “Quality assessment of digitally coded speech,” presented to University of Wyoming Electrical Engineering Graduate Seminar, Laramie, WY, Apr. 26, 2002.

S. Voran, “The channel-optimized multiple-description scalar quantizer,” presented to University of Wyoming Electrical Engineering Graduate Seminar, Laramie, WY, Apr. 26, 2002.

S. Voran, “Objective estimation of speech quality in the context of the IS-102.BABB-A vocoder mean opinion score conformance test,” presented to TIA TR-8.4, Westminster, Colorado, Jun. 11, 2002.

J. Wepman, “An overview of SDR and enabling technologies,” presented at ISART, Boulder, CO, Mar. 2002.

S. Wolf and S. Voran, “Advances in objective measurement of user-perceived video and speech quality,” presented to NLANR/Internet2 Joint Techs Workshop, Boulder, Colorado, Jul. 29, 2002.

Conferences Sponsored by ITS

NLANR/Internet2 Joint Techs Workshop, July 28-August 1, 2002, co-sponsored by NIST, NOAA, NTIA/ITS, and NCAR. Workshop participants included more than 250 researchers from academia, industry, and government. Internet2 is developing and deploying advanced network applications and technologies for research and higher education, accelerating the creation of tomorrow's Internet.

2002 International Symposium on Advanced Radio Technologies, March 4-6, 2002. The focus of this year's symposium was on state-of-the-art and future trends in radio technology, spectrum regulation, policy, and business. The keynote address was given by Michael Gallagher, Deputy Assistant Secretary for Communications and Information, U.S. Department of Commerce.

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.

Eldon J. Haakinson, National Chair of the U.S. contingent of ITU-R Study Group 3 (Radiowave Propagation).

Paul M. McKenna, 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).

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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).

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1. This Guide identifies-the design objectives and functionality of the Justice Standards Registry for Information Sharing. The Registry is a collection or repository of information about IT and communications standards (and-in some cases-the standards themselves) that have been assembled and cataloged as part of the U.S. Department of Justice interoperability effort to enable information sharing among practitioners in the Justice and Public Safety communities.

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Abbreviations/Acronyms

2.5-D	two and a half dimensional
3-D	three dimensional
3G	third generation

A

AFIWC/EWS	Air Force Information Warfare Center/Electronic Warfare Squadron
AGILE	Advanced Generation of Interoperability for Law Enforcement
AMPS	advanced mobile phone service
ANS	American National Standard
ANSI	American National Standards Institute
APCO	Association of Public Safety Communications Officials
APD	amplitude probability distribution
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
BLAST	Bell Labs Layered Space-Time theory
BPSK	binary phase shift keying
BW	bandwidth
BWCF	bandwidth correction factor

C

CCIR	International Radio Consultative Committee (now ITU-R)
CD	compact disk
CDA	code domain analyzer
CDMA	code division multiple access
CIP	critical infrastructure protection
CMTS	cable modem termination system
CONUS	continental U.S.
COTS	commercial off-the-shelf
CRADA	cooperative research and development agreement
CRPL	Central Radio Propagation Laboratory
CRSMS	Compact RSMS
CSPT	Communication System Planning Tool
CW	continuous wave

D

dB	decibel
DC	direct current
DFS	dynamic frequency sharing
DGPS	differential GPS
Diff-Serv	Differentiated Services
DLL	dynamic link library
DOC	Department of Commerce
DOD	Department of Defense
DOJ	Department of Justice
DSCP	digital sampling channel probe
DSP	digital signal processing
DSSS	direct sequency spread spectrum
DTAO	Defense Technology Analysis Office
DTV	digital television

E

EIA	Electrical Industries Association
EMC	electromagnetic compatibility
ESSA	Environmental Science Services Administration
ETS	Emergency Telecommunication Service

F

FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FDTD	finite-difference time domain
FED	Federal
FED-STD	Federal Standard
FHSS	frequency hop spread spectrum
FM	frequency modulation
FPGA	field programmable gate array
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
GETS	Government Emergency Telecommunications Service
GHz	gigahertz
GIF	graphics interchange format
GIS	geographic information system
Global	Global Justice Information Network Advisory Committee
GLOBE	global land one-km base elevation
GO	geometric optics
GPR	ground penetrating radar
GPRS	general packet radio service
GPS	Global Positioning System
GSM	Global System for Mobile

H

HAAT	height above average terrain
HDTV	high definition television
HF	high frequency
HP	Hewlett Packard
HPGL	HP graphics language
HTML	hypertext markup language
HTTP	hypertext transfer protocol

I

I2	Internet2
ID	identification
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IF	intermediate frequency
IITRI	Illinois Institute of Technology (IIT) Research Institute
IMT-2000	International Mobile Telecommunications 2000
INFOSEC	information system security
Internet2	2nd-generation Internet
IP	Internet protocol
IRL	Interoperability Research Laboratory
ISART	International Symposium on Advanced Radio Technologies
ISDN	integrated services digital network
ISM	industrial, scientific, and medical
ISO	International Organization for Standardization
ISSI	inter-RF subsystem interface

IT	information technology
ITCS	incremental train control system
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
IXC	interexchange carrier

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
Mbps	megabits per second
MHz	megahertz
MILCOM	Military Communications Conference
MIMO	multiple input multiple output
MOS	mean opinion score
MP	milepost
MPEG	Motion Picture Experts Group
MSTV	Association for Maximum Service Television, Inc.
MTA	media terminal adaptor
MW	megawatt

N

NASTD	National Association of State Telecommunications Directors
NBS	National Bureau of Standards
NCAR	National Center for Atmospheric Research
NCS	National Communications System
NGI	next generation Internet
NGN	next generation network
NII	National Information Infrastructure
NIJ	National Institute of Justice
NIST	National Institute of Standards and Technology
NLANR	National Laboratory for Applied Network Research
NOAA	National Oceanic and Atmospheric Administration
NPRM	notice of proposed rulemaking
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
OLES	Office of Law Enforcement Standards
OMB	Office of Management and Budget
OO	object oriented
ORTA	Office of Research and Technology Applications
OSM	Office of Spectrum Management
OT	Office of Telecommunications
OTAR	over-the-air rekeying
OTP	Office of Telecommunications Policy

P

P25	Project 25
PAS	priority access service
PBS	Public Broadcasting System
PBX	private branch exchange
PC	personal computer
PCS	Personal Communications Services
PDA	personal digital assistant
PDO	Program Development Office
PESQ	perceptual evaluation of speech quality
PN	pseudo-random
PRR	pulse repetition rate
PS/LE	public safety/law enforcement
PSNR	peak signal-to-noise ratio
PSTN	public switched telephone network
PSWN	Public Safety Wireless Network

Q

QoS	quality of service
QPSK	quadrature phase-shift keying

R

R&D	research and development
RCG	Radar Correspondence Group
RDBMS	relational database management system
RF	radio frequency
RFIMS	Radio Frequency Interference Monitoring System
RMON	remote monitoring
RMS	root mean square
RSEC	Radar Spectrum Engineering Criteria
RSMS	Radio Spectrum Measurement System
RTCP	realtime transport control protocol
RTP	realtime transport protocol

S

S-T	spatial-temporal
SBC	single board computer
SDMA	space division multiple access
SDR	software defined radio
SDTS	spatial data transfer standard
SFG	Standards Formulating Group
SG	study group
SIP	session initiation protocol
SIPRNET	Secret Internet Protocol Routable Network
SLA	service level agreement
SNR	signal-to-noise ratio
SONET	synchronous optical network
SRD	standard requirements document
SSCQE	single stimulus continuous quality evaluation

T

TA Services	Telecommunications Analysis Services
TB	terabyte
TDMA	time division multiple access
TIA	Telecommunications Industry Association
TIREM	Terrain Integrated Rough Earth Model
TR	technical report
TSB	Telecommunications Systems Bulletin
TV	television
TVRO	television receive-only

U

UHF	ultra high frequency
UMTS	universal mobile telecommunications system
UNIX	uniplexed information and computing service
URL	uniform resource locator
URSI	International Union of Radio Science
USCG	U.S. Coast Guard
USGS	U.S. Geological Survey
UTRA	UMTS terrestrial radio access
UWB	ultrawideband

V

V	volt
VAC	volts, alternating current
VHF	very high frequency
VoIP	voice over Internet protocol
VPN	virtual private network
VQEG	Video Quality Experts Group
VQM	video quality measurement

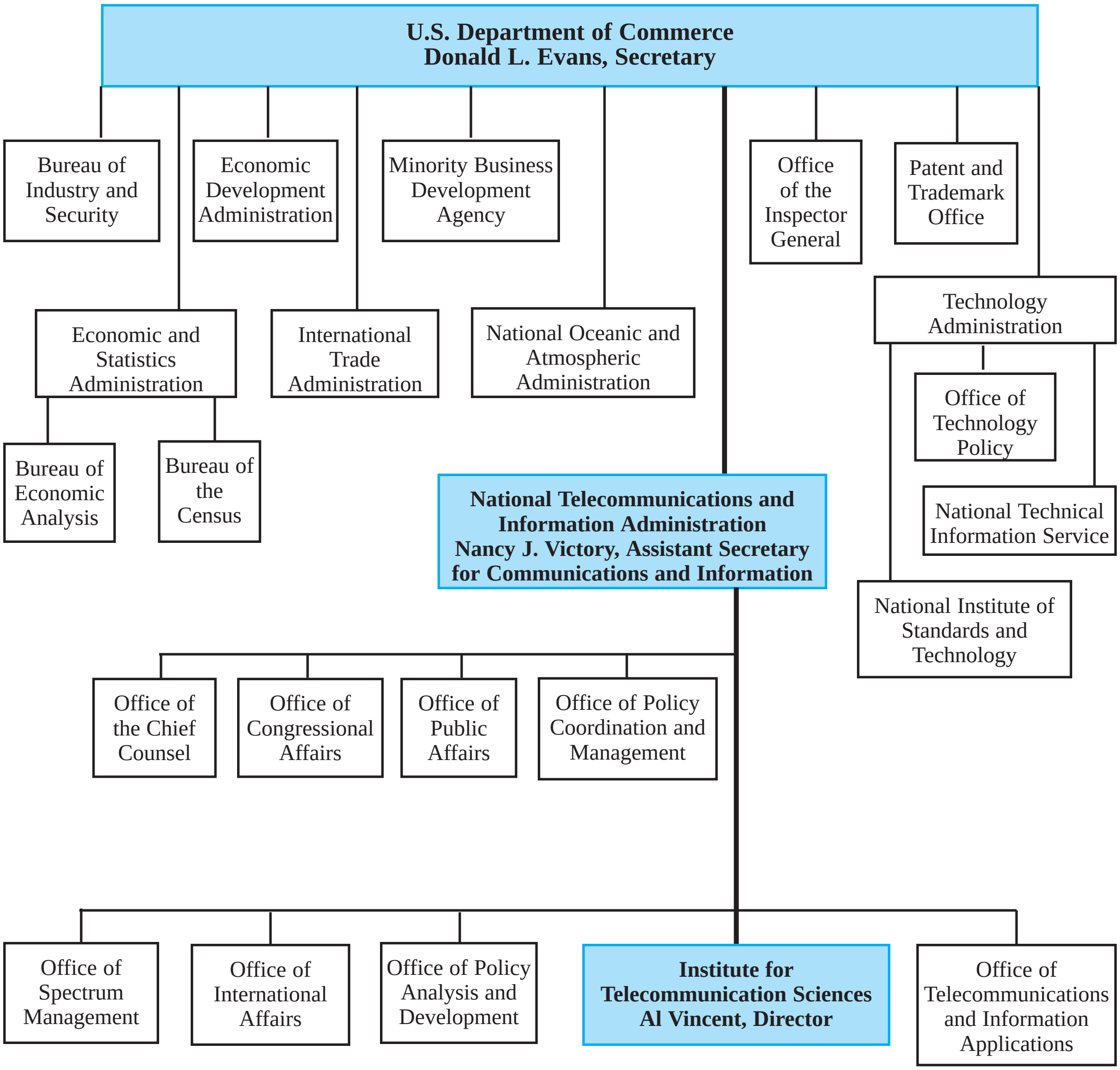
W

W-CDMA	wideband CDMA
WCTF	Wireless Communications Task Force
WDM	wave division multiplexing
Wi-Fi	wireless fidelity
WIN	wireless intelligent network
WLAN	wireless LAN
WNRC	Wireless Networks Research Center
WP	working party
WPAN	wireless personal area network

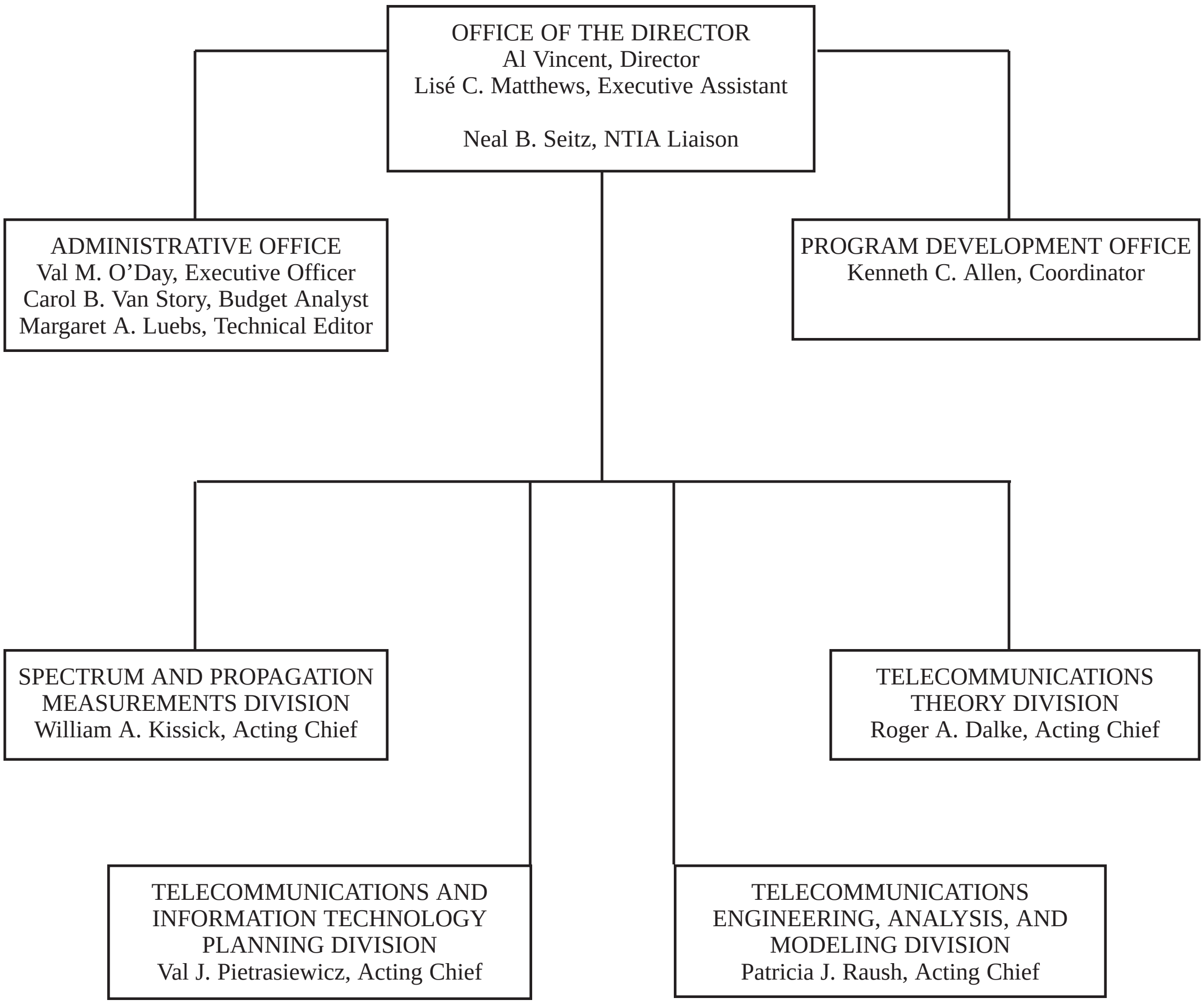
X

XML	eXtensible Markup Language

DOC/NTIA Organization Chart



ITS Organization Chart



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