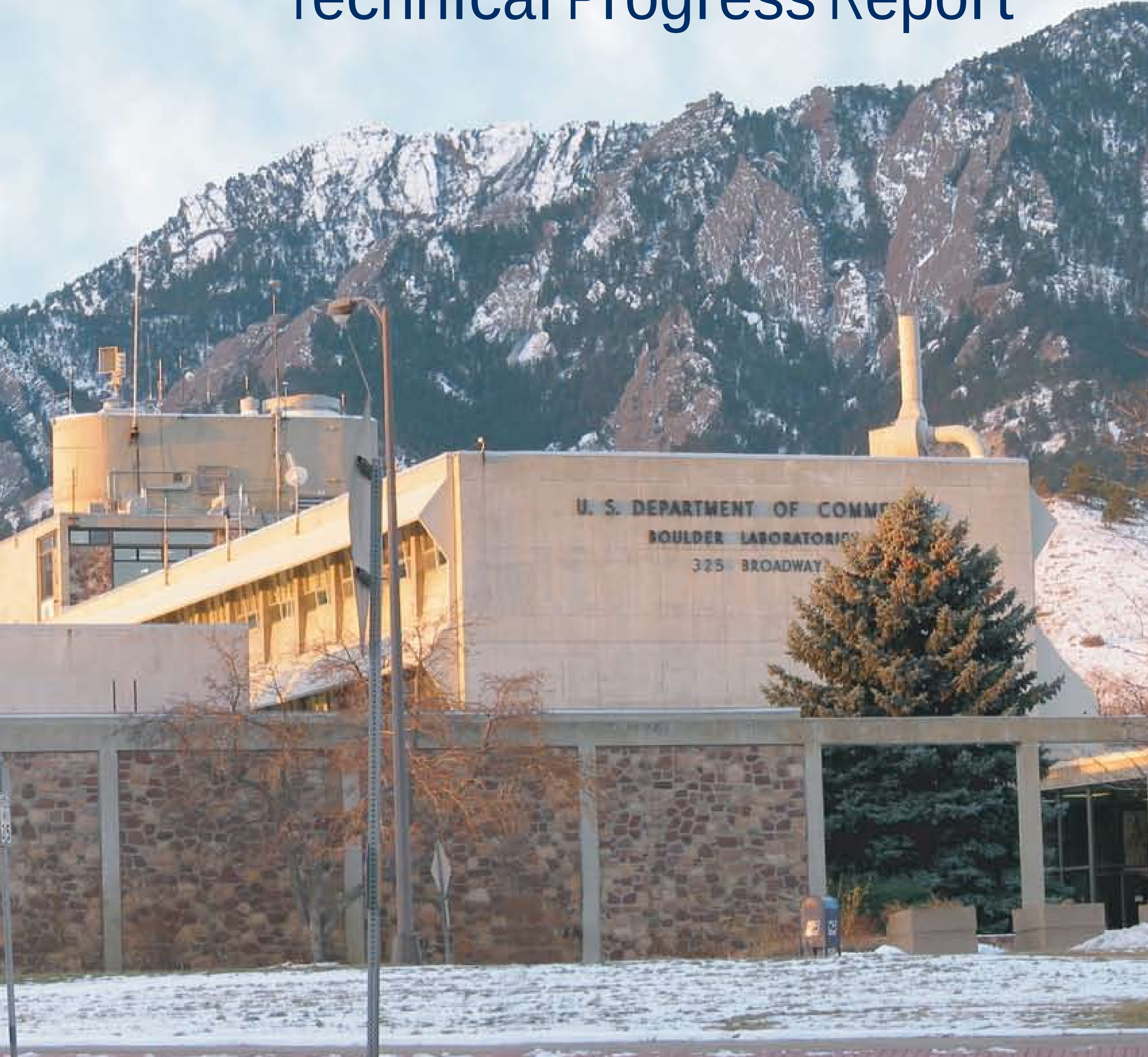
Institute for Telecommunication Sciences

2001

Technical Progress Report



Institute for Telecommunication Sciences

2001 Technical Progress Report

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

Nancy J. Victory, Assistant Secretary
for Communications and Information

January 2002

Contents

Measurements performed on the roof of the main building at the DOC Boulder Laboratories. Researchers are testing the effects of various E-field strengths on GPS receivers (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.

Sixty-foot-diameter dish antenna at the Table Mountain National Radio Quiet Zone, north of Boulder (photograph by W.A. Kissick).

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 2001 consisted of $3.9 million of direct funding from the Department of Commerce and approximately $4.6 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 later became the Central Radio Propagation Laboratory (CRPL) of the National Bureau of Standards, 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 decade, 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 2001 to both the public and private sectors.

ITS engineer operating suitcase system designed to inject interference into maritime radar receivers at Curtis Bay Coast Guard Station, Maryland (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, a rapidly increasing competition for access to the radio spectrum suggests that its shared use will require increasingly more complex planning and coordination 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

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.

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. To keep pace with technological changes in radio systems, the RSMS is being upgraded with hardware and better signal processing to support faster measurements, higher frequencies, and new modulation methods. The project is funded by NTIA.

Ultrawideband Signal Characterization

The Institute performs measurements of both the temporal and spectral characteristics of the time-domain-modulated radio technology called ultrawideband (UWB). Measurement methods are developed to identify the nature of UWB signals when received (observed) in various bandwidths. The project is funded by NTIA.

Effects of Ultrawideband Signals on GPS Receivers

The Institute identifies and analyzes the effects that a variety of UWB signals may have on various critical receiver systems used with the Global Positioning System (GPS). The resulting information is used to develop frequency management criteria (e.g. coordination distance) or new rules and regulations. The project is funded by NTIA, the U.S. Air Force, and the Federal Aviation Administration.

Spectrum Compatibility Measurements

Outputs

- Measurements of effects of pulsed interference into a digital earth station receiver.
- Propagation measurements to assess protection criteria between new digital television signals and the Table Mountain National Radio Quiet Zone.
- Broadband spectrum survey results at the Table Mountain National Radio Quiet Zone.

As new transmitter technologies are developed, the signals they generate may cause electromagnetic compatibility (EMC) problems when such systems are deployed in proximity to highly sensitive receivers. In FY 2001, NTIA has proactively engaged in two projects to determine the likely impacts of high-power transmitters. The purpose of these efforts has been to minimize the effects of EMC problems involving Government systems.

A recent concern of spectrum managers has been the possible effects of pulsed interference on digital earth station receivers. Interference effects have previously been measured and analyzed for analog earth stations, but digital earth stations can respond somewhat differently. One difference, for example, is that the performance of analog stations may be reduced gradually in the presence of increasing levels of pulsed interference, whereas digital receivers may fail abruptly. NTIA has needed to understand the precise conditions under which digital earth station receivers may experience interference effects.

To determine these conditions, an extensive set of measurements were performed at the ITS Boulder Laboratories. A digital, 4-GHz earth station (Figure 1) was configured to receive television signals. A broad variety of pulsed signals, with variable pulse width, pulse repetition rate, and pulse amplitudes, were generated by a custom-configured system. The pulsed interference was coupled into the earth station receiver via a hardline connection and the pulse widths, amplitudes, and repetition rates were varied

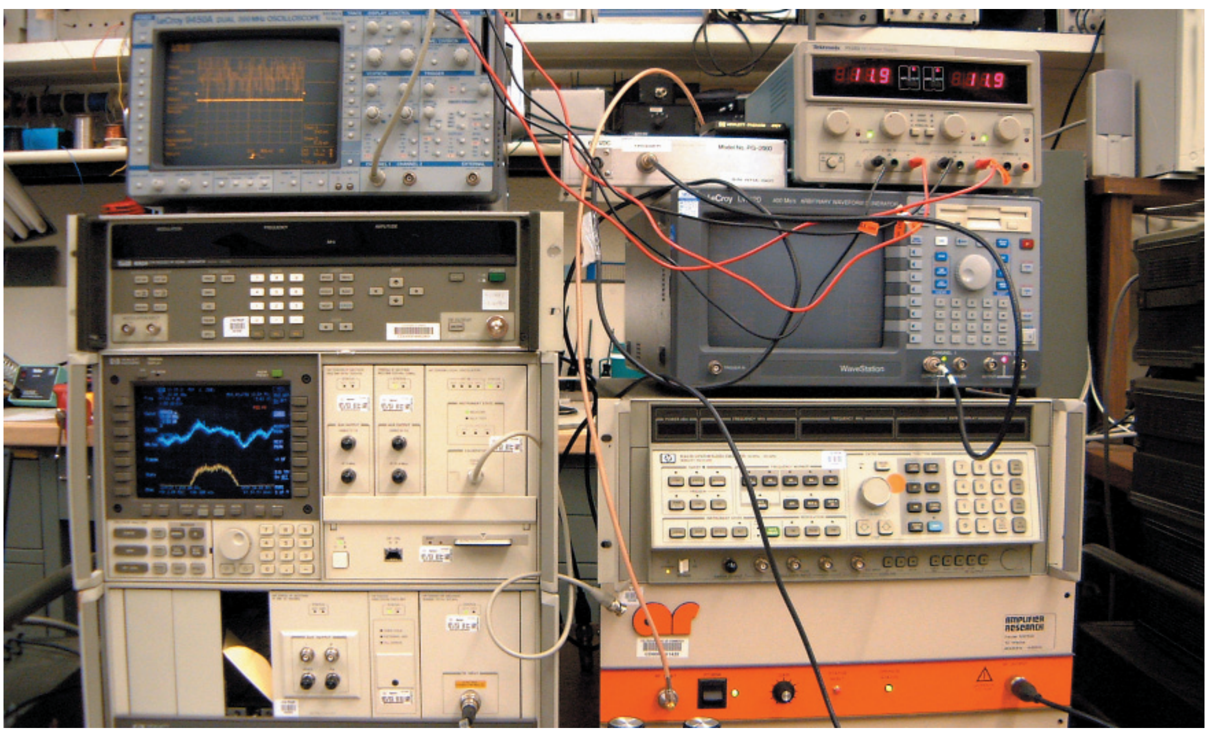


Figure 1. Digital earth station equipment used for interference testing and measurements at the ITS Boulder Laboratories (photograph by F.H. Sanders).

to determine interference thresholds for various combinations of these parameters. An NTIA report will soon be released with the results of this study. The data obtained will be used by spectrum managers to determine the likelihood that various types of pulsed emitters, including radars, may cause interference to digital earth station receivers under various circumstances of system design and deployment.

Another significant EMC issue that ITS addressed in FY 2001 was the Government's ability to predict the levels of future digital television (DTV) signals at the Table Mountain National Radio Quiet Zone north of Boulder, Colorado. Working jointly with the National Institute of Standards and Technology (NIST), ITS undertook a detailed study to assess the accuracy with which DTV signal levels could be predicted within the boundaries of the Quiet Zone along a variety of propagation paths from two different mountaintop transmitter locations. This study was important because the results would indicate whether predictions could be relied upon to correctly indicate the amount of signal attenuation (or other possible mitigating measures) that might be required of DTV transmitters to meet the statutory limits on radio signal levels within the Quiet Zone.

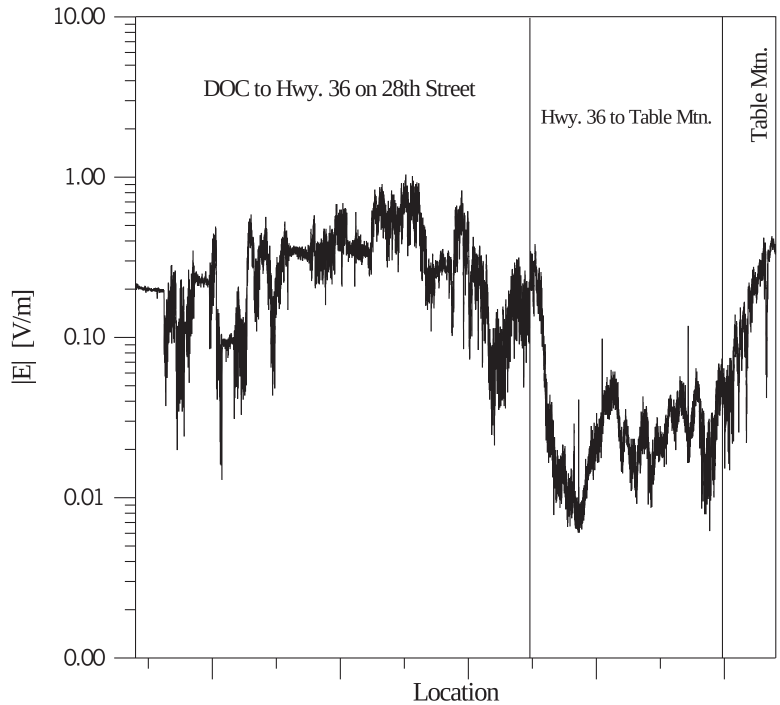


Figure 2. Propagation measurement results from Table Mountain National Radio Quiet Zone study, showing measured E-field levels from the DOC Boulder Laboratories, down 28th Street to Highway 36, and on to Table Mountain. These results are for a transmitter on Eldorado Mountain, 533 MHz frequency, 3.66 m transmitter height, and 2.95 m receiver height.

To test the predictions, the Radio Spectrum Measurement System (RSMS) was driven along a variety of routes in the Boulder area while measuring signal levels received from test transmittters at two mountaintop locations. The results of this propagation study were published in a joint NTIA-NIST report (see "Recent Publication" below). The study showed that predictions of propagation loss closely matched the measured values in the UHF television band, confirming the reliability of the propagation models. An example of the propagation measurement results is shown in Figure 2.

As part of the same report, the results of a broadband spectrum survey at the Quiet Zone were published. These results demonstrated that the current Quiet Zone signal levels meet Federally-specified limits.

Recent Publication

C.L. Holloway, F.H. Sanders, and P.M. McKenna, "Predicted and measured field strengths in the Boulder, Colorado, area from two proposed terrestrial digital television tower sites," NIST Technical Note 1519 and NTIA Report 01-387, May 2001.
http://www.its.bldrdoc.gov/pub/ntia-rpt/01-387

For more information, contact:
Frank H. Sanders
(303) 497-5727
e-mail fsanders@its.bldrdoc.gov

Spectral Assessment of Government Systems

Outputs

- Emission spectrum measurements on Government airborne surveillance radars to assess feasibility of operation in a selected band.
- Measurements assessing the effects of radar-to-radar signal coupling under conditions of spectrum band sharing, for a U.S. Contribution to the ITU-R.

The U.S. Government operates a large number of radar systems, and advances in technology continue to drive the development of new radars. But every new type of radar needs to be assessed for feasibility of operation in the presence of other existing radars and various additional receiver systems. ITS plays a key role in the Government's efforts to reliably and accurately determine the emission characteristics of new radar designs. In order to ensure that the Government utilizes scarce spectrum with maximum efficiency, ITS also conducts electromagnetic compatibility (EMC) measurements to determine whether (or under what circumstances) new and existing radars can share spectrum with each other.

To meet these mission requirements in FY 2001, ITS and the NTIA Office of Spectrum Management (OSM) performed measurements on a pair of new Department of Defense (DOD) airborne, long endurance surveillance radars. ITS also performed an extensive set of EMC measurements between a variety of maritime radars to determine their ability to share spectrum, and to provide the results as a U.S. Contribution to the International Telecommunication Union, Radiocommunication Sector (ITU-R).

The surveillance radars were measured at an indoor anechoic test facility on the East Coast. A suitcase-transportable measurement system was shipped from

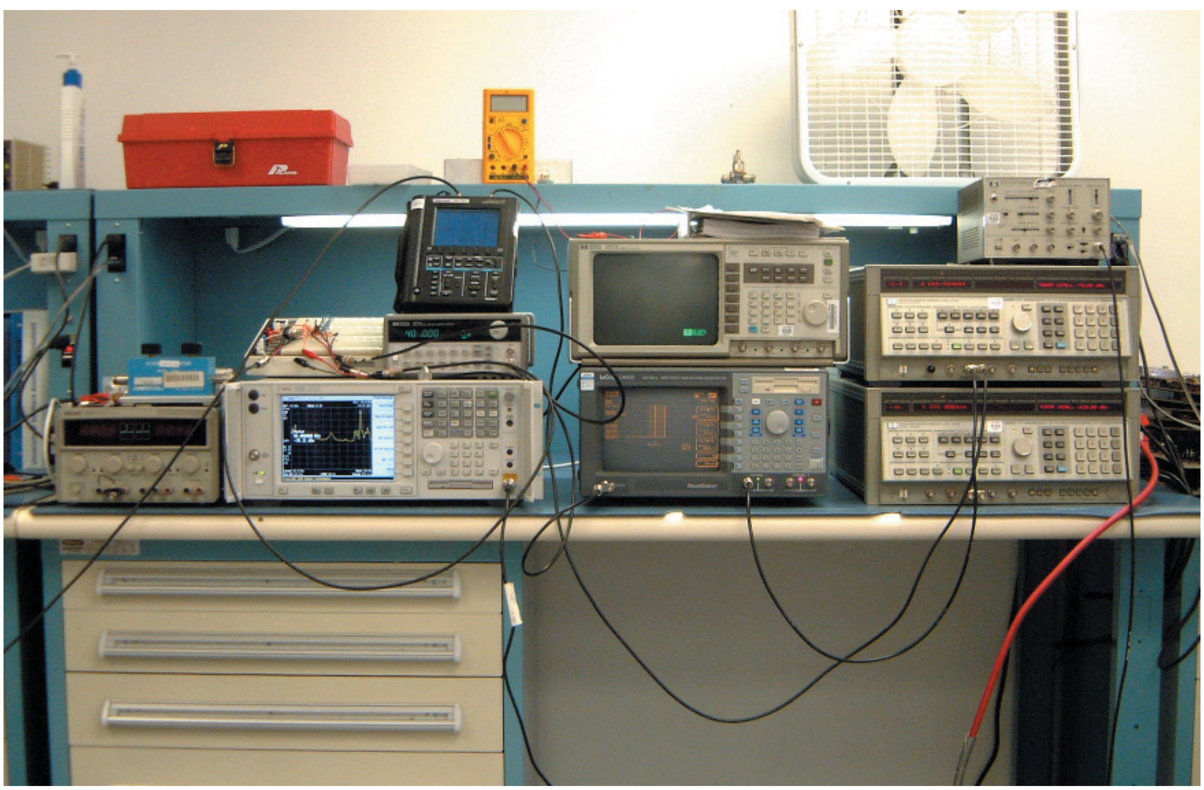


Figure 1. Pulsed interference generator and measurement equipment at Curtis Bay Coast Guard Station, Maryland (photograph by F.H. Sanders).

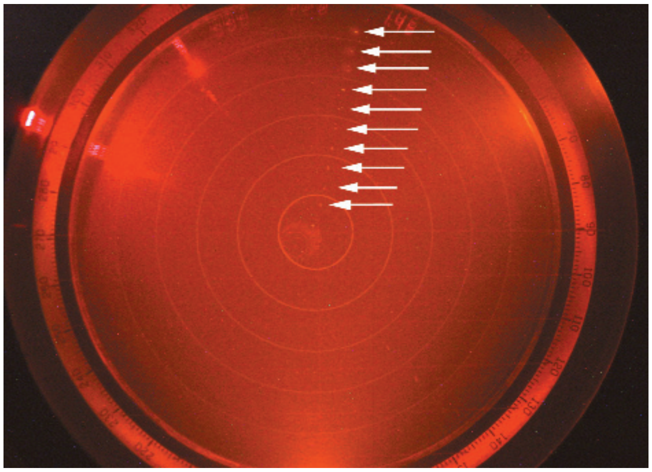


Figure 2(a). PPI scope display with only desired targets (generated by ITS hardware).

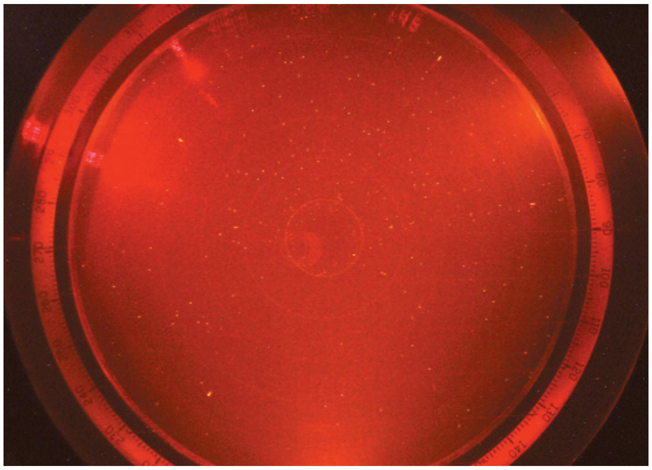


Figure 2(b): PPI scope display with desired targets and moderately high interference from ITS generator.

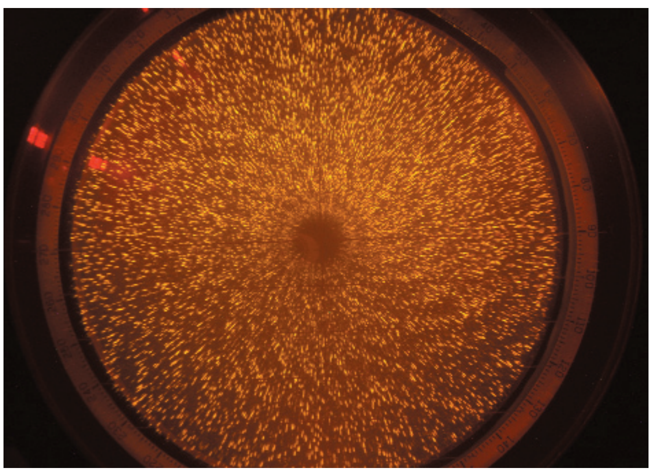


Figure 2(c): PPI scope display with extremely high interference (all photographs by F.H. Sanders).

Boulder for this purpose. The radars were operated in normal operational modes while computer-controlled measurements were performed on their emission spectra and emitted time waveforms. The results were forwarded to OSM and were used by the Spectrum Planning Subcommittee to assess the feasibility of operations in a selected spectrum band.

Another Government spectrum problem that ITS addressed in FY 2001 was the question of band sharing between a variety of maritime and naval air search radars. To carry out this study, ITS and OSM identified commonly used maritime navigation and surface search radars in the S-Band part of the spectrum. A signal simulator set that could simulate both desired radar targets and the emissions of other radars was designed and tested in Boulder, and then transported to the radar site (Figure 1). The radar signal simulator was coupled to two different receiver models of maritime surface search radars, and pulsed interference with a variety of pulse widths, pulse repetition rates, and signal amplitudes was injected into each type of receiver. Interference parameters were varied and the radar receiver plan position indicator (PPI) displays were monitored for interference effects. In Figure 2(a), the PPI display is shown under normal baseline conditions with only the (simulated) desired targets. In Figure 2(b), the PPI scope is shown under a condition of noticeable interference. In Figure 2(c), the interference has become severe.

ITS and OSM personnel documented the conditions under which simulated radar-to-radar interference ocurred. The results were analyzed and published as a U.S. Contribution to the ITU-R in October. While some conditions produced interference effects, it was also noted that a wide range of normal operational conditions resulted in no radar-to-radar interference.

For more information, contact:
Frank H. Sanders
(303) 497-5727
e-mail fsanders@its.bldrdoc.gov

Radio Spectrum Measurement System Upgrades

Outputs

- Development of amplitude-probability distribution (APD) measurement software for assessment of emissions from pulsed emitters.
- Development of a 20-MHz IF-bandwidth measurement capability to replicate the responses of wideband receivers.
- Planning for fourth-generation Radio Spectrum Measurement System (RSMS-4).

The NTIA Radio Spectrum Measurement System (RSMS) relies heavily on custom-designed software to accomplish its assigned operational tasks. In FY 2001, a significant task was the completion of measurements to determine the emission characteristics of ultrawideband (UWB) transmitters. In the course of these measurements, it was determined that emission spectrum measurements and time waveform measurements did not adequately represent the full range of UWB emission characteristics. An additional tool was required, one that would measure the statistical distribution of the emitted pulsed signals, i.e., the percentage of time that the emitted signal exceeded any given set of emission level thresholds. These data are described by amplitude-probability distribution (APD) curves (Figure 1). The APD can also be used to calculate maximum amplitude (peak), root mean square (RMS) average, log average, linear average, and many other useful statistical quantities.

New software was developed by ITS to collect a large number of time waveform data points from any specified transmitter. The new software then processed the amplitudes in the time waveforms to produce APD curves for each measured device. These curves were used in an NTIA report on UWB emission characteristics (see "Recent Publication" on next page).

Another requirement for the ongoing RSMS mission is to measure emissions from transmitters through a spectrum window that approximates the bandwidth of particular receivers. This capability is required, for example, for the characterization of the effects of transmissions from pulsed emitters on wideband receivers having nominal bandwidths up to 20 MHz.

In FY 2001, an existing ITS spectrum analyzer with a 3-MHz maximum bandwidth was augmented with a wideband-IF module that was commercially procured. ITS engineers used this module with a logarithmic amplifier, a digital oscilloscope, and calibration software to provide a new RSMS capability for the characterization of emissions of any transmitter in a 20-MHz bandwidth.

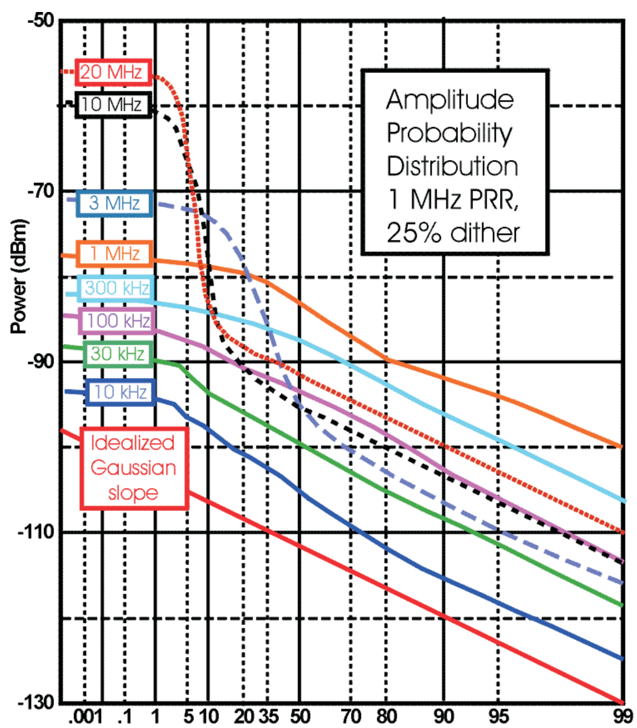


Figure 1. Representative APD graph for ultrawideband (UWB) transmitters.

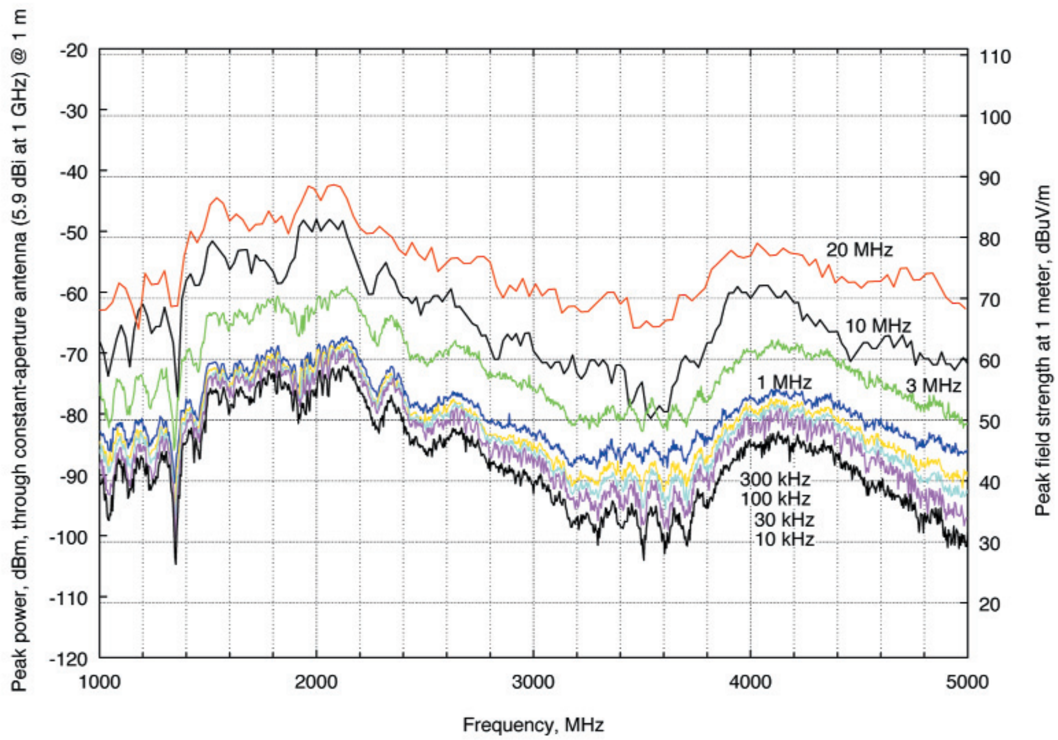


Figure 2. UWB emission spectrum in several bandwidths.

The new 20-MHz measurement capability was utilized to measure the emission spectra of a variety of UWB transmitters (Figure 2). It was also used to assess the effects that emissions from airborne surveillance radars might have on wideband terrestrial receivers.

Finally, the staff of the Spectrum and Propagation Measurements Division began planning for the design of a fourth-generation RSMS. (Funding is expected in FY 2002.) In order to meet expected project goals in FY 2002, advance planning began on hardware, software, and vehicular design for RSMS-4. Goals include retention of existing RSMS capabilities and the addition of advanced new capabilities. Existing capabilities for broadband spectrum surveys, measurements of individual transmitter emissions, and interference assessment and resolution will be augmented through the use of new hardware and software tools. These are expected to include advanced digital signal processing hardware and software; improved RF front-end designs incorporating new, wideband trackable YIG filters; and improved direction-finding capabilities. Much of the new software will be designed and developed in-house, as will the improved RF front-ends and radar direction-finding gear.

Recent Publication

W. Kissick, Ed., "The temporal and spectral characteristics of ultrawideband signals," NTIA Report 01-383, Jan. 2001.
http://www.its.bldrdoc.gov/pub/ntia-rpt/01-383

For more information, contact:
Frank H. Sanders
(303) 497-5727
e-mail fsanders@its.bldrdoc.gov

Ultrawideband Signal Characterization

Outputs

- A description of temporal and spectral characteristics of UWB signals based on analysis, simulation, and measurement.
- Development of UWB measurement and modeling techniques.
- Measurements of UWB interference to three Federal systems.
- Contributions to discussions with NTIA and FCC on proposed UWB rules.

Because the radio spectrum is a limited resource, a wide variety of creative approaches have been proposed for increasing the number of users that can occupy it. Recently, an approach called ultrawideband (UWB) technology has been developed, which employs very-short-duration electrical impulses to provide sensing and communications functions. Although the UWB pulses contain energy that spreads across wide stretches of spectrum already containing many licensed radio systems, UWB proponents claim minimal interference to existing users, due to the very low spectral power density of UWB signals. However, many users of traditional radio systems fear that UWB signals may cause massive interference.

Last year ITS began a major theoretical and experimental program to assist with assessing these claims. The results of this work provided critically needed data and modeling tools for decision-making regarding the deployment and potential ubiquitous use of UWB transmitters. A theoretical analysis of UWB signals was performed to provide insights into how UWB signals affect various types of RF systems. The analytical results are also useful for the validation and interpretation of measurements. An analysis of proposed UWB pulse position modulation schemes yielded the power spectrum and some band-limited signal statistics. From the signal statistics, a method was developed for predicting when a UWB signal appears like Gaussian noise.

UWB signals were measured as full-bandwidth pulse shapes, showing temporal characteristics such as the peak voltage and pulse widths (Figure 1). Since these pulses contained sub-nanosecond features, these measurements were technically challenging and required specialized expertise and facilities. Fast Fourier Transforms (FFTs) were performed on the pulse shapes to yield power spectra and field strength graphs (Figure 2). These graphs provided a reference set for comparison of spectrum measurements made with bandwidth-limited equipment. This comparison showed that the bandwidth-limited measurements (described below) gave emission spectrum results very similar to the full-bandwidth FFT results.

The bandwidth-limited measurements using commercial-off-the-shelf (COTS) equipment like spectrum analyzers are important for several reasons: They provide a more practical measurement approach for many commercial test laboratories; they give a more realistic indication of how UWB signals interact with traditional narrowband radio systems; and they permit observation of the effects

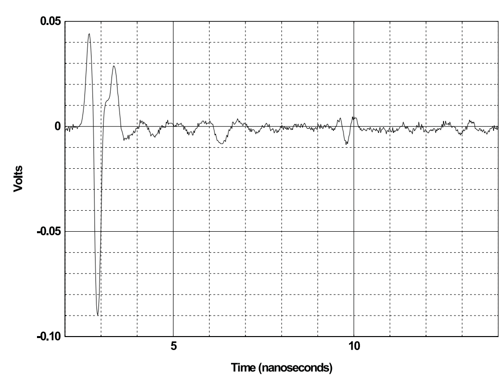


Figure 1. Full bandwidth pulse shape.

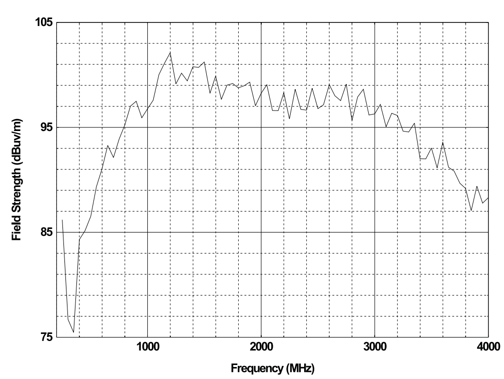


Figure 2. FFT spectrum from full-bandwidth pulse shape.

of various UWB modulation techniques such as dithering and gating. A major accomplishment was understanding how measurement bandwidth and UWB pulse repetition rate (PRR) affect the observed UWB signal characteristics, which typically range from impulsive to noise-like to continuous wave (CW) in appearance.

Amplitude probability distributions (APDs) were identified as a useful way to describe UWB signals as a function of measurement bandwidth (Figure 3). APDs also were used to compute the values equivalent to several detector functions commonly found in measurement equipment (e.g., peak, root mean square (RMS), average voltage, average log). The wide range of values for computed detector results (Figure 4) clearly show the importance of tightly specifying the correct measurement procedures for compliance with future UWB regulations. They also suggest that true RMS values will provide the most useful method of describing UWB signal levels.

Due to a potentially large proliferation of UWB devices, it is important to understand the effects of an aggregation of such devices. A statistical model was developed that can be used to calculate the power received from UWB devices randomly distributed over the surface of the Earth. This model is useful for predicting UWB interference power for terrestrial and airborne receivers.

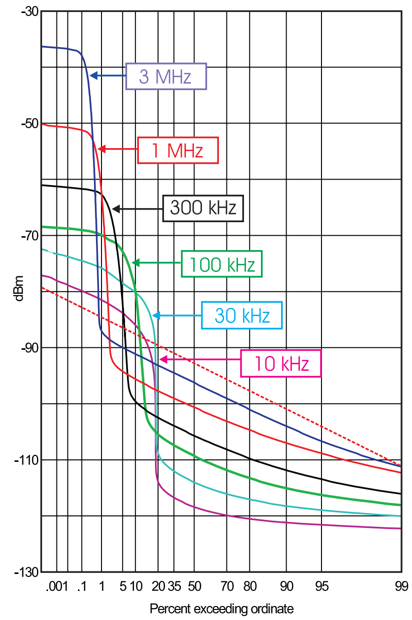


Figure 3. APDs measured in various bandwidths.

The most important aspect of UWB devices involves their effect on existing receivers. ITS investigated this by introducing UWB signals into three different Federal radar receivers, as well as a much more detailed series of measurements on GPS systems. The GPS tests are described on pages 14-15 of this technical progress report.

ITS efforts in FY 2001 have continued in numerous consultations with NTIA engineers and policy makers regarding the rules that NTIA and the Federal Communications Commission (FCC) are developing to regulate the widespread use of non-licensed UWB systems. ITS has written numerous short white papers and tracts concerning practical UWB measurement procedures, a methodology for inferring existing noise levels in critical frequency bands, the use of modern spectrum analyzers with RMS detectors, UWB interference to GPS receivers, and many more items of interest to the daily discussions. Although these papers will generally not become available publically, they have made valuable contributions to the policies that will eventually permit UWB devices to safely operate in an environment shared with large numbers of traditional radio systems.

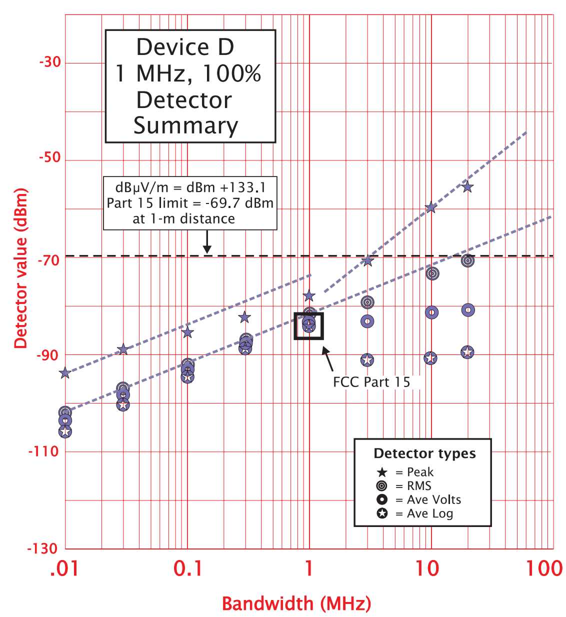


Figure 4. Detector summary, UWB device with 1-MHz average PRR.

Recent Publication

W. Kissick, Ed., "The temporal and spectral characteristics of ultrawideband signals," NTIA Report 01-383, Jan. 2001. http://www.its.bldrdoc.gov/pub/ntia-rpt/01-383

For more information, contact:
Dr. William A. Kissick
(303) 497-7410
e-mail wkissick@its.bldrdoc.gov

Effects of Ultrawideband Signals on GPS Receivers

Outputs

- Procedures for testing interference effects on GPS receivers by ultrawideband signals.
- Measurements of UWB interference to four GPS receivers.
- Two NTIA Reports describing results.

As a part of the major ITS program on ultrawideband (UWB) devices, measurements were conducted to determine interference potential to Global Positioning System (GPS) receivers from UWB devices. UWB effects on four different GPS receivers were measured by combining varying levels of different UWB signals with simulated GPS satellite signals and measuring GPS receiver performance. The results of the first two GPS receivers are described in NTIA Report 01-384 and the results of the second two receivers are described in NTIA Report 01-389. The primary objective of these measurements was to determine the effects of UWB interference on GPS receivers; a necessary set of secondary objectives was to identify metrics that are reflective of receiver performance for the intended application and to establish repeatable measurement methodologies. The results have provided the technical information needed by NTIA to develop policies for use of UWB by the Federal government (see NTIA Special Publication 01-45) and to work with the FCC to develop rules and regulations for UWB emissions.

Although originally developed for military applications, GPS has become a powerful enabling technology that has created whole new industries that are crucially dependent upon GPS signal reception. It is used extensively in aviation for en-route and non-precision-approach landing, and many additional uses are currently being developed. On our highways, GPS assists in vehicle navigation and fleet monitoring. Non-navigation applications include geodesy, surveying, mapping, and charting; geophysical and meteorological applications; and precise time and frequency synchronization used by telecommunications and electrical power distribution systems. Many additional systems, such as Enhanced 911, personal location, and medical tracking devices may soon be commercially available. Therefore, the importance of GPS systems — combined with the relatively low-power GPS signals and complex GPS receiver processing — made testing of UWB interference to GPS systems an important frequency management priority.

Although working with a new technology like UWB creates its own challenges, UWB technology was fairly well understood on the basis of earlier ITS work in characterizing UWB signals (see pp. 12-13). The real challenges of GPS testing come from the very complex nature of the GPS system. The tested GPS receivers are each implemented using massive amounts of internal software which synchronizes to the GPS signals, extracts the data, and calculates the required time, position, altitude, velocity, etc., as well as attempting to recognize and mitigate interference effects. Each receiver used software optimized for a particular mission, which varied widely between the receivers — and which reacted differently to interference. The effects of interference were often highly dependent on, e.g., the initial state of the receiver, and the exact frequency offsets between interference and the Doppler-shifted GPS signals. Because of the large amount of time needed for each receiver to become fully adapted to a given reference state before beginning a test, each test typically required many seconds (even minutes) to perform.

The test setup (shown in the figure) consisted of four primary parts — a GPS signal source, a UWB interference source, a GPS receiver, and a computer controller/data system. The GPS-source segment included a GPS satellite signal source and a noise source. The GPS satellite simulator allowed a variety of UWB signals to be tested against exactly the same satellite constellation (typically four satellites) over exactly the same simulated date and time. The noise source, simulating various sources of natural and man-made noise, was combined with the GPS signal to represent a GPS system operating under worst-case, real-world conditions. GPS receivers were exposed to a broad range of single-source and aggregate UWB signals. Individual UWB signals were produced using UWB pulse generators triggered by programmed arbitrary waveform generators (AWG). Various multi-source UWB interference

ITS engineers from the Spectrum and Propagation Measurements Division performing measurements in the ultrawideband interference testing laboratory (photograph by W.A. Kissick).

scenarios were conducted by combining up to six independent UWB signals to create an aggregate interference source. The four GPS receivers tested were chosen from a range of different technologies and applications. The first device was a basic receiver used for ground mobile guidance systems. The second device was a high precision surveying receiver that utilizes multiple specialized techniques for improving accuracy. The third device was a reconfigurable receiver used for multiple applications and which employs many of the most modern techniques for signal processing. The fourth device was an en-route aviation receiver.

The testing was accomplished using a complex computerized system that precisely controlled and monitored all inputs and outputs, using a precisely repeated series of test algorithms for all combinations of receivers and single and combined UWB interferers. This system operated for six months on a 24/7 basis, while being continually monitored to identify and repair test system malfunctions. These tests included a wide range of UWB signal types interfering with a sample of four GPS receiver types, which (not surprisingly) produced a wide range of effects on GPS receivers. A complete description of results can be found in NTIA Reports 01-384 and 01-389.

Recent Publications

D.S. Anderson et al., "Assessment of compatibility betwen ultrawideband (UWB) systems and global positioning system (GPS) receivers," NTIA Special Publication 01-45, Feb. 2001.

J.R. Hoffman, M.G. Cotton, R.J. Achatz, R.N. Statz, and R.A. Dalke, "Measurements to determine potential interference to GPS receivers from ultrawideband transmission systems," NTIA Report 01-384, Feb. 2001.
http://www.its.bldrdoc.gov/pub/ntia-rpt/01-384/

J.R. Hoffman, M.G. Cotton, R.J. Achatz, and R.N. Statz, "Addendum to NTIA Report 01-384: Measurements to determine potential interference to GPS receivers from ultrawideband transmission systems," NTIA Report 01-389, Sep. 2001.
http://www.its.bldrdoc.gov/pub/ntia-rpt/01-389/

For more information, contact:
J. Randy Hoffman
(303) 497-3582
e-mail rhoffman@its.bldrdoc.gov

ITS staff from the Telecommunications and Information Technology Planning Division describe the Division's work, including Voice over IP (VoIP) technology, to Assistant Secretary for Communications and Information Nancy Victory. After the presentation, Assistant Secretary Victory places a VoIP call to Washington (photographs by E. Gray).

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 broadband wireless systems. The project is funded by NTIA.

Network Interoperability The Institute identifies and provides unbiased perspectives for network interoperability problems of particular significance to U.S. interests and provides candidate approaches useful for resolving the problems. The project is funded by NTIA.

Network Survivability and Restoration The Institute uses traditional methods as well as network modeling and simulation tools to develop practical and effective ways to specify and assess the survivability performance and reliability of both wireline and wireless communications networks. This project is funded by the National Communications System (NCS).

Networking Technology The Institute defines a structured process for telecommunications and information technology planning and assessment studies, uses this process to identify needs for automated tools that aid in producing solutions that satisfy users' requirements, and prepares a handbook for performing the entire planning or assessment study process. This project is funded by NTIA.

Public Safety Telecommunications Interoperability Standards The Institute conducts a technical program aimed at providing effective interoperability and information-sharing among dissimilar telecommunications and information technology systems of the public safety community. The main thrust is the development of interoperability standards. Projects are funded by NTIA, NCS, and a Technology Center of the National Institute of Justice – NIST’s Office of Law Enforcement Standards.

Railroad Telecommunication Planning The Institute performs and analyzes channel occupancy measurements of a railroad’s conventional Land Mobile Radio (LMR) system operation to aid in planning for trunked radio network designs. The Federal Railroad Administration funds this project.

Telecommunication Terminology Standards By developing automated web-page and e-mail procedures, the Institute coordinates and leads the evolution of *Telecom Glossary 2000*, the 8000-entry glossary which was adopted in February 2001 as an American National Standard, T1.523-2001. This project is funded by NCS.

Voice over IP The Institute conducts experiments with Voice over IP (VoIP) protocols to better understand the complex issues surrounding the use of VoIP for public-safety communications. The project is funded by NTIA/OSM.

Broadband Wireless Standards

Outputs

- Preparation of technical standards and documents 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.

Table 1. Growth in Subscriber Penetration for Wireless Services

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

The wireless industry projects an explosive growth in wireless system use within the U.S. as more and more new users begin using wireless services. Figure 1 and Table 1 provide industry data and projections on U.S. deployment of wireless services by subscriber numbers and penetration.

As users expect better quality voice service and more features such as caller ID and call forwarding, the wireless services providers have moved from analog modulation on single channels to digital modulation using a variety of channel access methods. All of these changes are made to improve the quality of the service, add features, and serve more users on the system.

The wireless industry has made projections on how they expect the rollout of technology to progress in the next few years, as shown in Table 2. Besides the number of users increasing, 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).

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

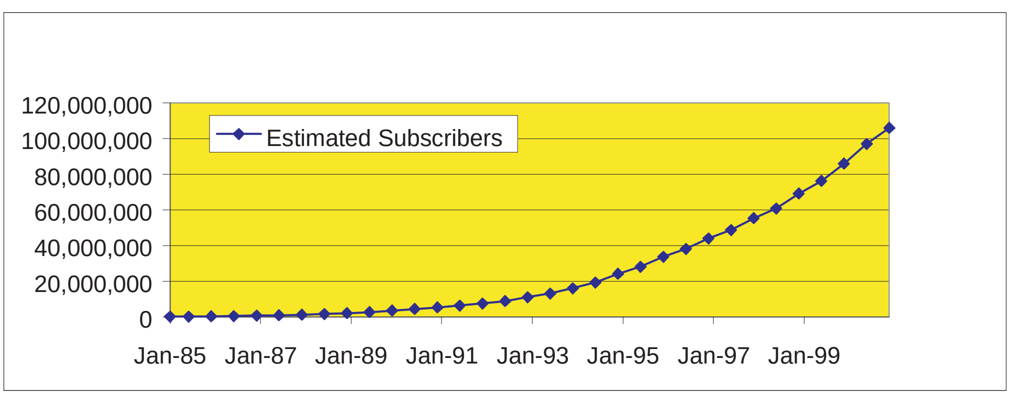


Figure 1. Growth in estimated number of wireless subscribers.

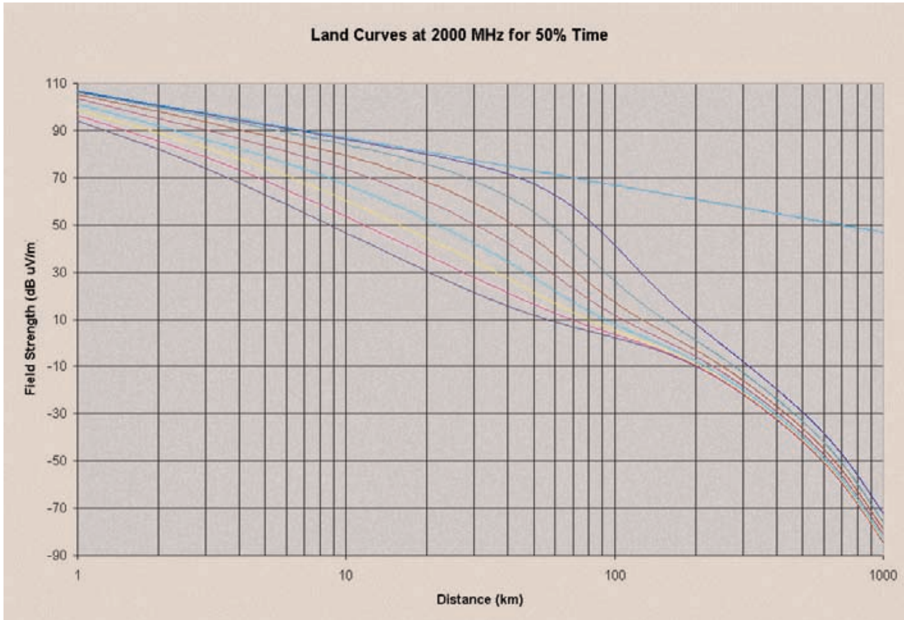


Figure 2. Predicted field strength values versus distance for mobile and broadcast systems over land at 2000 MHz for 50% of the time and 50% of locations.

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.

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 land-use, land-cover information into the Okumura-Hata model, to make it more responsive to the changing environment.

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, which blends features that the services had previously used independently of one another, thereby clarifying and unifying planning and coordination activities across the services. Figure 2 shows an example prediction of field strength for various land mobile base station or broadcast transmitter antenna heights.

For more information, contact:
Paul M. McKenna
(303) 497-3474
e-mail pmckenna@its.bldrdoc.gov

Network Interoperability

Outputs

- Identification and assessment of emerging network interoperability issues.
- Resources supporting telecommunication and information technology system planning efforts.

Network interoperability (NI) has become an overarching challenge of national and international significance. From a technical perspective, interoperability is required to provide a variety of telecommunication capabilities that meet users' needs, including the end-to-end transport of user information involving multiple, heterogeneous network technologies and multimedia applications. The NI challenge is of particular importance in promoting the deployment of interoperable public safety and criminal justice hybrid communication systems, broadband wireless and wireline technologies to rural and other underserved areas, and public and private telecommunication systems that meet national security and emergency preparedness needs. Figure 1 illustrates the concept of network migration, which involves the planned transition from legacy networks to preferred target networks. Three complementary dimensions frame the network migration challenge: interoperability of (1) multi-vendor equipment and services, (2) extant and emerging technologies, and (3) evolving user requirements and practices. A principal theme of the NI project is to promote the practical realization of viable networking choices among these dimensions, e.g., increasing networking procurement options and support of critical voice, video, data, and multimedia applications through alternative networking technologies.

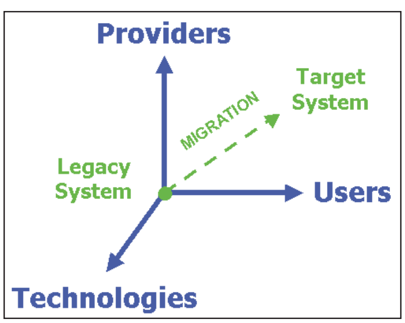


Figure 1. A fundamental long-term theme of the NI project is the practical realization of networking choices in three primary dimensions.

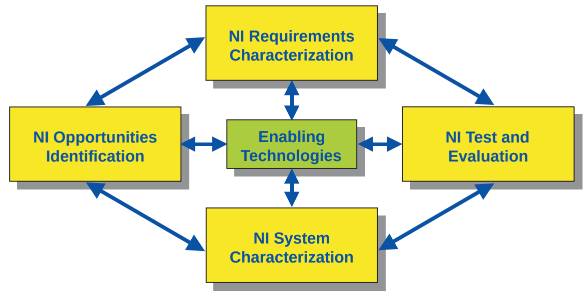


Figure 2. An overall perspective of the baseline network interoperability analysis framework.

During FY 2001, the NI project conducted technical activities in both research and application areas. Research efforts involved four related topics: NI frameworks (approaches), ontologies (problem contexts), enabling technologies (migration paths), and measurement methods (assessment techniques). Figure 2 provides an overall perspective of the initial NI analysis framework. The four major NI framework components (opportunities identification, requirements characterization, system characterization, and test and evaluation) each require more specialized approaches that may be dependent on particular problem domains.

Figure 3 provides a perspective of a general problem context for conducting NI technical studies. The generic NI system architecture includes the end-to-end exchange of user information within the context of constituent applications and NI architectures. Within a particular NI architecture, three primary levels are being explored: service, network element (NE), and traffic. NI issues at these levels include both "horizontal" and "vertical" considerations; for example, the former includes interaction of logical and physical NEs at network interfaces and the latter includes interactions among various protocol stacks that may be statically or dynamically instantiated in networks or user equipment. Traffic considerations lead directly to network resource allocation issues involving the cooperative offering of end-to-end network services among various, increasingly complex, arrangements of public and private providers. Figure 4 provides a conceptual view of NI evaluation as the collective interaction of conformance, compliance, and performance considerations. Ongoing studies are

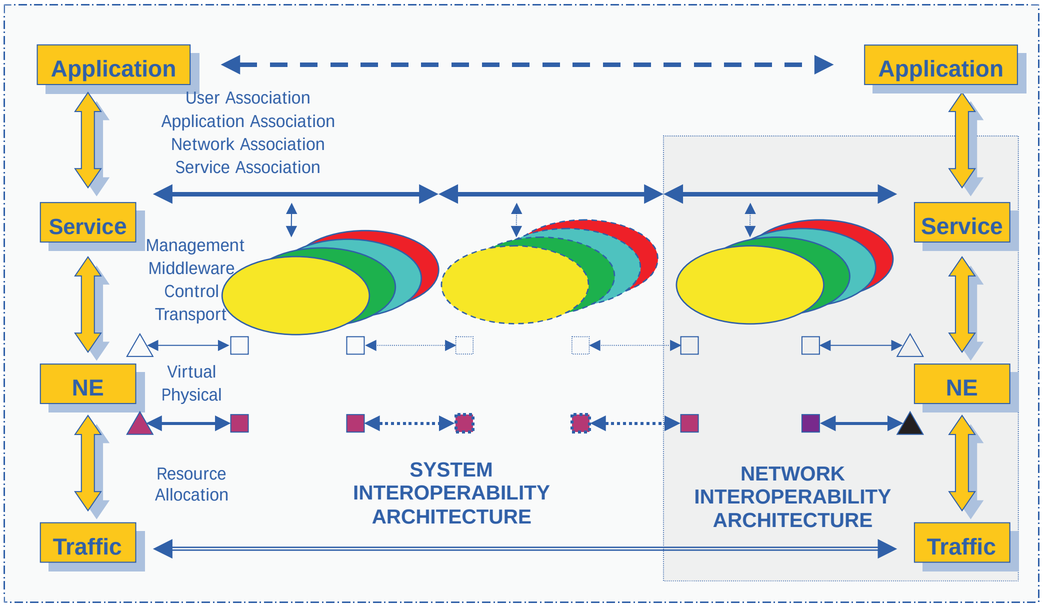


Figure 3. A general problem context for conducting network interoperability technical studies involves both system and network architectures.

exploring these concepts for their usefulness in addressing particular NI technical issues: conformance for assessing the extent to which network interfaces adhere to specified standards, compliance for assessing the extent to which given networking configurations are able to meet specified functional requirements (e.g., application support), and performance for assessing the extent to which the communication functions of access, information transfer, and disengagement are satisfied within operational (or planned) networks on both user-oriented and system-wide bases.

Application efforts focused on providing technical assistance to the Public Safety Telecommunications Interoperability Standards project. Technical standards contributions to ANSI-accredited TIA Committee TR-8 (Mobile and Personal Private Radio Standards) were submitted to assist evaluation of the Session Initiation Protocol (SIP) for its use in enabling communications among APCO Project 25 (P25) public safety wireless users that may roam between geographically dispersed radio frequency subsystems (RFSSs). Based in part on ITS performance measurements of representative SIP-enabled Voice-Over Internet Protocol (VoIP) equipment, SIP was recently recommended by the TR-8 and P25 groups (subject to further study) as one of the primary open standards upon which the RFSS Inter-Subsystem Interface will be defined.

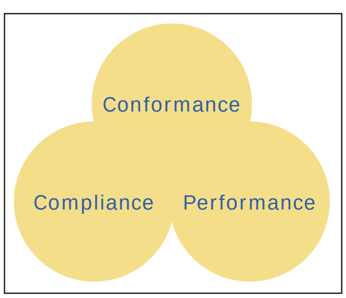


Figure 4. Network interoperability evaluation involves the collective interaction of conformance, compliance, and performance considerations.

During FY 2002 an emphasis will be placed on developing advanced NI evaluation capabilities to address cross-cutting technical issues. Examples include (1) IPv4 to IPv6 Internet protocol migration, (2) use of SIP, Multiprotocol Label Switching (MPLS), and related emerging protocols to provide scalable, multi-network call control and transport capabilities, (3) end-to-end performance allocation and verification involving heterogeneous network types, and (4) impact assessments of emerging middleware networks on end-to-end services and applications. Related studies are planned to address technical issues involving the increasing complexity of NI requirements characterization by employing, for example, Unified Modeling Language (UML) and Component-Based Design (CBD) approaches.

For more information, contact:
Randall S. Bloomfield
(303) 497-5489
e-mail rbloomfield@its.bldrdoc.gov

Network Survivability and Restoration

Outputs

- Technical contributions to ANSI Working Group T1A1.2.
- Technical report to NCS defining traffic-engineering techniques and reports on modeling and simulation to enhance network survivability performance.

There is a growing concern about the potentially devastating effects of network failures. Failures can occur as the result of natural disasters (flooding, hurricanes) or as the result of human action (war, terrorism, hacker attacks) or even by unintentional failures in software or control systems. The need for voice, video, and data messaging systems offering high reliability and high capacity is growing dramatically. Congested networks can break down under heavy traffic loads that are common during emergency situations. There is a need for standard survivability performance measures to characterize current and Next Generation Networks (NGNs). The ANSI-accredited Standards Committee T1 (Telecommunications) Working Group T1A1.2 (Network Survivability Performance) is working to meet these challenges with simple but effective performance metrics for use in the design of survivable networks.

The National Communications System (NCS) tasked ITS to participate in and develop technical contributions to T1A1.2 in order to provide more practical and effective ways of specifying and assessing the survivability performance and reliability of PSTN, wireline IP, and wireless communications networks. NTIA/ITS is helping to motivate, strengthen, and extend the work of T1A1.2. The results will advance national security and emergency preparedness

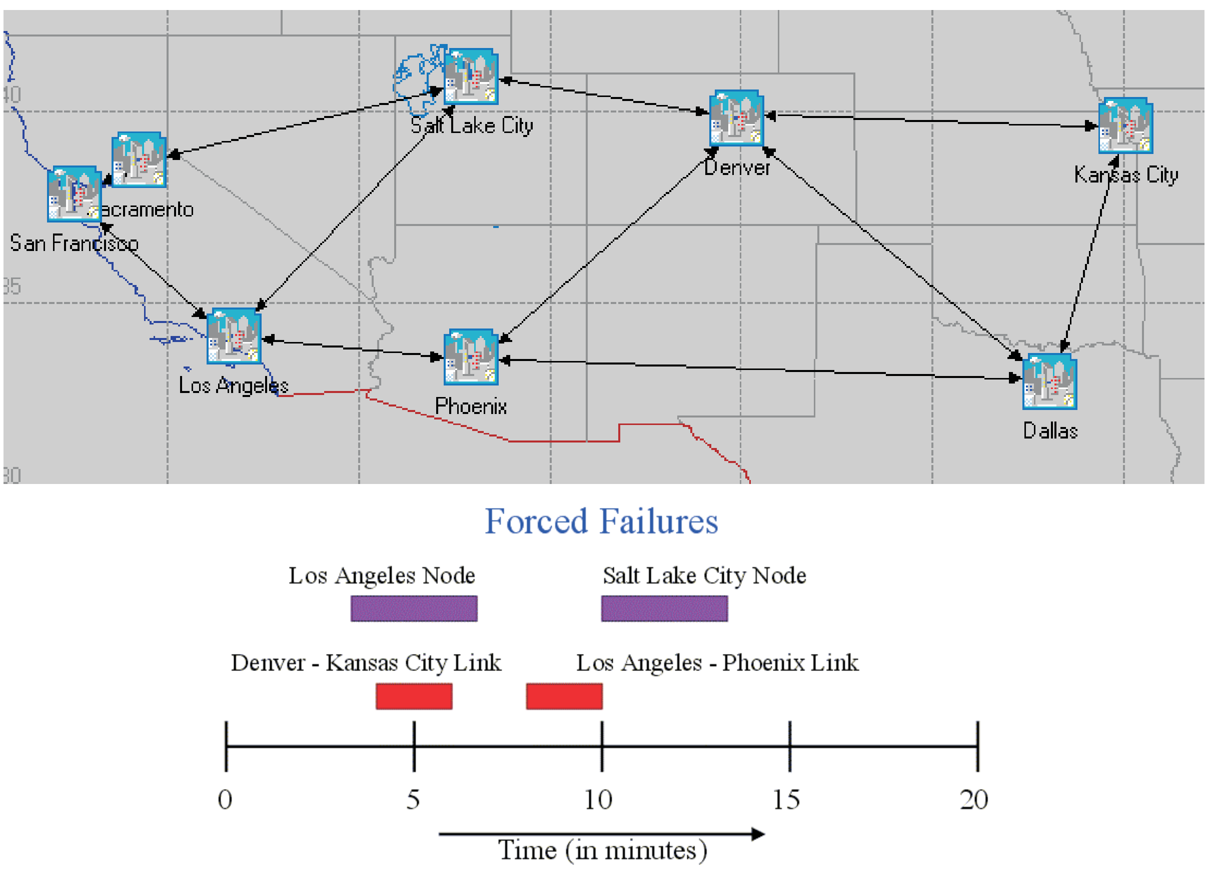


Figure 1. Regional network and failure modes.

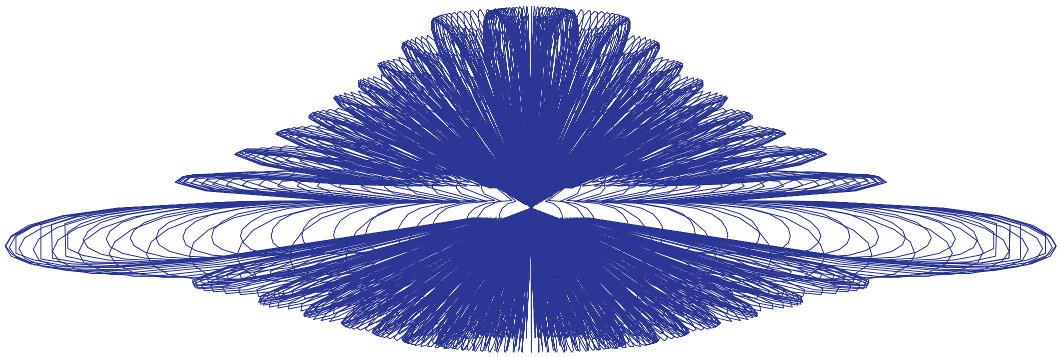


Figure 2. 3D antenna gain pattern for typical cellular/PCS base station.

(NS/EP) goals by making network survivability — and the potential benefits of survivability enhancement techniques — more quantifiable. 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.

Traditional analysis methods are not adequate to predict the effects of large service outages in the current and future network environments. Therefore, ITS is using network modeling and simulation tools to address the needs of T1A1.2, NS/EP, and the nation. While modeling and simulation are powerful tools for the assessment of threats and mitigation techniques, the simulations need to be well grounded in the physical measurement of important parameters. One of the goals of the project is to produce baseline models for reference network architectures that can be used both in standards organizations as well as in future network research by ITS and others. Figure 1 shows one such reference model developed in the Network Survivability and Restoration project and accompanying failure modes used in analysis.

In the support effort to protect the national security telecommunication infrastructure and assess the survivability performance of wireless communication networks, NTIA/ITS has developed model parameters to be used in simulating the cellular telephone network. Base station antenna models have also been developed for input to simulations. The base station antennas used for cellular systems can be of many types that provide a main beam that is narrow in the vertical (elevation) plane and relatively broad in the horizontal (azimuth) plane. The vertical beamwidth is made narrow for the purposes of frequency reuse in nearby cells and to maximize antenna gain for the link budget. The main beam is also tilted downward in the vertical plane to minimize cochannel interference, so that the frequency may be re-used in nearby cells. The antenna is symmetrical in azimuth and therefore provides an omnidirectional pattern in the horizontal (azimuth) plane. A three dimensional gain pattern for a typical base station antenna is shown in Figure 2.

During FY 2001, ITS presented numerous technical and editorial contributions to T1A1.2 which were included in T1.TR.70-2001, “Technical Report on a Reliability/Availability Framework for IP-based Networks and Services.” These contributions covered several topics including historical perspectives on network survivability, traffic engineering and queueing theory as it relates to packet networks, and terms and definitions for the new report. In FY 2002 ITS will continue to address network survivability and the measurement of its performance. The project will address technologies in the Next Generation Network. The work on survivability performance must of necessity be conducted with the help of representatives from network providers as well as NCS. The work in FY 2002 will focus on survivability in the NGN as well as address NS/EP concerns such as the Emergency Telecommunication Service (ETS).

For more information, contact:
Arthur A. Webster
(303) 497-3567
e-mail awebster@its.bldrdoc.gov

Networking Technology

Outputs

- Definition of structured planning process for telecommunication and information technology networks.
- Description and use of automated tools to assist network planners and managers.
- Handbook for telecommunication and information technology network planning available online via the Telecommunications Analysis Service at ITS.

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 determined most likely to provide the greatest benefits. The results, conclusions, and recommendations are contained in a document entitled *A Telecommunication and Information Technology Planning Process*, intended to become an NTIA Report as well as an online service available through the ITS TA Services system. The eight steps of the planning process are:

1. Identify the mission, business objectives, and functions of an organization.
2. Identify and assess all internal and external factors that will influence the organization's telecom and IT requirements.
3. Use the information from the first two steps to define the organization's functional requirements.
4. Identify existing telecom and IT capabilities including systems, networks, and services.
5. Evaluate the existing capabilities and determine if the requirements can be satisfied.
6. Regardless of the outcome of step 5, identify new technologies that can satisfy the organization's telecom and IT requirements either because they can not currently be satisfied or because they may be satisfied more cost effectively by a new solution.
7. Construct and evaluate alternative strategies and solutions.
8. Select and recommend the "best" solution for satisfying the organization's telecom and/or IT requirements.

There are many automated tools available to assist planners in the work they must do to identify and evaluate existing capabilities (steps 4 and 5) and while constructing and evaluating alternative solutions (step 7) to satisfy requirements. These automated tools are of two general types: (1) tools for discovering the topology of existing networks and monitoring utilization, availability, and traffic features of these networks, and (2) tools for modeling a network and predicting its performance. Evaluations of expected network performance may be based on discrete-event simulation, analysis-based modeling, or a combination (hybrid) of these technologies.

Much of the research done in FY 2001 has been to select and use tools considered most likely to enhance ITS' capabilities for network analysis (particularly as a part of planning and assessing networks to satisfy requirements for telecom and IT services). These tools were used to assist a government agency in evaluating a proposed upgrade to the existing network backbone of the agency. The tools used included:

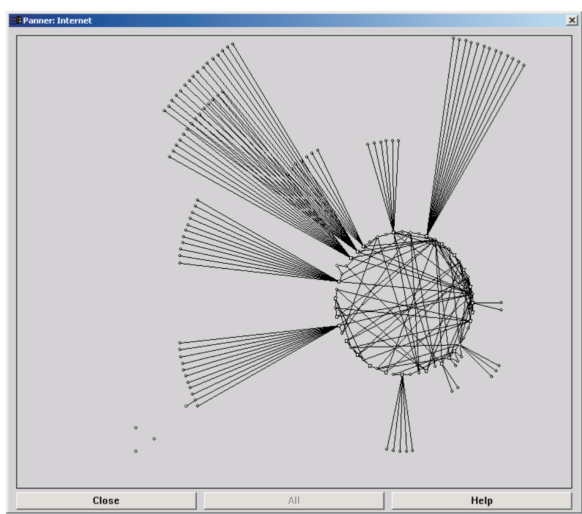


Figure 1. A network topology created by the use of a "discovery" tool.

1. A network “discovery” and management tool which was used to create a topology of the organization’s existing network infrastructure. This tool uses existing network management capabilities inherent in all networks to efficiently create a topology database for future network management or simulation. Figure 1 shows the output of this “discovery” tool.

2. A network “sniffer” tool which allows a user to monitor network traffic and performance over a period of time. The output of this tool can be used to characterize a specific application or to determine the utilization of a network segment. This tool allows the network manager or engineer to develop a background model of network traffic or utilization upon which further studies can be performed.

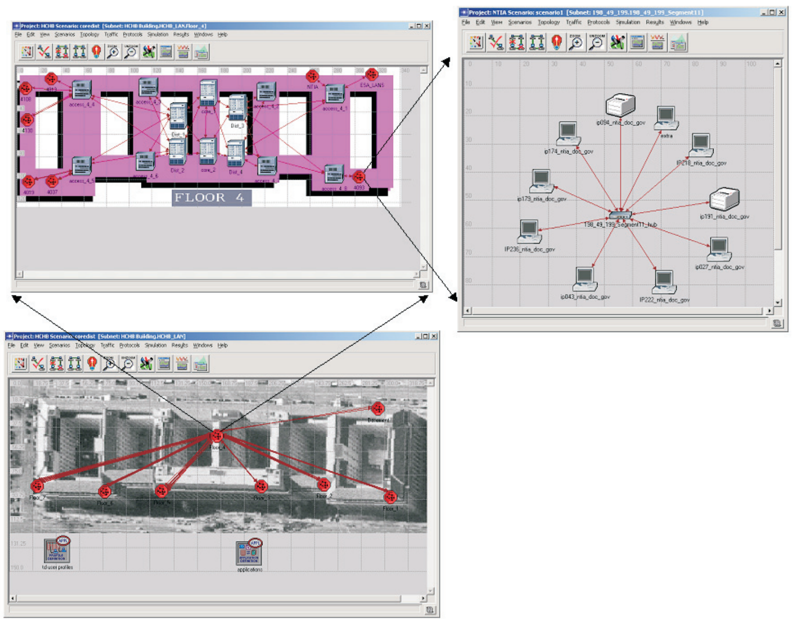


Figure 2. A proposed network topology placed within a simulation tool.

3. A network modeling tool which allows the network engineer to simulate the performance of a network under various scenarios and topology modifications. This allows the engineer to determine if proposed network strategies and solutions will meet existing needs or proposed future needs. Figure 2 shows the placement of the “discovered” topology of Figure 1 into a proposed new topology within the simulation tool.

Once the existing infrastructure and traffic are known, they can be transposed onto a proposed network design in order to determine if the proposed design can meet existing traffic load and utilizations as well as future expected traffic. Figure 3 shows the simulated traffic through a core switch of a proposed network design when existing traffic loads are sent through the switch in the new topology. The network engineer can perform “what if” scenarios on this new topology and simulate the effects of network failures or changes on the performance of other areas of the network. This process gives the network engineer greater confidence in his/her design strategy or analysis assessment.

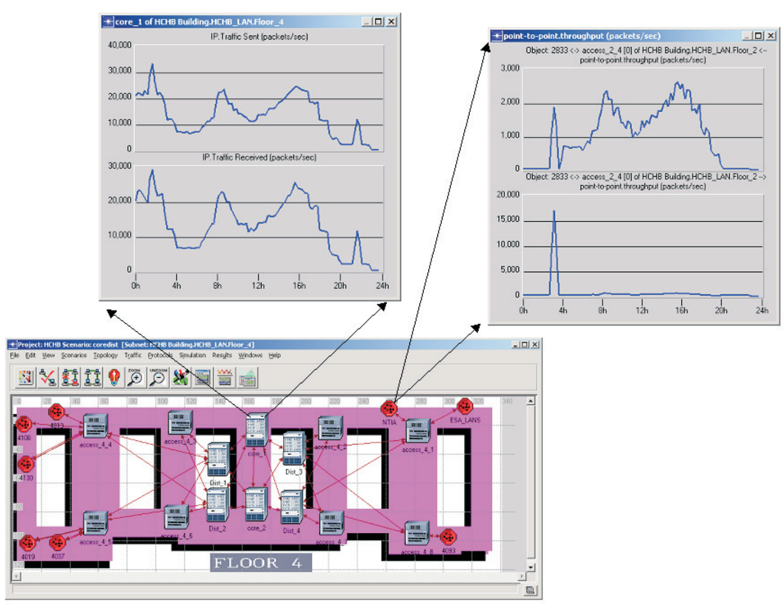


Figure 3. The traffic through a core switch and link determined by network simulation.

For more information, contact:
Robert O. DeBolt
(303) 497-5324
e-mail rdebolt@its.bldrdoc.gov

Public Safety Telecommunications Interoperability Standards

Outputs

- Voice and data encryption standards.
- Specifications for Interoperability Process and Procedures testing of public safety radios.
- Justice XML data dictionary for information technology (IT) applications.

With the explosion of telecommunications and information technologies has come a disturbing trend – a lack of interoperability among systems. This is demonstrated most dramatically in the public safety community, as police and other agencies fail to communicate with each other during multi-jurisdictional events. Even when calamities do not occur, however, daily interoperability problems plague public safety agencies nationwide. ITS is conducting a technical program aimed at providing effective interoperability and information sharing among dissimilar public safety telecommunications and information technology systems. 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: the National Communications System (NCS), the National Institute of Justice (NIJ) (through its Advanced Generation of Interoperability for Law Enforcement (AGILE) Program), and the Public Safety Wireless Network (PSWN) program (jointly sponsored by the Departments of Justice and Treasury). The three parts of the ITS program are summarized below.

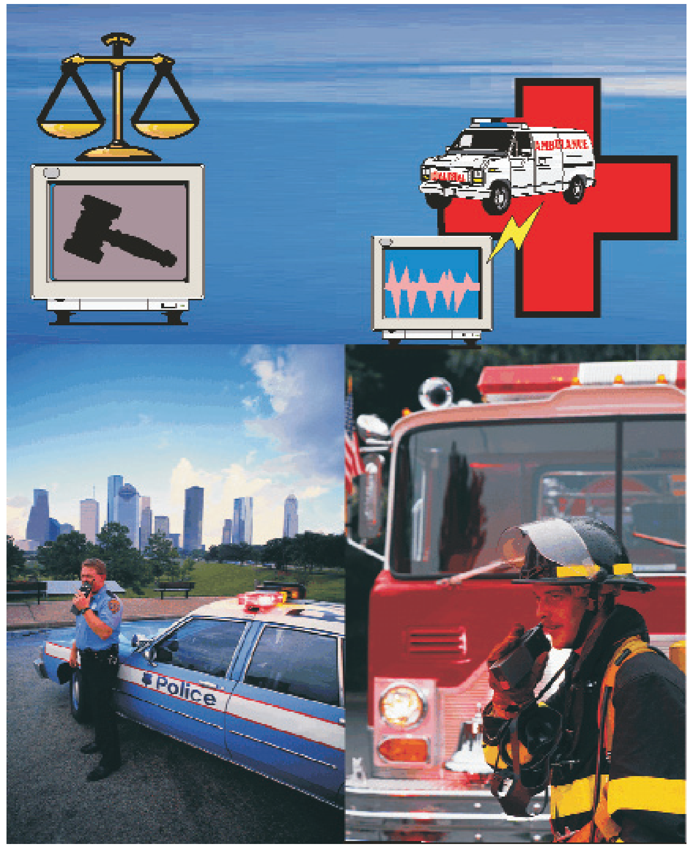
National Communications System Support

The Institute is assisting NCS's Technology and Programs Division (NCS-N2) 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 of Project 25 has been completed. It 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 may be developed. ITS efforts have mainly supported Phase 2. Phase 3 (sometimes referred to as "Project 34") has also begun, and is focused on the development of standards for wideband mobile data applications.

The NCS, Federal law enforcement agencies, and the National Security Agency (NSA) 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 related Telecommunications Industry Association (TIA) TR 8 Encryption Committee to insure that TIA standards meet Government requirements. ITS also participates in other TIA TR 8 Committees and Project 25 working groups as necessary to insure 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 and for the over-the-air-rekeying (OTAR) of Project 25 radios.

Public Safety Wireless Network (PSWN) Support

The objective of the Public Safety Wireless Network program is to provide nationwide wireless communications for law enforcement personnel within Justice and Treasury. Because of their interaction with Federal law enforcement officials, State and local law enforcement agencies are invited to share telecommunication systems with their Federal counterparts. PSWN has selected Project 25 technology for its radio system and requires the standards to be developed in order to implement the systems. ITS has provided some of the technical engineering support to develop standards and specifications for the Project 25 system. In particular, ITS has been involved with the development of the Interoperability Process and Procedures specifications. Last year, ITS developed the test procedures for the data aspects of OTAR for encryption, which will become a Project 25 Standard. ITS is presently developing the test specifications for Data Services, and for Voice Operations in Trunked Systems. ITS has also provided technical support to develop the Inter-RF SubSystem Interface (ISSI) specification. This document defines the message and control flow across the ISSI to allow mobile units to roam from one jurisdiction's radio system to another. Specifically, ITS contributed to the understanding of features and timing for the Session Initiation Protocol, which has been chosen by Project 25 as the protocol to set up individual and group calls between radio networks.



Promoting wireless communications and information technology interoperability and information sharing among practitioners in the public safety community.

NIJ's AGILE Program Support

As the U.S. Department of Justice's science and technology arm for assisting State and local agencies, NIJ has been addressing telecommunications and information technology (IT) interoperability issues for some time. However, the AGILE program has applied a concentrated thrust to facilitate the efforts of the practitioners in the justice and public safety communities to effectively coordinate and share information. This is being accomplished primarily through standardization. The AGILE program is providing specialized technical support to help define users' requirements, and then to address and satisfy those functional needs by identifying and advocating the use of the most applicable standards developed by standards development organizations, standards related organizations, and practitioner groups. Standards are then recommended within the context of a nationwide information sharing framework. ITS leads the AGILE standardization activities under the auspices of NIST's Office of Law Enforcement Standards (OLES), one of NIJ's technology centers.

During FY 2001, considerable progress was made in the AGILE Program's objectives regarding IT applications by teaming with the Department of Justice's Office of Justice Programs (OJP), and the Global Justice Information Network (simply called "Global"). Global, as the Group of Groups, represents all practitioners in the Justice community (e.g., law enforcement, courts, corrections, prosecutors, defense, etc.). ITS worked with Global's Infrastructure/Standards Working Group to help establish processes and procedures for addressing information-sharing standardization issues, and assisted the practitioners in confronting key technical issues. For example, in regard to common data representation across Justice sectors, ITS helped reconcile three opposing implementations of the XML (eXtensible Markup Language) standard developed independently by different practitioner groups. Standardized data conventions were established, and a (working) data dictionary was formed with over 120 commonly defined data elements.

For more information, contact:
Val J. Pietrasiewicz
(303) 497-5132
e-mail valp@its.bldrdoc.gov

Railroad Telecommunication Planning

Outputs

- Demonstration of spectrum usage efficiency by the deployment of new advanced radio technology and infrastructure along the Pacific northwest rail corridor in support of the Federal Railroad Administration and Oregon Dept. of Transportation's high-speed rail pilot program.

Photo courtesy of Union Pacific Railroad.

Digital land mobile radio (LMR) equipment, complying with TIA-102 standards, employs narrowband strategies and radio channel trunking solutions in order to more efficiently utilize radio spectrum resources. The railroads, through an ad-hoc committee known as the Wireless Communication Task Force (WCTF) that also includes representatives from radio manufacturers and State and Federal Governments, have been investigating migration, compatibility, and interoperability issues associated with introducing this new equipment into their existing LMR networks.

Extensive channel occupancy measurements of the railroad VHF band in the Portland, Oregon, area were conducted, and an analysis of channel usage statistics was performed. The measurements were taken at a leased communications site that provided extensive (RF) "visibility" over the Portland area, utilizing the on-site railroad LMR antenna system infrastructure. Figure 1 shows the test equipment setup at the communications site.

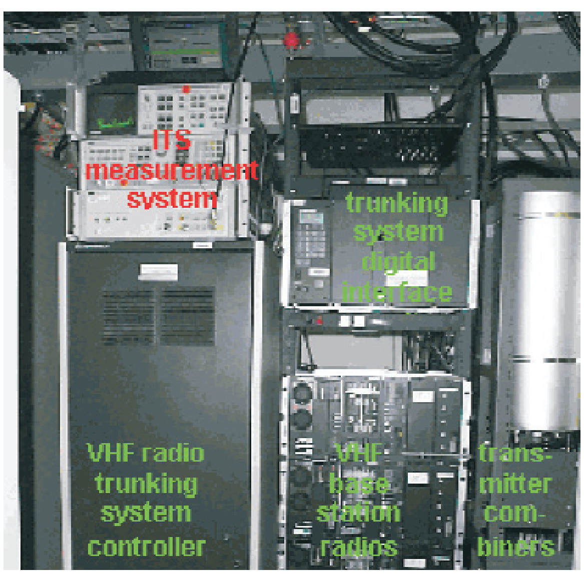


Figure 1. Channel occupancy equipment setup.

A number of characteristics, with regard to conventional usage of the railroad VHF band, were determined:

- ***Busiest hour for each of the 91 railroad channels and for the entire band***

Table 1 summarizes the busiest-hour activity of a few of the 91 channels, i.e., the greatest percentage of channel occupancy (or utilization), type of service such as dispatch or yard, as well as the date and time that the maximum utilization of each channel occurred.

Table 1. Busiest-hour Channel Utilization for Several Railroad VHF Channels

Chan	% Occ'y	Service Type	Busiest Hour	
			Start	Stop
27	89.4	dispatch	05/04/01 12:27:34	05/04/01 13:27:31
38	45.2	yard	05/30/01 10:50:11	05/30/01 11:50:10
52	100	PBX phone patch	05/14/01 22:24:26	05/14/01 23:24:25
66	42.7	dispatch	05/07/01 09:35:45	05/07/01 10:35:44
76	52.2	dispatch	05/07/01 10:27:55	05/07/01 11:27:54
94	89.7	executive mobile-tel	05/04/01 11:03:04	05/04/01 12:03:04

- ***Busiest hour for the aggregate of the 91 channels comprising the railroad VHF band***

Figure 2 shows information similar to that presented in Table 1, except that Figure 2 shows, in graphical form, maximum band utilization, i.e., when the sum of all 91 channel occupancies was maximum. This figure also shows the underlying channel characteristics during that hour.

In the figure, the band occupancy is shown as a horizontal line spanning across all channels at 21.2%, and the individual channel occupancies during this same time frame are shown as vertical bars.

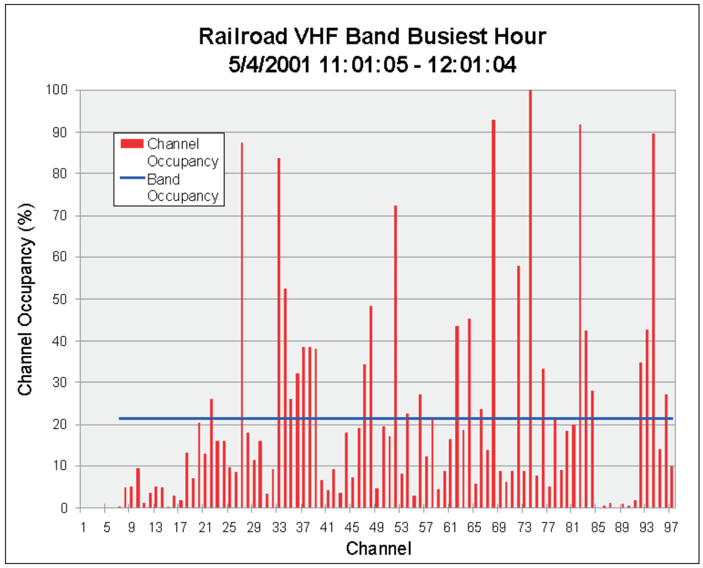


Figure 2. Railroad VHF band busiest-hour, Portland, Oregon, May 2001.

- ***Message length statistics***

Message length refers to the duration of a radio transmission. Message length statistics were determined for each individual channel, as well as the aggregate of all 91 channels. Figure 3 shows the measured message-length distribution for the entire railroad VHF band throughout the month of May 2001.

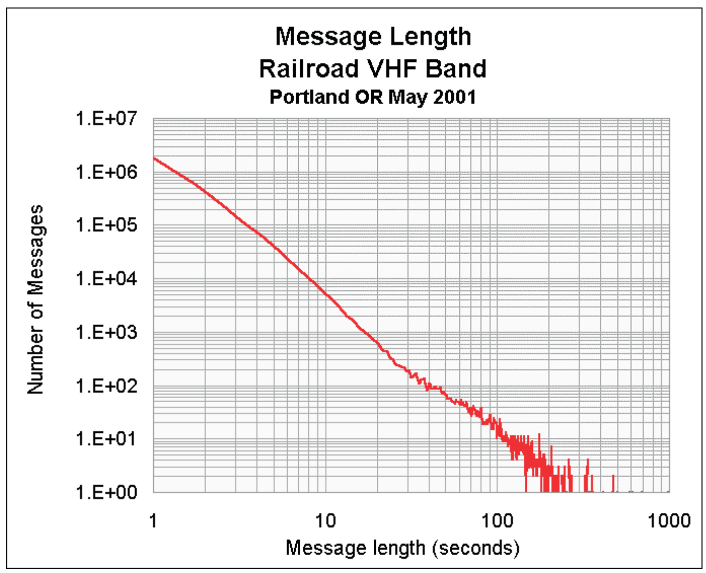


Figure 3. Message length distribution, railroad VHF band, Portland, Oregon, May 2001.

Knowing the characteristics of message lengths and channel utilization in the current conventional, non-trunked LMR system is invaluable when designing a trunked radio system. Knowing the communications traffic loading in the conventional case allows the system designer to determine how many trunked channels will be required to provide a given grade of service. Trunking systems dynamically allocate channel assignments to users on demand, providing the same capacity as non-trunked systems, but with fewer channels. Thus, a gain in spectrum efficiency can be had, and growth in communications traffic load capacity can be supported without the need for additional spectrum.

It is expected that during the second quarter of FY 2002, a number of Portland railroad user groups will be migrated onto the trunking system. Once this has been accomplished, an assessment of how well a lesser number of (trunked) channels can support an equivalent communications traffic load as before can be evaluated.

For more information, contact:
John M. Vanderau
(303) 497-3506
e-mail jv@its.bldrdoc.gov

Telecommunication Terminology Standards

Outputs

- ANS T1.523-2001, *Telecom Glossary 2000*, on the web.
- NTIA Report on the development of the glossary.
- T1A1 Contribution 2001-005 to announce the completion of the on-line development of *Telecom Glossary 2000*.
- T1A1 letter ballots 837 and 938 to initiate and then approve the glossary's development.
- ITU-T Study Group 13 Contribution #B01-04-115, to consider including the glossary as an annex to Recommendation I.112.

Common understanding of technical terminology is essential in a wide range of telecommunications planning functions, including the development of interoperable equipment and the generation of precise product and procurement specifications. ITS, under sponsorship of the National Communications System (NCS), has spearheaded the development of telecommunications terminology standards for many years through its leadership and technical contributions in the development of the FED-STD-1037 series of telecommunication glossaries.

FY 2001 work involved three major activities: (1) coordinating a standards project proposal with Committee T1 (Telecommunications) and its sponsoring organization, the Alliance for Telecommunications Industry Solutions (ATIS); (2) updating the glossary using ITS-developed web, e-mail, and "virtual meetings" techniques in lieu of the traditional face-to-face standards meetings; and (3) serving as convener of the T1 Ad Hoc Group to address new entries that update the glossary's contents on security, Internet/web technology, and photonics, and that incorporate T1-standardized telecommunication terms.

After coordination with ATIS and the Committee T1 Advisory Group, ITS participants formally incorporated T1 letter ballot comments into the glossary. The completed glossary was adopted by the American National Standards Institute (ANSI) as American National Standard T1.523-2001, on February 28, 2001.

The ANS, *Telecom Glossary 2000*, enhances FED-STD-1037C by adding terminology addressing new technology areas and eliminating government-specified material and obsolete terms (e.g., "Mosaic"). The ANS also added more than 900 terms defined in T1-developed standards, requirements, and reports.

The project was accomplished using web-based processes, including on-line HTML revision of definitions and data entry, e-mail communication, and "virtual meetings." During FY 2001, ITS staff members developed and presented to the revision committee several innovative techniques for automated e-mail and web entry of proposals for draft definitions. These electronic revision methods have several advantages:

- **Wider reach:** The revision achieves a broader exposure due to the web-review techniques.
- **Cheaper:** The cost is less because participants are not required to travel to meetings.
- **Faster:** Revision is faster and participation is more efficient because participants can review terms intermittently, between other tasks.
- **Focused participation:** Participants can focus their revision efforts on their own fields of interest and expertise.

ITS staff also published an NTIA Report (01-385) which describes and evaluates the on-line standards development process.

In addition to the 5800 entries already in FED-STD-1037C, more than 2100 new entries were proposed, including 1250 new entries of (1) web/Internet terms (e.g., cookies, portal, web browser); (2) security terms (including INFOSEC definitions from NSTISSI No. 4009); and (3) photonics terms (e.g., photonic computer, photonic switching); as well as 900 entries from T1 standards and reports. During FY 2001, ITS also upgraded the website to bring it into compliance with the World Wide Web Consortium's (W3C) Web Content Accessibility

A still frame from the video clip illustrating "block distortion," from Telecom Glossary 2000.

Guidelines for producing web pages with accessibility to people with disabilities. These additions and enhancements keep the standard abreast of rapidly changing technologies, make it more accessible, and augment its contents to reflect both industry and government needs.

The end product of the work is now an ANS, in the form of a web-based HTML document comprising more than 8,000 entries, 69,000 hyperlinks to terms and definitions, 92 figures, 4 video clips (e.g., "block distortion," a still frame of which is shown in the figure), and 2 audio clips (one each for "hiss" and "ALE clean tones"). The document is equipped with its own search engine, optimized for glossary application, similar to that provided in the web-accessible version of FED-STD-1037C. That earlier version of the standard will continue to be available during the revision process at:
http://www.its. bldrdoc.gov/fs-1037/

The draft of the newer, updated glossary, *Telecom Glossary 2000*, can be viewed on the Web at http://www.its.bldrdoc.gov/projects/telecomglossary2000/

The revised standard is also accessible free of charge at the ATIS/T1 web page and at
http://www.atis.org/tg2k/

Recent Publication

W.J. Ingram and E.M. Gray, "On-line development of an interactive web glossary," NTIA Report 01-385, Apr. 2001.
http://www.its.bldrdoc.gov/pub/ntia-rpt/01-385/

For more information, contact:
Evelyn M. Gray
(303) 497-3307
e-mail egray@its.bldrdoc.gov

Voice over IP

Outputs

- Technical report defining benefits and constraints on VoIP use for public safety applications.
- Measurements of setup times for H.323 protocols over local networks and SIP protocols over local networks and the Internet.

There is currently a great deal of interest in migrating traditional telephony away from circuit-switched networks onto IP-based packet-switched networks. Voice over Internet Protocol (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.

Within the local area network (LAN) environment, where the entire network is typically under the control of a single entity, and unforeseen congestion situations are rare, VoIP offers great benefits. However, within the Internet environment, where link bandwidths and traffic flows exhibit large variations, problems ranging from packet loss to network delays engender significant concerns about quality of service (QoS).

In an effort to better understand the complex issues surrounding VoIP, ITS instituted a project during FY 2001 to examine the various standards associated with the technology. Within this project several VoIP systems were measured at the packet level to determine the setup delays which might be encountered in normal operation. For these experiments, two different candidate protocols were tested, the International Telecommunication Union (ITU) H.323 protocol and the Session Initiation Protocol (SIP) proposed by the Internet Engineering Task Force (IETF).

Both of these protocols are widely used within the VoIP environment to accomplish call setup (signaling and exchange of relevant parameters like vocoder type, sampling rate, etc.) and call teardown. The context of these measurements was public safety applications, where rapid establishment of calls is vital in tactical situations. In particular, these experiments were designed to determine if candidate systems could meet requirements of the proposed Project 25 radio system, where call setup times are restricted to one second or less.

The experimental setup for all candidate systems included the use of a software-based protocol analyzer. This allowed accurate determination of the complexity of the setup protocol and precision in the timing of the delay between the initiation of a call at the near end of the connection, and the production of the ring signal at the distant endpoint. In order to reduce bias in the experimental results from short term network delay conditions, the experiments were repeated a number of times and the results were averaged.

Comparisons of the H.323 delays with those of SIP produced the observation that SIP delays were typically much shorter. In these experiments the mean SIP delay was approximately 385 ms. compared to 3.3 seconds for the H.323 protocol. This result was not unexpected since H.323 is a considerably more complex protocol that demands a greater number of transactions between the endpoints to set up a call, as shown in Figure 1.

A comparison of Figure 1 with the SIP call flow diagram in Figure 2 shows that a SIP call can be initiated with as few as six network transactions, compared to seventeen for H.323. It should be noted that H.323 began as a mechanism to establish audio-visual conferences over LANs, so setup timing was not an important consideration in the original H.323 specification.

Although not investigated in these experiments, the capability to examine VoIP network transactions at the packet level also allows ITS engineers to study the effect of Real Time Protocol (RTP) and Real Time Control Protocol (RTCP) on the behavior of VoIP packets. Network simulation is available, as well as the ability to drive the simulator with trace information captured from existing VoIP installations. Finally, in conjunction with the Wireless Network Research Center (WNRC) at ITS, VoIP packets from wireless networks like IEEE 802.11 can be acquired and analyzed.

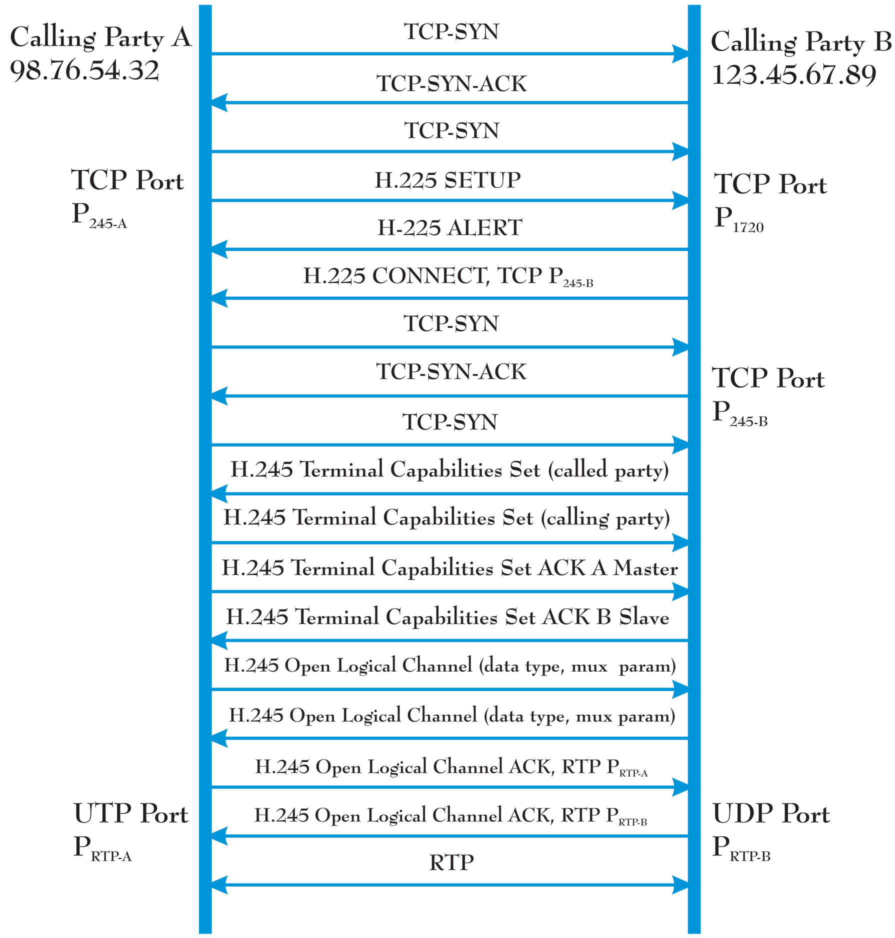


Figure 1. H.323 call setup.

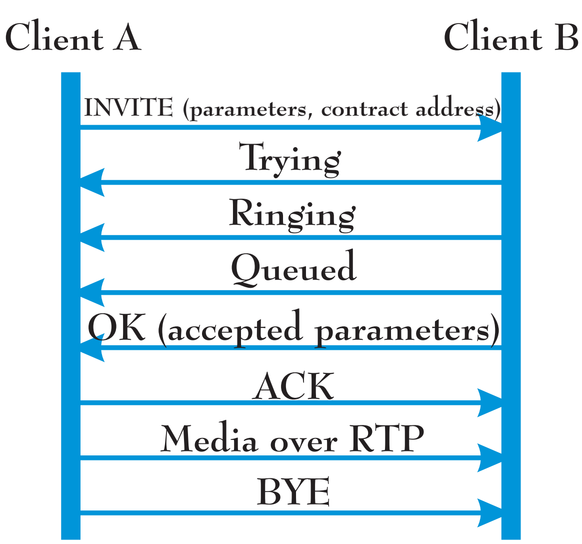


Figure 2. Session Initiation Protocol (SIP) call setup.

For more information, contact:
Dr. Robert B. Stafford
(303) 497-7835
e-mail rstafford@its.bldrdoc.gov

To introduce the new Wireless Networks Research Center (WNRC), Institute staff took some of the WNRC's wireless networks tools on the road. Shown is the Exhibition Booth for the U.S. Department of Commerce, NTIA/ITS, at MILCOM 2001 in Virginia, October 2001 (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 wireline 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 a national security/emergency preparedness (NS/EP) environment.

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 and enhanced.

The **Wireless Networks Research Center** (WNRC) opened in May 2001. ITS is noted for its expertise in wireless communications, in particular the ability to measure, predict, and analyze various wireless communication systems. 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 the Tools and Facilities section, p. 81, 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.

Wireless Network Discovery The Institute's tools are used to analyze wireless networks by collecting network protocol messages and physical RF link measurements to identify wireless network behaviors such as usage patterns, channel resource allocation and network topology. This project is funded by the National Communications System (NCS).

Wireless Priority Access Service The Institute assists the Office of the Manager, National Communications System (OMNCS) in developing a wireless priority access service (PAS) capability, critical to NS/EP communications. This project is funded by NCS.

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 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. The power of the GIS format allows for the use of any spatial database, such as aerial photo imagery. This work was funded by the Dept. of Defense and ARINC.

MODELING

Propagation Model Development In coordination with NTIA's Office of Spectrum Management, the Institute develops enhancements to existing propagation models and works to harmonize related models. The technical products from this effort are presented on behalf of the U.S. at the ITU. The project is funded by NTIA.

Tactical Communication Deception System The Institute analyzed communication systems operated by tactical units, including the existing communication deception system, and developed an improved performance model. This project was funded by the U.S. Army CECOM.

PCS Applications

Outputs

- Interference models for the PCS technologies currently in use as well as proposed third generation (3G) systems.

- Contributions to an industry-developed inter-PCS interference standard for predicting, identifying, and alleviating interference related problems.

Personal Communications Services (PCS) has become the choice for mobile voice and data communication and is a significant resource during emergency recovery of telecommunication services following a natural disaster. PCS networks of varying technologies from many providers cover a majority of this nation's area. Most areas are serviced by multiple, independent, non-interoperable systems which use the same radio frequency bands and infrastructure (base station sites and towers), contributing to one source of interference. Another source of interference occurs when damages occur to the terrestrial telecommunication system and users 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. To aid in their understanding, the interfering environment caused by large numbers of active users and competing technologies must be characterized.

Several standard propagation models are accepted by industry members (for example: Okumura and COST-231/Walfish/Ikegami) but no interference models have been developed or accepted. In 1997, ITS developed a PCS interference model (Ferranto 1997*). The initial development covered system-specific interference models to determine co-channel interference from the immediate and adjacent cells, for two licensed PCS technologies: PCS 1900, which is a narrowband time division multiple access (TDMA) system based on Global System for Mobile (GSM), and code division multiple access (CDMA) based on IS-95. The model takes into account system considerations and management functions (such as power control in IS-95) that are affected by the dynamic nature of the interference.

The generic model involves a hexagonally arranged circular cellular geometry, with each cell having six adjacent cells. A single base station is located in the center of each cell and any number of mobile stations are randomly located within a cell's radius. The interference model consists of four components:

- Base-to-mobile link:

  ❶ victim base station is interfered with by mobile stations in adjacent cells.

  ❷ victim base station is interfered with by mobile stations in the same cell.

- Mobile-to-base link:

  ❸ victim mobile stations are interfered with by base stations in adjacent cells.

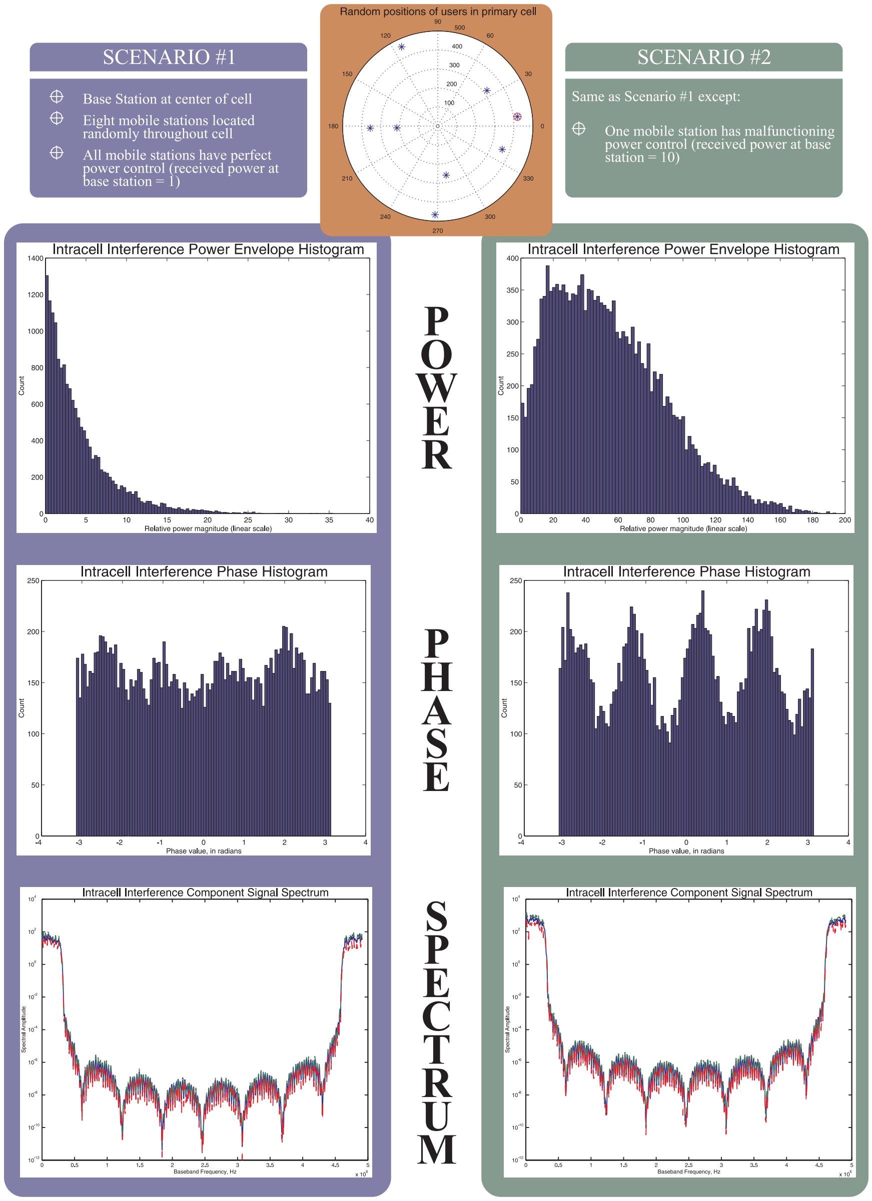
  ❹ victim mobile stations are interfered with by the base station in the same cell (for IS-95 systems only).

The output of the model is an aggregate interference waveform, examples of which can be seen in the figure on the next page for two different scenarios. This waveform can be input to a hardware simulator or a software modeling program to evaluate system designs or can be used in an actual hardware implementation. It also can be used to characterize one-on-one, one-on-many, and many-on-one interference. As a result, potential solutions can be proposed; these solutions can be used by field personnel to solve existing problems or to anticipate and avoid potential problems.

Since the development of the model began, 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

*J.G. Ferranto, "Interference simulation for personal communications services testing, evaluation, and modeling," NTIA Report 97-338, Jul. 1997.

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. ITS has responded to these changes by upgrading the interference model to the ANSI/TIA/EIA-95B standard adopted in 1999. This is a first step in upgrading the model to the 3G technologies. These upgraded models are being developed such that the output data from the new models will be compatible with the output data from the original models; this will allow users to characterize possible problems between the different technologies as the 3G systems are implemented as well as characterizing interference problems with the existing PCS networks. Some of this work is being performed in the new Wireless Networks Research Center (see pg. 81).



Sample output from the ITS interference model for two different scenarios.

In addition to its model development, ITS continues to contribute to inter-PCS interference understanding through participation in the development of a proposed American National Standard “Third Generation Systems and Licensed Band PCS Interference” as a member of the Telecommunication Industry Association (TIA) committee TR46.2 (Mobile & Personal Communications 1800 – Network Interfaces).

For more information, contact:
Timothy J. Riley
(303) 497-5735
e-mail triley@its.bldrdoc.gov

Wireless Network Discovery

Outputs

- Real-time assessment of wireless infrastructure for emergency communications.
- Wireless link measurements.

Wireless communications networks are evolving away from a simple one-to-one correlation between frequency band and communications channel. A wireless network user's communications channel consists of an aggregate of physical and logical sub-channels. Each sub-channel controls some aspect of a wireless network access session for a user. For example, a typical wireless cellular call must complete a complex series of negotiations between the handset and a base station before allowing a user access to the network. Control channels, once established between a base station and mobile user, facilitate call setup, advanced service requests, air interface resources management, and real-time wireless traffic measurements amongst a myriad of other functions.

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, i.e., simple RF power measurements alone are inadequate.

Network management protocols insure that RF spectrum is used effectively and efficiently in real time. The low level (data link and network layer) protocol messages that are exchanged between handsets and network contain a wealth of information about the network, but this information is not often readily available. ITS has developed a nascent capability to examine the interaction between link layer messages and radio resources. This capability provides crucial information for Federal emergency communications planning activities in addition to advancing publicly available network characteristics data.

ITS' tools can analyze wireless networks by collecting network protocol messages and physical RF link measurements to identify wireless network behaviors such as usage patterns, channel resource allocation and network topology. This multifaceted viewpoint is necessary since many emerging 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 has to be decoded to gain access to the Walsh code domain which is required to measure traffic channel activity. A similar situation 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 require examination of the integral connection between network protocols and radio resources.

ITS has the capability to peer into wireless networks by using unique tools and techniques that unify the complex relationship between the software and hardware infrastructures of wireless networks. These tools, housed in the new Wireless Networks Research Center (see pg. 81), can be used to identify the behavior of wireless infrastructure topologies on a real-time basis. Figure 1 shows a recent study of IS-95 base station activity in the Boulder County area. The different colors indicate the predominant base station selected by the handset during that portion of the drive test. The base station is identified by information derived from the paging channel. Figure 2 indicates the dwell time at each base station during the drive test. ITS has the capability to decode and process a broad range of parameters that are available in low level messaging for all U.S. cellular and PCS technologies.

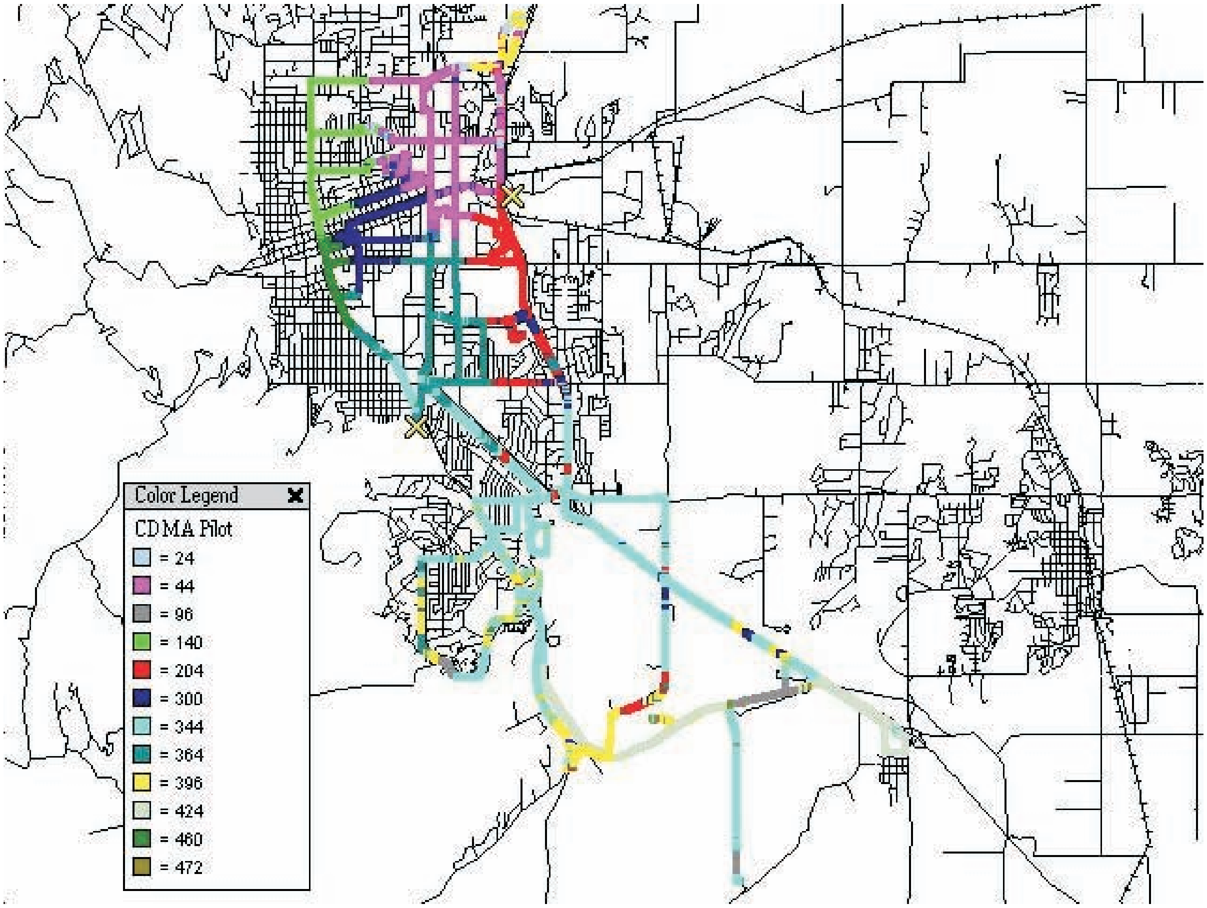


Figure 1. Reception map for Boulder County IS-95 base stations.

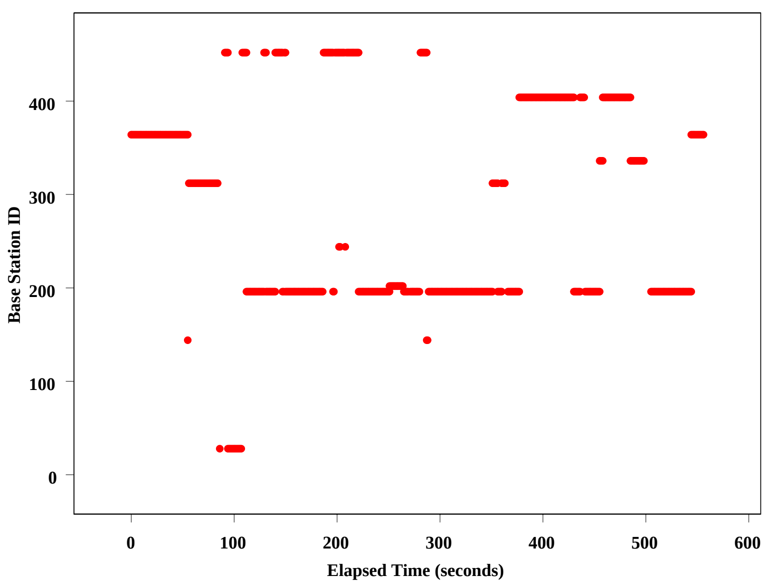


Figure 2. Variation of IS-95 base station versus time during mobile measurement.

For more information, contact:
Christopher Behm
(303) 497-3640
e-mail cbehm@its.bldrdoc.gov

Wireless Priority Access Service

Outputs

- TIA TR45 standard requirements document.
- Technical contributions to national standards organizations.

Government subscribers have become dependent on commercial wireless communications for the performance of their mission, in particular for national security and emergency preparedness (NS/EP) communications. NS/EP responders frequently require wireless connectivity in order to provide communications in a mobile environment when responding to emergencies such as earthquakes, hurricanes, and floods. Commercial wireless service provides a cost-effective capability for NS/EP communications that leverages the use of the public switched telephone network (PSTN) rather than a cost-prohibitive private network. In addition to minimizing costs and deployment time, this arrangement provides broad accessibility.

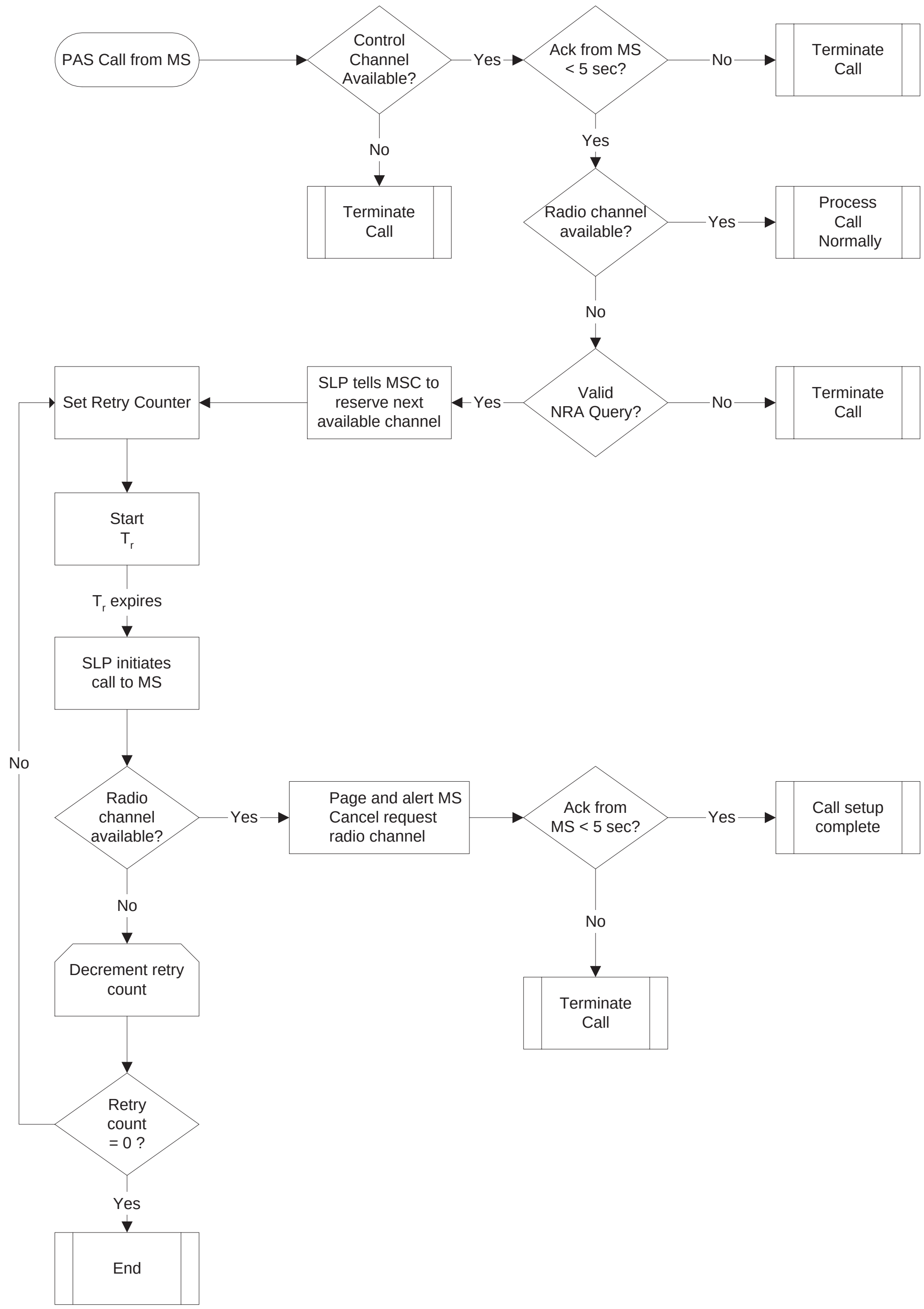
However, following a disaster, severe network congestion in any surviving telecommunication systems can cause high call blocking in both wireless and wireline communications. Thus a priority access service (PAS) is necessary to enable critical disaster relief officials to provide services when they are most needed. A wireline PAS currently exists, the Government Emergency Telecommunications Service (GETS) program, but a wireless capability is still lacking.

ITS is assisting the Office of the Manager, National Communications System (OMNCS) in the development of a wireless PAS capability. The PAS program was developed by the Federal Communications Commission (FCC) and is managed by OMNCS. The FCC rules do not require PAS to be implemented, they merely permit service providers to offer PAS to public safety personnel at the Federal, State and local levels.

The wireless PAS capability leverages the use of existing commercial wireless networks to provide NS/EP users priority access to the next available voice channel in a wireless path in the event that network congestion is blocking call attempts. PAS is activated on a per call basis and is applicable to mobile-to-wireline, wireline-to-mobile and mobile-to-mobile links. When an NS/EP user places a PAS call and the service is activated, the mobile set (MS) requests a voice channel via the control channel messaging. In non-congested environments a voice channel is allocated to the mobile set and the call is connected. In congested environments a voice channel may not be available, so the network will not be able to grant one. In this situation PAS is invoked: the NS/EP caller is placed in a queue and will be given the next available voice channel. PAS does not preempt calls in progress and is to be used only in emergency situations where network congestion is blocking call attempts.

PAS can be implemented over cellular, PCS, specialized mobile radio (SMR) and other commercial wireless technologies as ascertained by the FCC. Per the FCC Second Report and Order, the OMNCS is tasked with managing the PAS program. As PAS evolves, several implementations may be proliferated. One solution that is currently being pursued employs the Wireless Intelligent Network (WIN). This approach is being standardized via the Telecommunications Industry Association (TIA) and the 3rd Generation Partnership Project 2 (3GPP2) standards bodies. WIN builds on existing wireless architectures, which enables a graceful evolution to an intelligent network without making current wireless infrastructures obsolete. Examples of WIN services include radio controlled services, incoming call screening, prepaid charging, and global roaming.

As part of the TIA standards development process, a standards requirements document (SRD) is being developed, which contains a description of PAS with possible technical scenarios. The flow chart in the figure on the next page shows one of the proposed radio access queuing solutions.



PAS radio access queuing flow chart.

For more information, contact:
Christopher Redding
(303) 497-3104
e-mail credding@its.bldrdoc.gov

Telecommunications Analysis Services

Outputs

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

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

Currently available are: on-line terrain data with some 1-arc-second (30 m) and 3-arc-seconds (90 m) resolution for much of the world and GLOBE (Global One-km Base Elevation) data for the entire world; the US 1990 census data with the 1997 population updates; Federal Communications Commission (FCC) databases; and geographic information systems (GIS) databases such as the land use/land cover (LULC) database. For more information on available programs see the Tools and Facilities section (p. 79-81) or call the contact listed below.

The TA Services computer was recently upgraded and is now ten times faster than before, with about 210 gigabytes of storage capacity (three times the previous capacity). We have also obtained 1-arc-second (30 m) terrain data for CONUS with some data at 10 m resolution, which will become available later in FY 2002.

TA Services is currently assisting broadcast television providers with their transition to digital television (DTV) by providing a model for use in

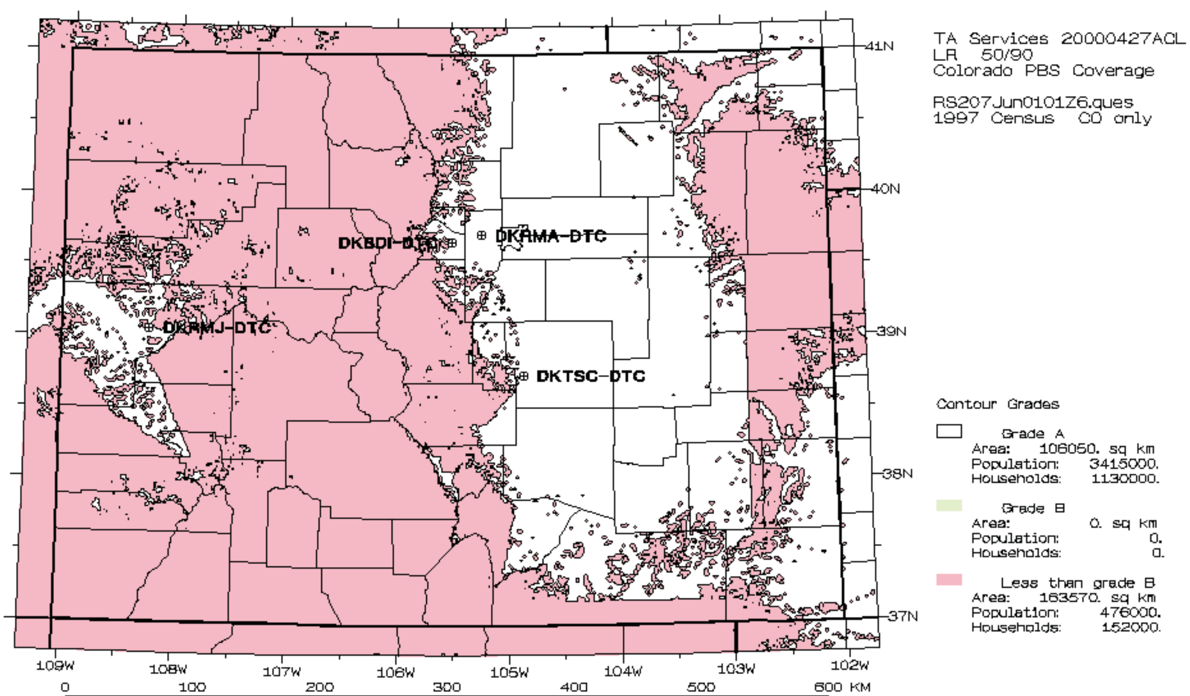


Figure 1. Interference analysis for proposed PBS digital coverage in Colorado.

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 households within those areas. Figure 1 shows the result of a study done showing the proposed PBS digital coverage for Colorado. The model can also determine the contribution to interference from other stations to a selected station or 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 these 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 a table which shows the distance and bearing from the selected station to each potential interferer as well as a breakdown of the amount of interference each station generates. This model can be accessed via a network browser.

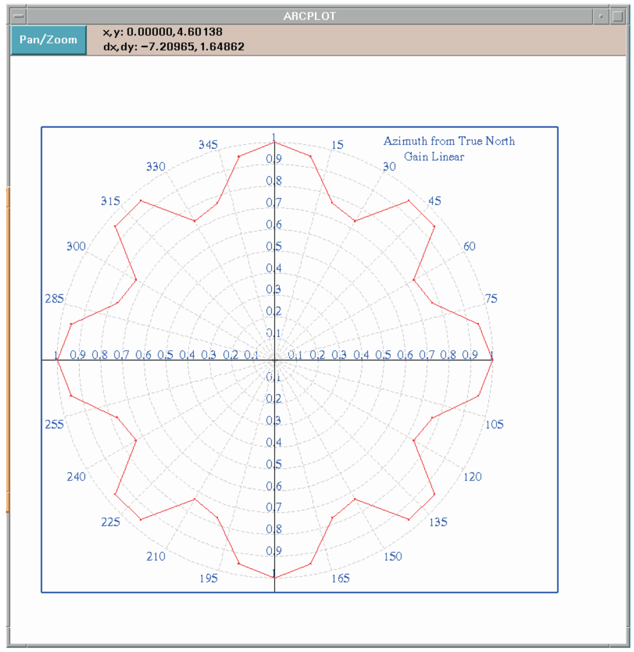


Figure 2. Antenna pattern from the user catalog in the TA Services PCS/LMDS model.

TA Services continues to develop models in the GIS environment for personal communications services (PCS) and local multipoint distribution systems (LMDS). A GIS efficiently captures, stores, updates, manipulates, analyzes, and displays all forms of geographically referenced information. The use of GIS has grown substantially over the past several years. As a result, databases necessary for telecommunication system analysis are becoming available in forms easily imported into the GIS environment. These databases, including terrain, roads, communications infrastructure, building locations and footprints, land type and use, and many others, can be maintained in commonly used and available relational database management systems (RDBMS) that can be connected to the GIS or placed into the GIS RDBMS. This greatly reduces the amount of database development necessary in PCS/LMDS modeling.

As the frequency increases in a particular application, the level of detail required to describe the path also increases. At PCS and LMDS frequencies, we need to know the location of trees and buildings, the kind of vegetation a signal is penetrating, and the shape and materials used in buildings. Software available at ITS allows us to import digital stereo photographs or other remote sensing data taken from aircraft at relatively low altitudes or spacecraft and convert these images to three dimensional models of the region. This highly accurate surface is then imported into the GIS PCS/LMDS model.

The PCS/LMDS model under development at ITS lets a user select a region of interest with a database generated or imported into the model. These environment and analysis results can be displayed in two or three dimensions. A user can create a database of transmitters and antenna patterns from which to create analysis scenarios. The GIS software reads the location of the transmitter from the map and stores it in the transmitter definition table. Antenna patterns can be imported, entered in table form, or drawn on the screen by a user as shown in Figure 2.

Analysis scenarios consist of a set of transmitters, antennas, and models chosen to produce propagation results for a region of interest. Models include a line of sight (LOS) model, a diffraction model, and a ray tracing model under development by two prominent U.S. universities.

For more information, contact:
Gregory R. Hand
(303) 497-3375
e-mail ghand@its.bldrdoc.gov

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.
- Performance predictions in stand-alone or trunked environments.

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 in Denver made from an imported digital elevation model and image at 1 meter resolution. There are four transmitters defined for this particular analysis.

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 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. This kind of data is now commonly available on the web from such sources as the Federal Communications

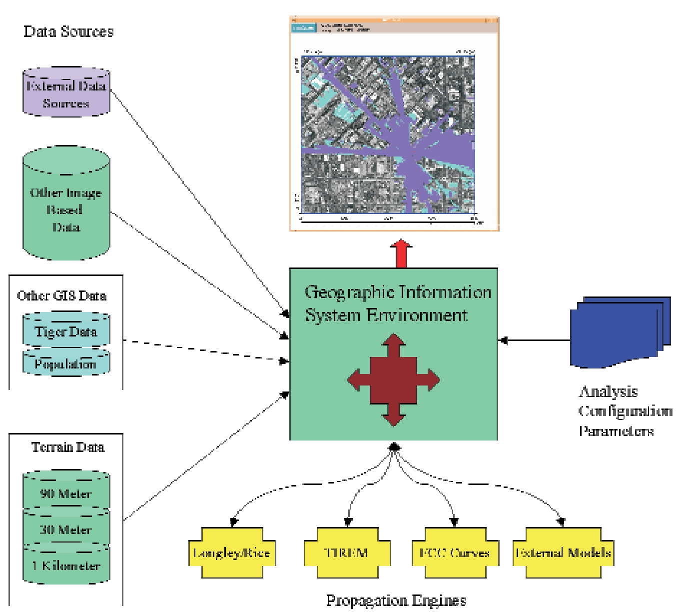


Figure 1. Overview of the CSPT model.

Commission (FCC) and antenna manufacturers. From this catalog of equipment, the user creates scenarios of transmitters and antennas. Each transmitter within the scenarios can be made active or inactive for any particular analysis calculation.

After creating the transmitter database, receivers, and antennas, the user selects a set of these for a particular study, and defines the type of analysis to be performed. The analysis can be a propagation prediction of one of the following types:

1. Create a line of sight (LOS) coverage only.
2. Calculate signal strength within the LOS region.
3. Calculate signal strength based upon terrain diffraction.
4. Calculate signal strength along a single path.

Propagation predictions from multiple transmitters can be overlayed to determine locations of redundant coverage or areas of interference. The output from a propagation prediction analysis can be displayed in any one of the following forms: field intensity (dBuv/m); available power (dBm); basic transmission loss (dB), or signal/ noise power ratio (dB). Signal strength calculations are performed by one of several prediction models according to the user's choice. The models included are:

- Longley/Rice – for analysis options based upon terrain diffraction.
- Tirem – for analysis options based upon terrain diffraction.
- Hata – for urban or suburban environments.
- Cost231 – for urban/suburban environments.
- FCC Curves – for areas larger than 5 km.

Analysis results are draped on top of the analysis area image. These results can be shown in two or three dimensions. Figure 1 shows an area of transmitter coverage for downtown Denver, in 2D. Figure 2 shows the same area of Denver in 3D. Figure 3 shows the transmitter coverage from Figure 1 draped onto the image of Figure 2. The user can zoom into any region of the analysis area and look at individual cell values of signal strength or interference.

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 currently being written. We suggest that users have an account with ITS on our TA Services computer so that we may provide phone support.

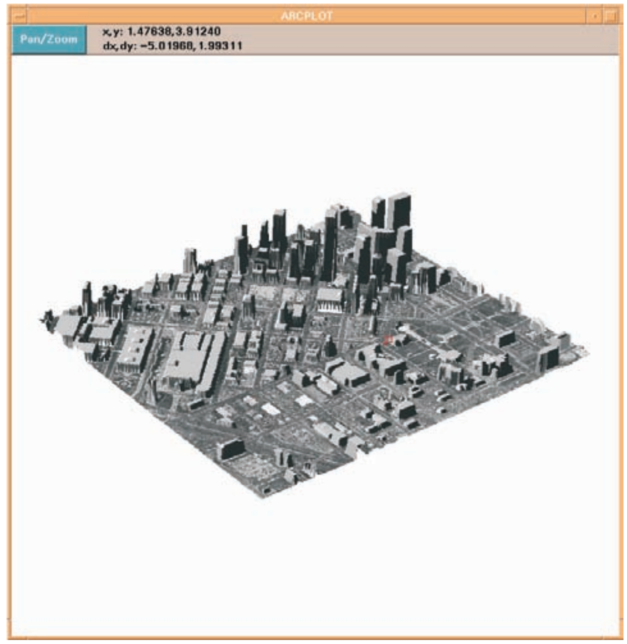


Figure 2. CSPT analysis showing an area of Denver in 3D.

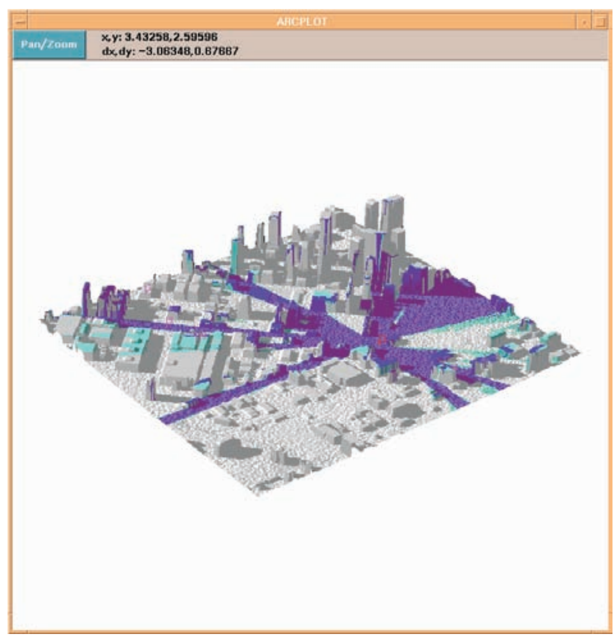


Figure 3. Same area of coverage shown in Figure 1, draped onto the image from Figure 2.

For more information, contact:
Robert O. DeBolt
(303) 497-5324
e-mail rdebolt@its.bldrdoc.gov

Propagation Model Development

Outputs

- Comparison of algorithms used in ITM and TIREM models.
- Comparison of ITM and TIREM models to various measurement datasets.
- Technical contributions to ITU Study Group 3.

ITS' work on propagation model development in FY 2001 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 is described below.

ITM & TIREM Intercomparison

The Irregular Terrain Model (ITM) developed by ITS and the Terrain Integrated Rough Earth Model (TIREM) developed by OSM/IITRI were very similar thirty years ago. Both models are based on the National Bureau of Standards (NBS) Technical Note 101.* The ITM model has remained virtually unchanged since the early/mid eighties, but the TIREM model has undergone many significant changes during the same time period.

In FY 2001 ITS began a project to describe and compare the algorithms used in each of these models. 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. Effective antenna heights have a very significant effect on the results of calculations for propagation loss. When the analysis is complete, the final report will contain a summary of the results of the comparison of the algorithms used in ITM and TIREM. This analysis is expected to provide a better understanding of these algorithms, as well as 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 2001, 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.

Certain difficulties arose when the results of two previous prediction-and-measurement comparison studies were examined. The two studies considered measurement data from sources (i.e., datasets) that had substantial commonality and both studies found comparable mean and variance statistics for the models' prediction errors, as these applied to the measurement datasets in question. However, careful 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

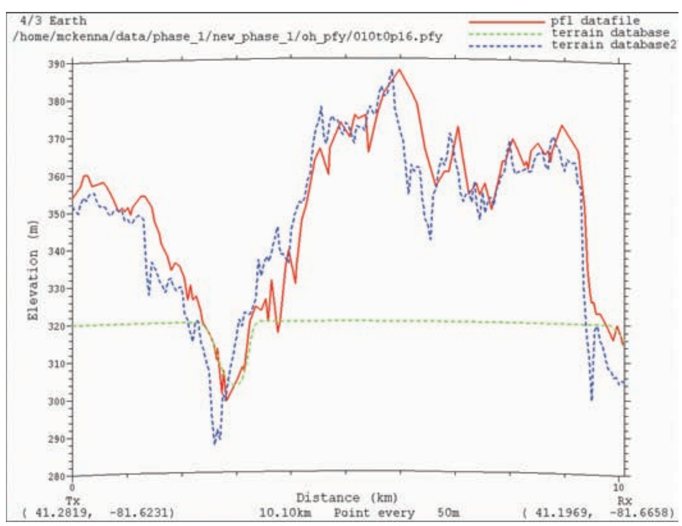


Figure 1. Comparison of profiles for a 10.1-km path in northeast Ohio.

*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).

the predictions, and, hence, the prediction errors, were subject to significant correlation. Therefore, work on this project in FY 2001 was devoted to the resolution of these correlation difficulties.

The first difficulty, differing model predictions on ostensibly identical paths, is related to previously unrecognized discrepancies between the terrain elevation data in two U.S. terrain databases, Database A (shown in green in the figures) and Database B (shown in blue in the figures). Using manually extracted profiles taken from topographic maps (shown in red in the figures), for some of the datasets in question, it is possible to choose one terrain database over the other. Figure 1 shows a plot of the terrain profile for an area in northeast Ohio and Figure 2 shows a similar plot for an area in Virginia. The differences between the two digital terrain databases and the manually extracted profile can be clearly seen in these figures. Figure 3 shows a plot of the terrain profile for a mountainous area of Colorado. For the Colorado data, both datasets agree more closely with each other and with the manual data; however, in view of the Ohio and Virginia data it seems prudent to rely exclusively on Database B.

The second difficulty encountered in this study was the computation of statistics in the presence of correlated data. Stated succinctly, when one infers mean and variance statistics employing correlated data, faulty inferences can occur because these data are neither independent nor identically distributed. ITS has proposed a mechanism for the data correlation and tested it on several measurement datasets. Results show that there is substantial correlation in the data and that the statistics are affected by this correlation. In datasets where multiple measurements were attempted on any given path, the correlation among these measurements gives rise to a concentrated variance that greatly exceeds the variance that would have been estimated for any single measurement series, using standard univariate techniques. There are interesting differences in the contributions of each model's prediction error to these concentrated variances, and this result is expected to lead to useful guidance in the harmonization effort going forward.

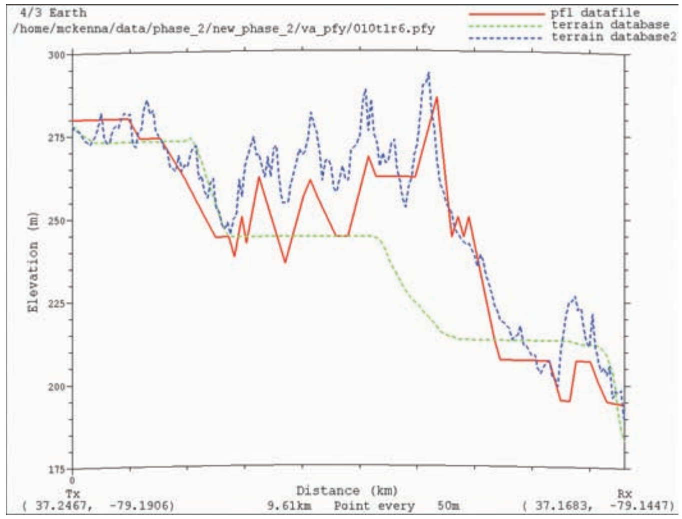


Figure 2. Comparison of profiles for a 9.61-km path in Virginia.

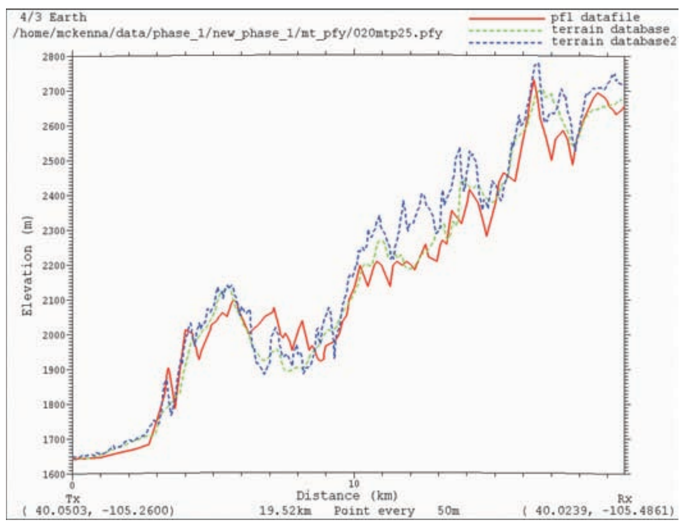


Figure 3. Comparison of profiles for a 19.52-km path in the Colorado mountains.

For more information, contact:
Paul M. McKenna
(303) 497-3474
e-mail pmckenna@its.bldrdoc.gov

Tactical Communication Deception System

Outputs

- Analysis and specification of previous deception system.
- Inventory and requirements of tactical units' communication networks.
- Model and specifications of an upgraded deception system.

Physical decoys have long been deployed by the military to pose delusory threats. For example, missile decoys may be launched with intercontinental missiles to represent multiple "warheads" where only one exists. Similarly, a tactical communication deception system (CDS) can be deployed to emit radio signals like those from an operational tactical unit. Opposing forces must then decide which signal, if any, is being transmitted by the actual tactical unit. A CDS should be relatively inexpensive, portable, and able to be remotely deployed and controlled.

The U.S. Army tasked ITS to analyze the communication systems operated by its tactical units. The analysis included networks, noise, and the performance of the existing CDS. ITS then proposed a model for an improved CDS.

In an earlier study, ITS characterized the existing frequency hopping-frequency shift keyed (FH-FSK) CDS emulator. Therefore, our original focus in the current study was on the commonly-used FH-FSK radio system and how to improve the existing CDS. Most radio systems employed by the Army use some form of frequency modulation (FM), either analog or digital. A typical wireless FM system model, similar to that used by the Army, is shown in Figure 1. Mathematical models were provided to describe the bandwidth required for these systems with parameters used by the Army. Following a meeting at White Sands Missile Range with U.S. Army personnel that disclosed battlefield scenarios involving other radio equipment unique to the tactical operational unit, the focus was widened to include this other equipment.

Our proposal for a new CDS is shown in Figure 2.

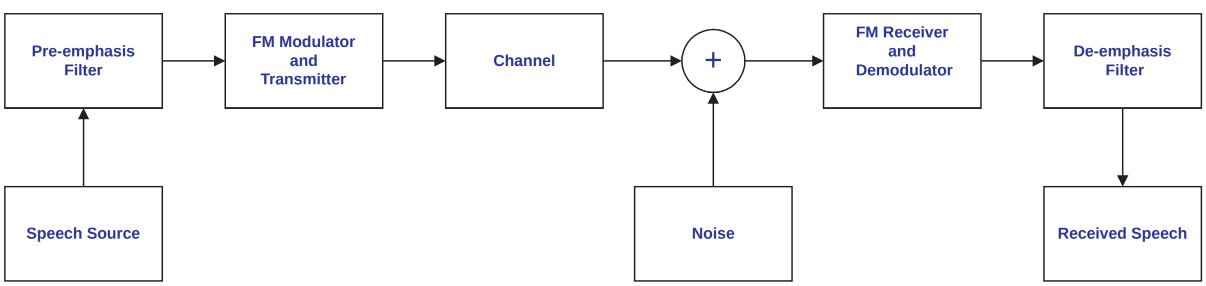


Figure 1. Typical wireless FM system model.

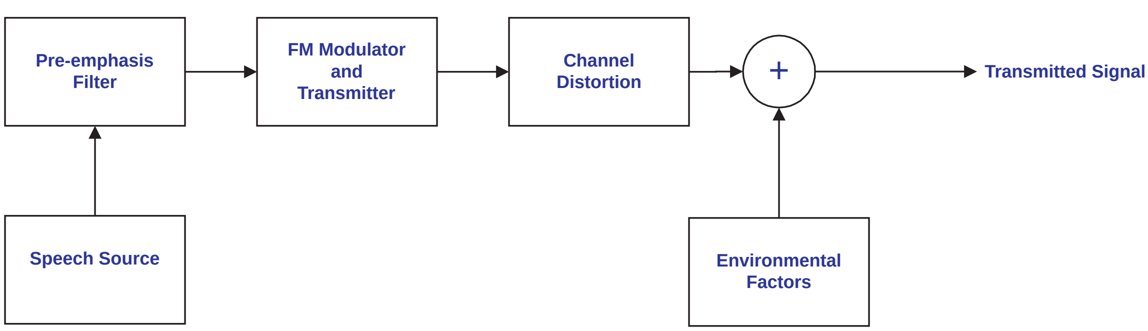


Figure 2. Model of proposed communication deception system (CDS).

In addition to an FM transmitter, it includes a Channel Distortion block and an additive Environmental Factors block at the output. The channel for these applications might be modeled with a Ricean probability model where the probability values are time varying in accordance with the changing environment. By choosing model parameters properly, power in the direct path or line of sight (LOS) can be varied with indirect paths and provide the illusion of mobile or stationary platforms.

The Environmental Factors block was provided for the representation of the man-made or natural noise. Impulse noise from generators and other equipment may be present and provide more realism to the deception signal. Furthermore, these frequencies are generally contaminated by galactic and solar noise in addition to lightning and switching noise. The amplitude of the impulse noise is commonly modeled by a log-normal distribution or a "power-rayleigh" distribution. The interarrival times can be described by a gamma distribution.

Future tasks could include the development of the model shown in Figure 2 and the construction of a prototype system to demonstrate the CDS in the field.

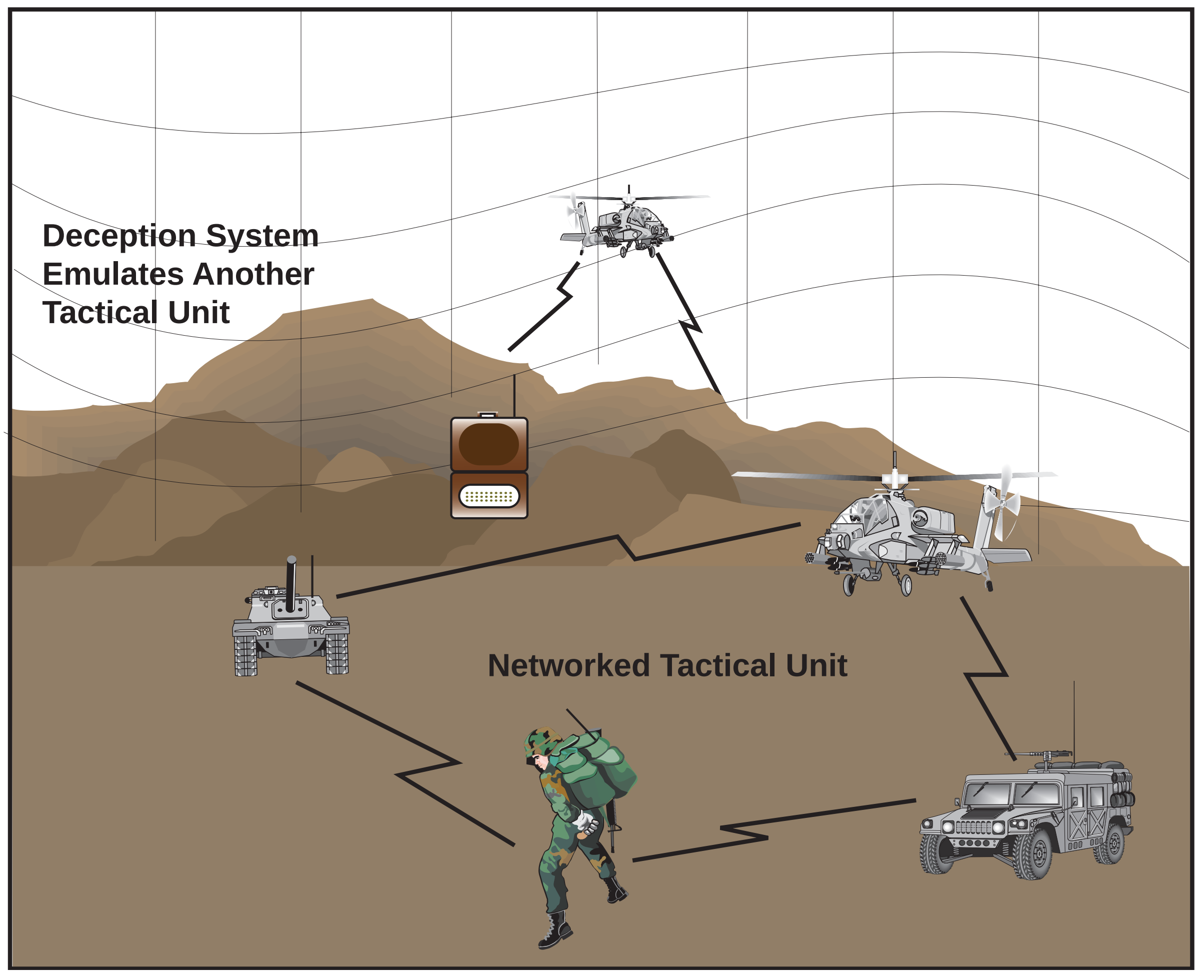
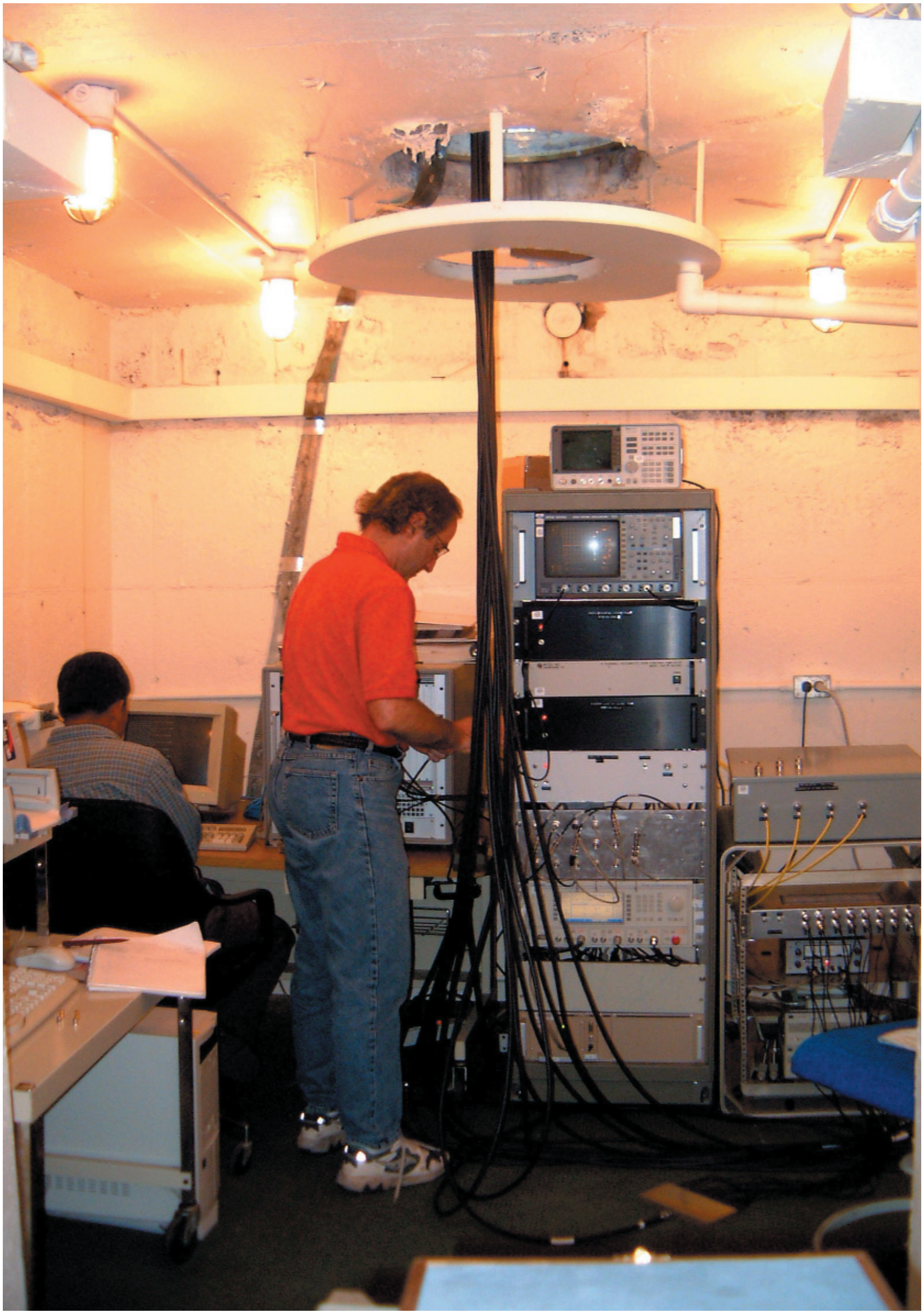


Figure 3. Battlefield communication network with activity and a remote CDS (drawing by A. Romero).

For more information, contact:
Dr. Edmund A. Quincy
(303) 497-5472
e-mail equincy@its.bldrdoc.gov



ITS engineer from the Telecommunications Theory Division performing measurements of a multi-element antenna array built for 3G services (photograph by F.H. Sanders).

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, and new technologies have required 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 and quality is affected by the earth's surface, the atmosphere, the ionosphere, antenna designs, and natural and man-made electromagnetic noise sources. This work is resulting in new models for the transmission of 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 area the Institute develops perception-based measurements for multimedia services. ITS transfers all of this technology to both public and private users, where knowledge is transformed into new products and opportunities.

Areas of Emphasis

Adaptive Antenna Testbed The Institute is developing an advanced antenna testbed to be used in the investigation of "smart" antennas, which will 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 more robust and effective techniques for speech and audio coding, transmission, and quality assessment. Projects are funded by NTIA.

Augmented Global Positioning System The Institute provides technical support for the design and implementation of a nationwide differential GPS service that will provide navigation and positioning information to surface users throughout the country. The project is funded by the Federal Highway Administration.

High Power Electromagnetic Fields The Institute is involved in research to assess the vulnerability of telecommunications switching stations and cellular base stations to high power electromagnetic radiation generated by RF devices. The project is funded by the Central Intelligence Agency.

Software Defined Radio Technology The Institute is involved in research on advanced radio systems including software defined radios and smart antennas. Projects are funded by NTIA and the Department of Defense.

UHF Radio Frequency Noise The Institute is involved in research to analytically predict the performance of a digitally modulated radio link operating in non-Gaussian noise. The prediction is based on UHF man-made noise measurements conducted by the Institute. 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 involving the radio propagation channels that will be employed in new personal wireless communication technologies such as third generation wireless (3G). Projects are funded by NTIA and Lucent Technologies.

Adaptive Antenna Testbed

Outputs

- Wideband radio channel sounding measurements.
- Propagation loss, fading, delay, and Doppler statistics over a broad bandwidth.
- Antenna array diversity gain data.
- Angle of arrival data for adaptive antenna schemes.
- 16-element MIMO response over a conductive ground plane.

The use of wireless, mobile, personal communications services (PCS) is expanding rapidly. Multiple-access schemes based on frequency division, time division, and orthogonal codes are presently used to increase channel capacity and optimize channel efficiency. Adaptive or “smart” antenna arrays can further increase channel capacity through spatial diversity. 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 adaptive 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-random (PN) code generator to apply binary phase-shift keying (BPSK) modulation to a radio carrier at the transmitter. The received signal is correlated 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 multiple input, multiple output (MIMO) testing at the NIST open area test site (photograph by F.H. Sanders).

Figure 2. Dipole antenna elements used by MIMO array (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 (OATS), as shown in Figures 1 and 2. The objective of the test was to evaluate the MIMO system capacity in a known RF environment. 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 consisted of the signal from all 16 transmitters as combined by the radio channel. After recording the 16 receive channels, a 16 by 16 channel matrix $\boldsymbol{H}$ can be assembled to show how the signals from each of the 16 transmitters combine at the 16 receivers. The MIMO capacity for a communications link with $\boldsymbol{n_T}$ transmitters and $\boldsymbol{n_R}$ receivers depends on the number of and independence of the paths represented in $\boldsymbol{H}$ as well as the channel signal-to-noise ratio. The capacity can be calculated using the following formula:

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

$$where\ I = identity\ matrix$$

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

$$H = complex\ transmission\ matrix$$

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

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, system performance evaluation, channel model development and verification, and large communications system simulations. (See the Tools & Facilities section, p. 73, for more information about the ATB.)

For more information, contact:
Peter B. Papazian
(303) 497-5369
e-mail ppapazian@its.bldrdoc.gov

Recent Publications

P. Papazian, P. Wilson, M. Cotton, and Y. Lo, “Flexible interoperable transceiver (FIT) program test range I: Radio propagation measurements at 440, 1360 and 1920 MHz, Edwards Air Force Base, CA,” NTIA Report 00-380, Oct. 2000.

P. Papazian, P. Wilson, M. Cotton, and Y. Lo, “Flexible interoperable transceiver (FIT) program test range II: Radio propagation measurements at 440, 1360 and 1920 MHz, Ft. Hood, Texas,” NTIA Report 00-381, Oct. 2000.

P. Wilson, P. Papazian, and Y. Lo, “A comparson of 1920 MHz mobile channel diversity gain using horizontal and vertical arrays,” to be published in *IEEE Transactions on Communications*, Dec. 2001.

Audio Quality Research

Outputs

- Algorithms and software for speech and audio coding and quality assessment.
- Technical papers and reports documenting new results.
- Subjective measurements and objective estimates of speech and audio quality.

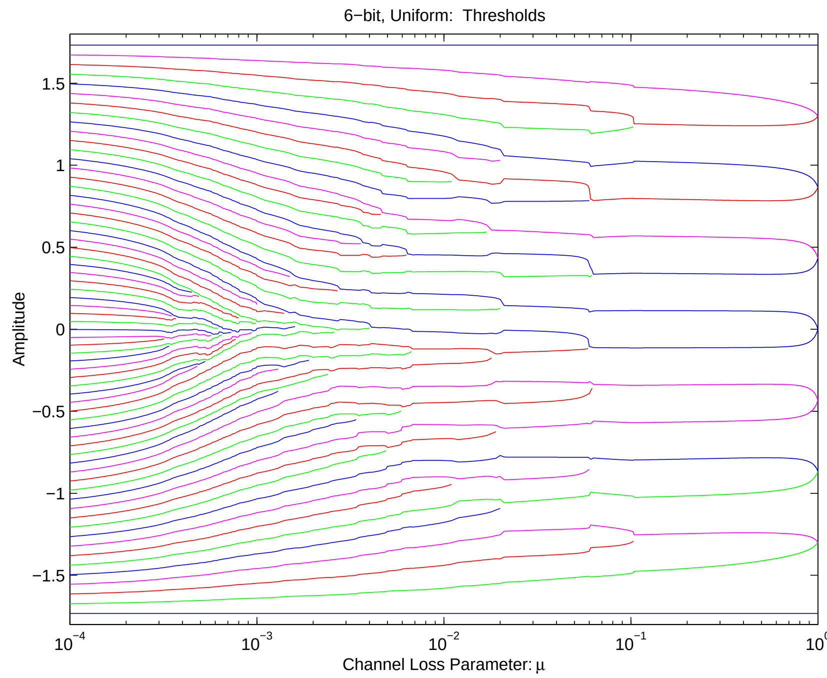
Digital compression and transmission of speech and audio signals have enabled the recent explosion of telecommunications and broadcasting offerings. These offerings include digital cellular telephone services, voice over Internet protocol (VoIP) services, voice messaging systems, digital audio broadcasting, Motion Picture Experts Group (MPEG) 1, Layer-3 (MP3) music files, and MPEG Advanced Audio Coding systems. Digital compression allows these systems to deliver good-quality speech using bit rates between 4 and 64 kbit/s. Audio signals, including music and entertainment soundtracks, are typically delivered at rates between 16 and 256 kbit/s per channel. Compressed speech and audio signals can be transmitted as data packets, thus sharing channel capacity and possibly radio spectrum with other data streams and hence with other users.

Digital compression algorithms generally trade off quality, bit-rate, delay, and complexity. Researchers strive to develop algorithms that maximize speech or audio quality while minimizing bit-rate, delay, and complexity. In addition, the robustness of compression algorithms to lossy channels is becoming increasingly important in many applications. Examples of lossy channels include those provided by wireless systems and those provided by the Internet. The ITS Audio Quality Research Program seeks to develop practical new ideas to increase quality and robustness, or to lower bit-rate, delay or complexity of digital speech and audio compression and transmission.

In many new and emerging 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 carefully controlled experiments to gather subjects' opinions of the speech or audio quality of various compression and transmission systems. In addition, the Program has developed and verified tools for the objective estimation of telephone bandwidth speech quality. These tools have been used extensively to further program goals, and to support related efforts both inside and outside of ITS.

In FY 2001 the Audio Quality Research Program conducted numerous studies in these areas, three of which are summarized here. In one study, ITS staff derived and implemented four different algorithms for fitting two noisy data vectors to each other while jointly minimizing two resulting fitting errors, and simultaneously maintaining the ratio of those two error powers at a fixed value. The algorithms are used to generate more realistic fits between subjective quality measurements and objective quality estimates of speech, audio and video signals. The general paradigm is that there is a true underlying value of quality for each signal and that both the objective estimate and subjective measurement provide noisy approximations to that true value. With estimates of the noise levels in both the objective estimate and the subjective measurement, one can apply the new fitting algorithms to explicitly acknowledge each of those noise sources and their relative power levels when fitting the two to each other. By explicitly acknowledging both noise sources, better subjective-objective fits can be obtained. This then enables better objective estimators of speech, audio, and video quality.

Another FY 2001 study addressed the robustness of a 7200 bit/s speech coder. The need arose to send a small amount of signaling information in a particular digital radio system. Since the radio channels were already fully occupied by the 7200 bit/s speech traffic, it was proposed to simply "steal" half the bits from the speech coder for 60 ms periods at regularly spaced intervals. The decoder would then periodically receive a 3600 bit/s signal and would produce lower speech quality at the corresponding moments. ITS staff interfaced hardware implementations of the speech encoder and decoder to a data acquisition system that was attached to a personal computer. This allowed staff to capture the encoder bit stream, perform the necessary manipulations in software, and then play the modified bit stream back to the decoder. Additional equipment was used to inject high-quality speech recordings into the encoder and to record the decoder output. A total of 150 recordings were made and these were provided to decision-makers to allow them to hear first-hand exactly how robust this particular coder is to this particular type of channel impairment.



Thresholds for a 2-channel, 6-bit channel-optimized multiple-description scalar quantizer vs. channel loss parameter.

Program staff also developed a family of quantizers specially designed for multiple-description coding applications. Multiple-description audio coding uses multiple physical or virtual transmission channels to gain robustness to channel failures and to generate "soft" rather than "hard" failure of the audio signal when the transmission channels fail. Program staff derived necessary and sufficient design equations for multiple-description scalar quantizers that minimize the expected quantization error for a given data distribution and set of channel state probabilities.

These channel-optimized multiple-description scalar quantizers reduce to conventional Lloyd-Max scalar quantizers when the design channel conditions are very good or very bad. In fact, a 2-channel, *b*-bit channel-optimized multiple-description scalar quantizer slowly collapses from a *b*-bit Lloyd-Max scalar quantizer with no redundancy (when designed for good channel conditions) to a pair of *b*/2-bit Lloyd-Max scalar quantizers with 100% redundancy (when designed for poor channel conditions). Staff designed 2-channel, channel-optimized multiple-description scalar quantizers for the uniform, Gaussian, Laplacian, Rayleigh, and Chi-squared distributions at 2-8 bits/sample. The figure above shows the thresholds for the 6-bit uniform distribution case. Note that at the left edge of the figure, the channel conditions are very good (channel loss parameter $\mu = 0.0001$) and these thresholds define $2^6 = 64$ quantization cells. At the right edge of the figure, the channel conditions are very poor (channel loss parameter $\mu = 1.0$) and these thresholds define only $2^3 = 8$ quantization cells. Staff use the repeating pattern of four colors assigned to the thresholds to simplify the task of keeping track of particular thresholds as these quantizers evolve and collapse. It is expected that quantizers like this one will allow for more robust transmission of speech and audio signals over pairs of lossy wireless or Internet channels. Note that multiple virtual channels can be obtained by using multiple codes or slots in CDMA, TDMA, or FDMA systems, or by creating multiple packet streams in Internet systems.

Technology transfer efforts in the program continued in FY 2001. Program results were disseminated to industry, Government, and academia through presentations, participation in workshops, conferences and symposia, and laboratory demonstrations. Program results are also made available through the program web site located at http://www.its.bldrdoc.gov/home/programs/audio/audio.htm

For more information, contact:
Stephen D. Voran
(303) 497-3839
e-mail svoran@its.bldrdoc.gov

Augmented Global Positioning System

Outputs

- Planning of the number and location of GWEN differential GPS reference stations required to provide nationwide signal coverage.

- Recommended frequency assignments and transmitter powers for differential GPS reference stations.

The NAVSTAR global positioning system (GPS) is a space-based radionavigation system that consists of a constellation of 24 satellites in 6 orbital planes. GPS provides precise and accurate three-dimensional position, velocity, and time to users worldwide, 24 hours per day. GPS was originally developed as a military system. Although still used in this capacity, GPS also provides significant benefits to the civilian community. To make GPS service available to the greatest number of users while ensuring that national security interests are protected, two GPS services are provided. The precise positioning service (PPS) provides full system accuracy to military users. The standard positioning service (SPS) is available for civilian use but has less accurate positioning capability than PPS, approximately 100 m. Because the SPS accuracy does not meet most civilian navigation and positioning requirements, various augmentations to GPS are used to provide higher accuracy positioning, as well as increased integrity and availability of the positioning information. One form of augmentation, differential GPS (DGPS), can provide 1- to 10-m accuracy for dynamic applications and better than 1-m for static users. In a 1994 report,* the result of a study done for the Department of Transportation, ITS recommended implementation of a radio beacon system, operating in the 300-kHz band, modeled after the U.S. Coast Guard's (USCG) local area DGPS. This system would provide nationwide coverage of DGPS for surface applications.

For the past five years ITS researchers have been conducting a study, sponsored by the Federal Highway Administration, to determine the optimum location and operating parameters of the DGPS reference stations required to provide this civil navigation and positioning service to all surface users across the nation. This new service will be known as

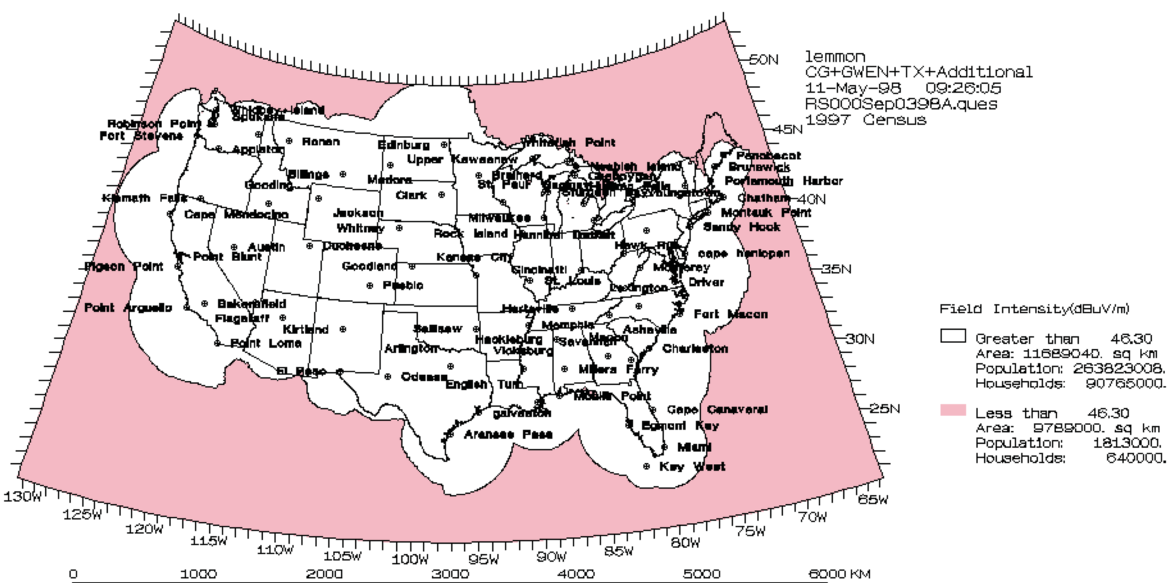


Figure 1. Signal coverage prediction plot showing nationwide coverage of the planned nDGPS service.

*R.O. DeBolt et al., "A technical report to the Secretary of Transportation on a national approach to augmented GPS services," NTIA Special Publication 94-30, Dec. 1994.

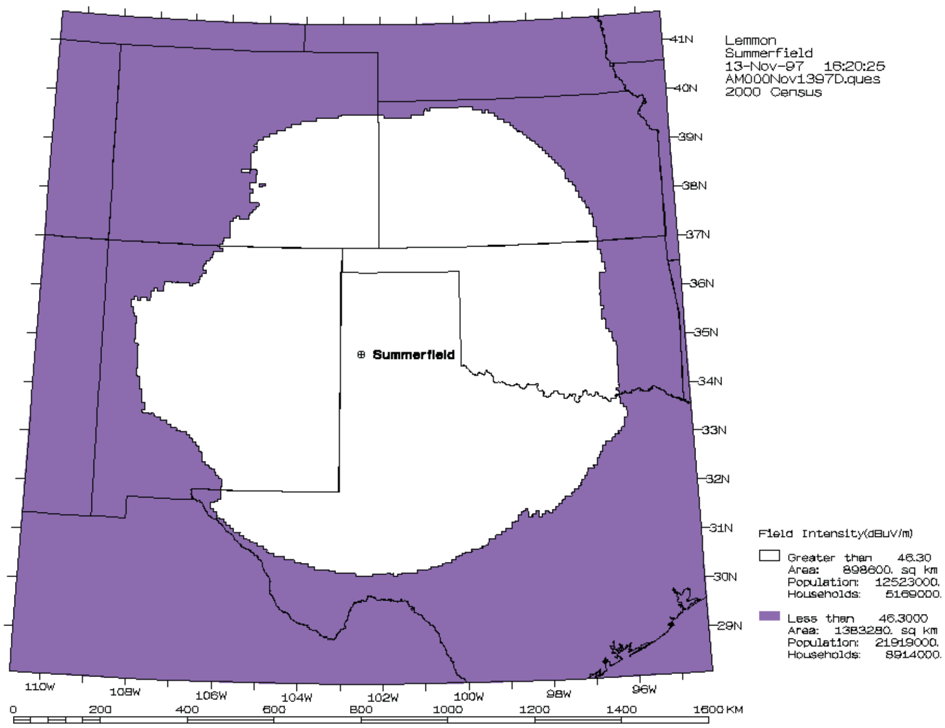


Figure 2. Signal coverage prediction plot for the DGPS reference station at Summerfield, TX.

the nationwide differential global positioning system (nDGPS). The use of this service will have an enormous impact on a diverse set of activities, including ocean and land transportation, surveying and mapping, farming, waterway dredging, recreation, emergency location and rescue operations, and many others that have not yet been identified.

The foundation of nDGPS is the DGPS reference stations currently operating or planned by the USCG and the U.S. Army Corps of Engineers. This system provides coverage of the radio-beacon DGPS signal for coastal areas, harbors, and inland waterways. ITS designed a network of additional DGPS reference stations to provide nationwide coverage of the DGPS signal. To achieve this additional signal coverage, ITS used the Ground Wave Emergency Network (GWEN) sites, owned by the U.S. Air Force Air Combat Command. The GWEN system is an existing Federal Government asset that provides a cost-effective method of implementing nationwide coverage of the DGPS signal. The GWEN sites were used at existing locations or moved to new locations as required to complete the nDGPS signal coverage. Figure 1 shows a signal coverage prediction plot of this nationwide coverage.

Installation of the GWEN DGPS reference stations is currently underway. By the end of FY 2001, twenty stations were operational, one was under construction, and five more were planned to be operational by the end of the calendar year.

In FY 2001, ITS has provided technical support, required for the implementation of the nDGPS, to the Department of Transportation. Much of this support has been in the form of interference analyses required to assess the impact of newly installed DGPS reference stations on existing aviation beacons in the 300-kHz frequency band. These analyses are particularly important for those stations whose transmitter powers have been increased from the recommended levels to provide signal coverage in unanticipated coverage gaps. A signal coverage prediction plot for one such station, at Summerfield, Texas, is shown in Figure 2.

For more information, contact:
Dr. John J. Lemmon
(303) 497-3414
e-mail jlemmon@its.bldrdoc.gov

High Power Electromagnetic Fields

Outputs

- Analysis of the high power RF threat to telecommunications infrastructure.
- Indoor propagation models.

High level electromagnetic fields can interfere with and damage electronic hardware, and thus can disrupt or disable computer software. High power radio frequency (RF) fields could therefore pose a threat to critical infrastructures that depend on electronic equipment, such as public and private telecommunications networks. Moreover, RF devices have been developed that are designed to disrupt electronic equipment and thus represent an emerging threat to the telecommunications infrastructure. The objective of the ITS High Power Electromagnetic Fields project was to perform an assessment of the vulnerability of public and emergency telecommunications systems to high intensity RF fields. In particular, the following questions were addressed:

> Can the loss of a node (or nodes) cascade through the telecommunications network causing a large-scale system blackout or crash?
>
> Can high intensity RF fields disrupt or disable a node (such as a switching station or a wireless base station)?

The basic conclusions that were reached are:

> The overall public telecommunications network has sufficient redundancy and capacity to withstand the loss of even multiple nodes. A full nationwide system collapse is not envisioned as a possible scenario. Loss of equipment or failure of software at a telecommunications switching station or a wireless base station could lead to a large local outage, but is not likely to cascade further within the system.
>
> Neither public network switching stations nor cellular base stations are intentionally hardened against high intensity RF fields, and the shielding provided by concrete and re-bar construction is negligible for wavelengths on the order of, or smaller than, the re-bar spacing. A switching station could therefore be disrupted, although the probability of disruption is difficult to assess due to the variety and complexity of building layouts. Wireless base stations are extremely vulnerable to high power devices operating within the base station pass band, since antennas and feedlines would carry the undesired power directly into the electronics.

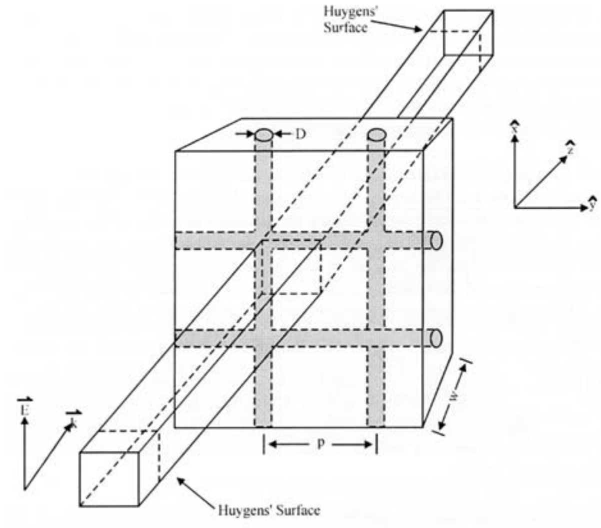


Figure 1. Reinforced concrete wall structure used to calculate transmission coefficients shown in Figure 2.

These initial conclusions were based on a review of telecommunications networks, discussions with providers, and basic estimates of the coupling of RF energy into telecommunication systems. However, to more accurately assess the vulnerability of these systems to high intensity RF fields, a more detailed analysis was undertaken. In particular, a model of the transfer function relating a source external to a building and equipment internal to a building was developed. This more accurately defines the threat to equipment located within buildings.

Electromagnetic models of the penetration of RF energy into structures were developed. The most basic penetration models, infinite slab models, were used to determine the loss of RF energy as a function of frequency, slab thickness, and electrical conductivity. This strategy was applied to both homogeneous and heterogeneous slab materials.

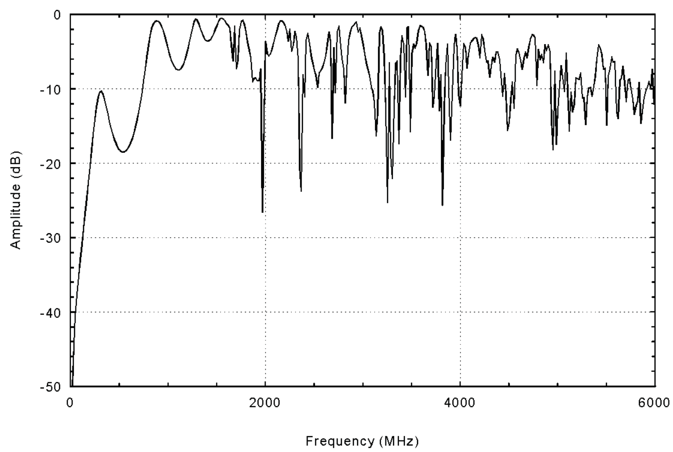


Figure 2. Transmission coefficient for a reinforced concrete wall.

Figure 3. Typical cellular base station antenna (photo by F.H. Sanders).

An example of these models is shown in Figures 1 and 2, which illustrate a reinforced concrete slab and the resulting transmission coefficient as a function of frequency. Also, penetration via apertures in infinite slabs were analyzed, with attention given to the different analytical approximations that are appropriate for the different regimes of aperture dimension relative to a wavelength. Using these results, the propagation of RF energy in the interior of a structure was analyzed, and a model of indoor propagation was developed. It is noteworthy that the model predictions are consistent with measurements and simulations of indoor propagation.

In addition to analyzing the penetration of RF energy into structures not intended to collect electromagnetic energy, the coupling of energy into cellular base stations via the base station receive antennas, as depicted in Figure 3, was also investigated. These results were used to develop analytical tools that can be used to predict received power levels inside structures that house telecommunications equipment and in cellular base stations.

Recent Publications

P. Wilson, E. Haakinson, and R. Dalke, "Vulnerability of wireline and cellular telecommunications networks to high power radio frequency fields," NTIA Report 01-382, Nov. 2000.

J.J Lemmon and R.A. Dalke, "Analysis of the RF threat to telecommunications switching stations and cellular base stations," NTIA Report (in progress).

For more information, contact:
Dr. John J. Lemmon
(303) 497-3414
e-mail jlemmon@its.bldrdoc.gov
or
Dr. Roger A. Dalke
(303) 497-3109
e-mail rdalke@its.bldrdoc.gov

Man-made Noise in the UHF Band

Outputs

- Measurements of man-made noise.
- Analysis and modeling of man-made noise.
- Prediction of radio link performance in the man-made noise environment.

Man-made electromagnetic noise radiates unintentionally from power systems, automobile ignition systems, electric motors, and various electronic devices. Although often benign, man-made noise sometimes interferes with the operation of a radio link. The degree of interference is dependent upon the proximity of the man-made noise source, frequency, radio link modulation, and the statistics of the noise amplitudes which are in general dependent on the bandwidth of the victim receiver.

Band-limited man-made noise statistics are often non-Gaussian and therefore cannot be fully characterized by average power. Furthermore, band-limited man-made noise statistics are non-stationary in that they vary from location to location and from hour to hour. These facts have wide ramifications for measurement of man-made noise and prediction of the performance of radio links operating in the man-made noise environment. For example, man-made noise is measured by accumulating and storing the statistics of a large number of noise power samples in a histogram. These samples must be acquired over times and locations that yield stationary statistics. Finally, the locations must include a wide variety of rural, residential, and business settings.

Man-made noise was comprehensively measured at frequencies up to 250 MHz in the 1970s. These measurements were used to model noise powers for radio link design. Since the devices and systems that produce man-made noise change with technological innovation, it is reasonable to question the accuracy of these older models. In the last five years ITS has completed two noise measurement campaigns intended to “spot check” VHF and UHF man-made noise levels.

These spot checks have shown that VHF noise in business areas is likely to have remained approximately the same as that measured in the 1970s. However, VHF residential noise power is likely to have decreased. UHF noise power was not measured in the 1970s. The spot checks have shown that man-made noise is present in these bands. For example, Figure 1 shows median, mean, and peak power of 402.5-MHz business noise over a 24-hr period at downtown Denver, CO. The variable mean and peak powers are due to the addition of noise in the environment to the noise introduced by the measurement system.

Statistics of power levels over a 3-day period for the same location are shown in the cumulative distribution function in Figure 2. The median of the mean power is often used in link budget analysis to represent the value that is exceeded in 50% of locations and hours for 50% of the time within an hour. In this case the median is approximately 4 dB. However, the cumulative distribution function also shows that radio links requiring 99% reliability must add 4 dB to the link margin.

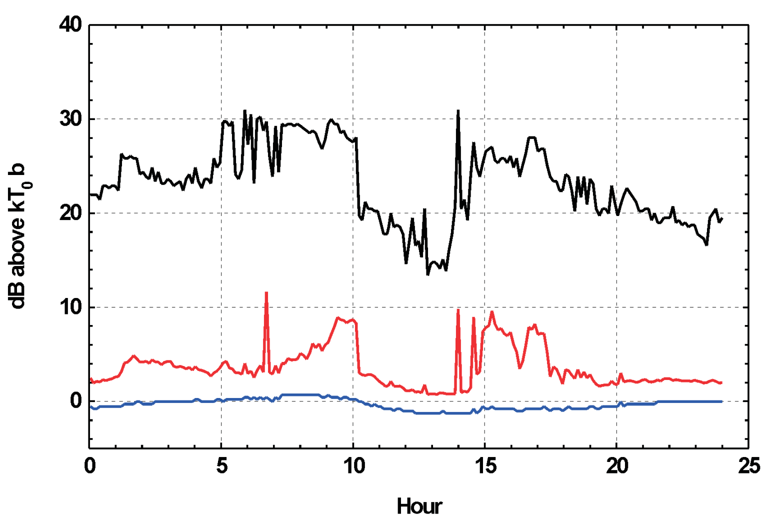


Figure 1. Median (blue), mean (red), and peak (black) power of 402.5-MHz business noise over a 24-hr period in downtown Denver, CO.

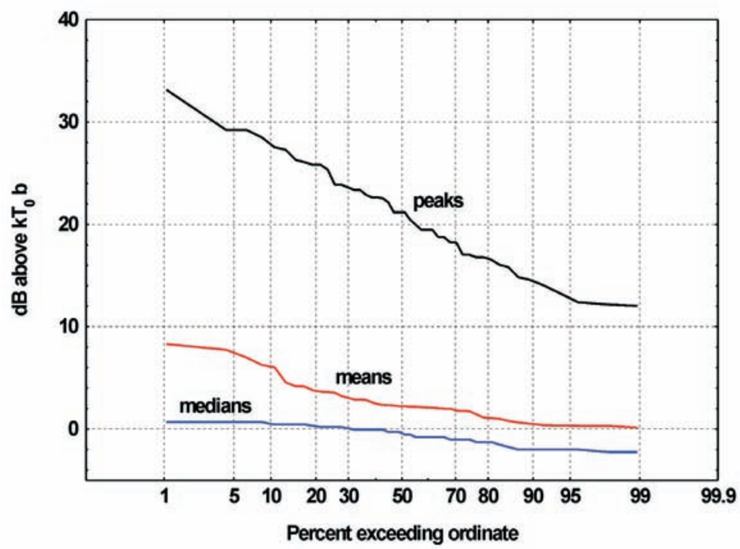


Figure 2. Power levels over a 3-day period in downtown Denver, CO.

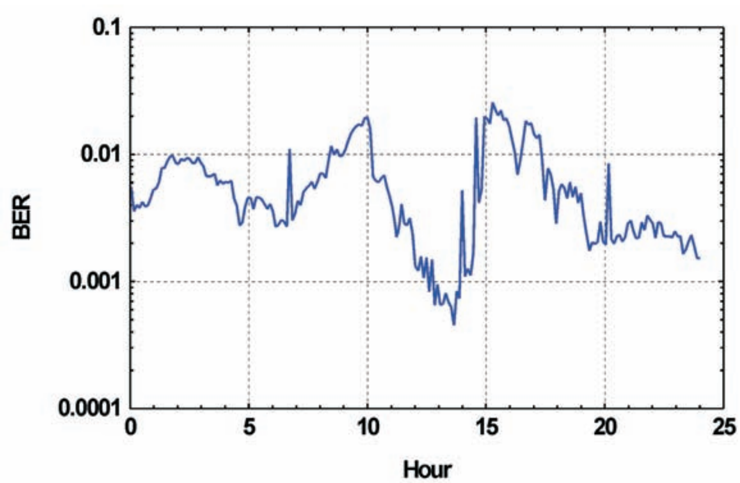


Figure 3. Bit error rate (BER) in the presence of the 402.5 MHz business noise shown in Figure 1.

Recently, ITS engineers have developed a method for analytically predicting performance directly from man-made noise measurement statistics. Figure 3 shows the bit error rate (BER) in the presence of the 402.5-MHz business noise shown in Figure 1. The signal level is assumed to be -119 dBm and the receiver noise floor is -126 dBm (2-dB noise figure and 36-kHz noise equivalent bandwidth) yielding a 7-dB signal-to-noise-ratio (SNR). The corresponding BER for coherent binary phase-shift keying is 0.001 in Gaussian noise. Analytic results show that BER can fluctuate as much as one order of magnitude *for the same SNR.* For example, around 2:00 p.m. (hour 14) the BER rises from 0.0007 to 0.007.

Future work will focus on characterizing man-made noise from the ever-changing technological landscape and continued improvement of measurement techniques. The principles of man-made noise measurement and modeling can be applied not only to unintentional radiators such as electric motors and automobile ignition systems, but also may be used to characterize the emissions from recently proposed ultrawideband and ubiquitous FCC Part 15 transmitters. Also, at this point very few indoor man-made noise measurements have been conducted. The indoor environment is important to characterize because many of the new electronic devices which produce man-made noise and the emerging technologies that are likely to be affected by man-made noise are used inside buildings.

Recent Publications

R.J. Achatz, Y. Lo, P.B. Papazian, R.A. Dalke, and G.A. Hufford, “Man-made noise in the 136 to 138-MHz meteorological satellite band,” NTIA Report 98-355, Sep. 1998.

R.J. Achatz and R.A. Dalke, “Man-made noise power measurements at VHF and UHF frequencies in residential and urban environments,” NTIA Report 02-390, in press.

For more information, contact:
Robert J. Achatz
(303) 497-3498
e-mail rachatz@its.bldrdoc.gov

Software Defined Radio Technology

Outputs

- NTIA Report on the implementation and testing of a software defined radio (SDR) cellular base station receiver.
- Overview article on SDR, to be published in the *NTIA Spectrum News*.

Within the past decade, software defined radio (SDR) has moved rapidly from concept to reality. SDRs are currently available for cellular and PCS base stations as well as fixed station military applications. While SDR technology has enabled some practical products, the current implementations suffer from limitations that preclude development of a practical and widely deployed handheld SDR. Challenges remain for implementation of practical handheld SDR devices, including reduction of power consumption, size, weight, and cost. However, several SDR experts believe that handheld SDRs will be in widespread use within five years. This prediction is supported by the continuing rapid development of SDR, driven by tremendous advances in key components. These key components include high-speed, high spurious-free dynamic range analog-to-digital and digital-to-analog converters; high-speed digital signal processing devices such as application specific integrated circuits (ASIC), digital signal processors, field programmable gate arrays (FPGA), and general purpose processors; and wideband linear power amplifiers.

While there are differing opinions as to what an SDR actually is, a good general definition is found in the recently adopted American National Standard, *Telecom Glossary 2000* (see pp. 30-31 and pp. 78-79). An SDR consists of a receiver and/or transmitter with the following properties: (a) the received signal is digitized and then processed using software-programmable digital signal processing techniques (digitization may occur at the radio frequency (RF), the intermediate frequency (IF), or baseband); (b) the modulated signal to be transmitted is generated as a digital signal using software-programmable digital signal processing techniques. The digital signal is then converted to an analog signal for transmission (the conversion to analog may occur at baseband, the IF, or the RF).

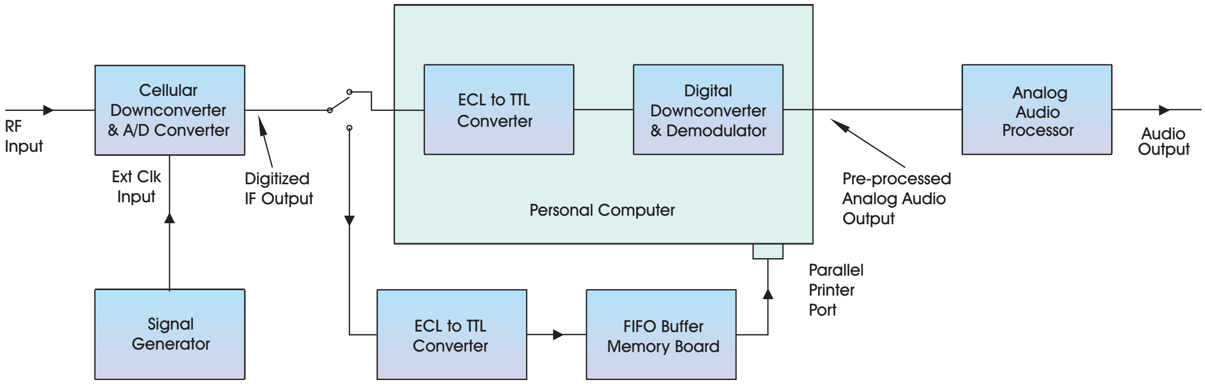
A key factor in SDR is that software programmability allows easy changes of the radio's fundamental characteristics such as modulation types, operating frequencies, bandwidths, multiple access schemes, source and channel coding/decoding methods, frequency spreading/despreading techniques, and encryption/decryption algorithms. Traditional, hardware-based radios required hardware changes to modify these fundamental characteristics of a radio.

SDRs can provide great advantages over traditional radios. Manufacturers could benefit by developing a single SDR platform on which multiple radios could be implemented simply by loading different software. Because the single SDR would replace multiple hardware radios, a greater economy of scale could be achieved that would drive the cost down. New radios would not have to be designed for the plethora of wireless standards that continue to emerge; all changes could be made in software utilizing a common hardware platform. Interoperability problems experienced by public safety/law enforcement agencies and the military could be eased by SDRs. Users would only have to purchase a single SDR to perform many different radio functions simply with a change in software.

Because of the increasing importance of SDR in wireless communications, ITS has been involved in SDR research since the mid-1990's. Work in SDR technology at ITS continued this year with the publication of an NTIA Report on the implementation and testing of an SDR cellular base station receiver.

There is a mystique surrounding SDRs: what they are, how they are designed, how they operate, and how performance is determined or verified. NTIA Report 01-388 provides insight into some of these SDR aspects by presenting a detailed example SDR receiver design along with a set of performance measurements at various stages of the receiver. For this example, an Advanced Mobile Phone System (AMPS) cellular base station receiver was configured using SDR technology.

The architecture of our SDR receiver is shown in the figure on the next page. It consists of four basic blocks: the cellular B-band downconverter and analog-to-digital (A/D) converter, the digital downconverter and demodulator board that operates in a



Architecture for the software defined radio cellular base station receiver.

personal computer, a first-in first-out (FIFO) buffer memory board, and an analog audio processor. This modular architecture has the advantage of permitting observation of the received signal at various stages of the processing. Signals may be observed at the digitized IF output, the digitally downconverted and filtered baseband output, the digital FM demodulator output, and the analog audio output.

Measurements of adjacent and alternate channel desensitization, intermodulation spurious response attenuation, and protection against spurious response interference at the analog audio output of the receiver easily met TIA/EIA specifications for 800-MHz cellular base stations. At the digitized IF output, aliasing was shown to occur under certain frequency and signal level inputs; however, a good deal of filtering is present in the system to greatly minimize the interfering effects of this aliasing. A strong RF in-band interfering signal was shown to render weak desired signals undetectable. These weak desired signals are easily detectable in the absence of large interfering signals. The digital automatic gain control in the digital downconverter was shown to be essential for the proper operation of the digital FM demodulator.

While our SDR receiver was implemented as an AMPS cellular system, different cellular systems can be implemented via software changes using the current hardware. If the cellular downconverter were replaced with a wideband downconverter with a very wide RF tuning range and if further digital signal processing were performed using an FPGA and/or a digital signal processor, then an extremely versatile SDR receiver could be achieved. With this type of SDR receiver, many different types of receivers could be implemented strictly via software changes.

In another effort, ITS initiated a study of SDR for public safety/law enforcement (PS/LE) applications. The PS/LE communication needs are being analyzed, along with how SDR can be used to help meet these needs. One issue being studied is whether PS/LE communication needs can be met by using SDR for subscriber units only, for the infrastructure only, or whether both are required. Based upon the needs analysis, a set of specifications for a PS/LE SDR is being developed, including requirements such as frequency range of operation, required bandwidths, required spurious-free dynamic range, and required services (such as analog FM voice, Project 25 voice and data, IS-54 digital cellular telephone, etc.). Finally, an analysis is underway to assess the viability of current SDR systems, subsystems, and components for PS/LE applications.

Recent Publication

J. Wepman and J. Hoffman, "Implementation and testing of a software defined radio cellular base station receiver," NTIA Report 01-388, July 2001.

For more information, contact:
Jeffery A. Wepman
(303) 497-3165
e-mail jwepman@its.bldrdoc.gov

Video Quality Research

Outputs

- Digital video quality measurement technology.
- Journal papers and 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 replacing all existing analog video systems and making possible the creation of many new telecommunication services (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 video performance of these systems are required by government and industry for specification of system performance requirements, comparison of competing service offerings, network maintenance, and optimization of the use of limited network resources such as transmission bandwidth. 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 U.S. telecommunications industry. The increases in quality of service made possible with the new measurement technology benefit both the end-users and the providers of telecommunication services and equipment.

Figure 1. Demonstration of continuous subjective quality monitoring using a slider (photograph by S. Wolf).

To be accurate, digital video quality measurements have to be based on perceived “picture quality” and have to be made in-service using the actual video being sent by the users of the digital video system. The primary reason for these requirements is that the performance of digital video systems is variable and depends upon the dynamic characteristics of both the input video (e.g., spatial detail, motion) and the digital transmission system (e.g., bit-rate, error-rate). To address this problem, ITS developed a new measurement paradigm that is based upon extraction and comparison of perception-based features (e.g., edges, motion) that can be easily communicated through low-bandwidth data channels in the broadcast network. This measurement paradigm has received two U.S. patents, been adopted as an ANSI standard (ANSI T1.801.03-1996), and is being used by organizations worldwide.

Figure 2. Demonstration of Windows-based objective video quality measurement tool (photograph by S. Wolf).

A primary advantage of the ITS approach is the ability to make accurate in-service objective measurements of digital video quality (i.e., continuous real-time quality monitoring). To obtain a benchmark for evaluating the effectiveness of this monitoring, ITS has also implemented a subjective testing facility. Viewers continuously rate the quality of digital video by moving a sliding knob (called a slider) up and down (see Figure 1). The slider position relates to the perceived quality level (e.g., from bad to excellent) and this position is continuously sampled and recorded by a computer-based system for subsequent analysis.

To facilitate the transfer of ITS in-service objective measurements of digital video quality to private industry, UNIX-based and Windows®-based automated video quality measurement tools have been developed. These tools include (1) video calibration — video system gain/level correction and spatial/temporal registration of the input and output video streams, (2) four objective video quality metric calculations, optimized for specific digital video applications (TV, Videoconferencing, General — wide range of quality, Developer — wide range of quality + fast computation), and (3) root cause analysis summaries that give the perceptual relations between the objective metrics and specific digital coding artifacts (e.g., blurring, block distortion, jerky or unnatural motion, added noise, error blocks). Figure 2 shows an example of the Windows-based automated video quality measurement tool.

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, “The relationship between performance and spatial-temporal region size for reduced-reference, in-service video quality monitoring systems,” in *Proc. SCI / ISAS 2001 (Systematics, Cybernetics, and Informatics / Information Systems Analysis and Synthesis)*, Jul. 2001.

W. Ashmawi, R. Guerin, S. Wolf, and M. Pinson, “On the impact of policing and rate guarantees in Diff-Serv networks: A video streaming application perspective,” in *Proc. SIGCOMM 2001 (Association for Computing Machinery, Special Interest Group on Data Communications)*, Aug. 2001.

For more information, contact:
Stephen Wolf
(303) 497-3771
e-mail swolf@its.bldrdoc.gov

Wireless Propagation Research

Outputs

- Methods of predicting the impulse response for an indoor propagation channel and the delay spread of the multipath channel.
- Assessment of the geometric optics approximation for indoor ray-trace models.
- Survey of data analysis techniques applied to complex impulse response measurements.

For several years the Institute has been involved in research efforts related to wireless communication applications and theory. The majority of this work has been related to the outdoor propagation environment. Recently, with the emergence of new indoor wireless local area networks and wireless local campus networks, we have concentrated our efforts on investigating the indoor propagation environment. The objective of this effort is to support new wireless technology development and help U.S. industry compete in the worldwide telecommunications marketplace. More specifically, ITS develops models and measurement systems to predict and measure propagation characteristics of various multipath environments. This work supports the advancement of new techniques and technologies (e.g., smart antennas and diversity) to overcome limiting factors for indoor communication systems.

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. Figure 1 shows a typical calculated impulse response from this model. Ray-tracing can be time consuming; hence, the Institute has also developed a simplified model for calculating the impulse response and delay spread for the indoor channel in a matter of seconds on a personal computer. Results for this simple model are also shown in Figure 1. Notice that the simple model captures the same major features described by the ray-trace model.

In an attempt to assess the validity of the ray-trace model, we have investigated the accuracy of some assumptions used in ray-tracing. 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 2 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.

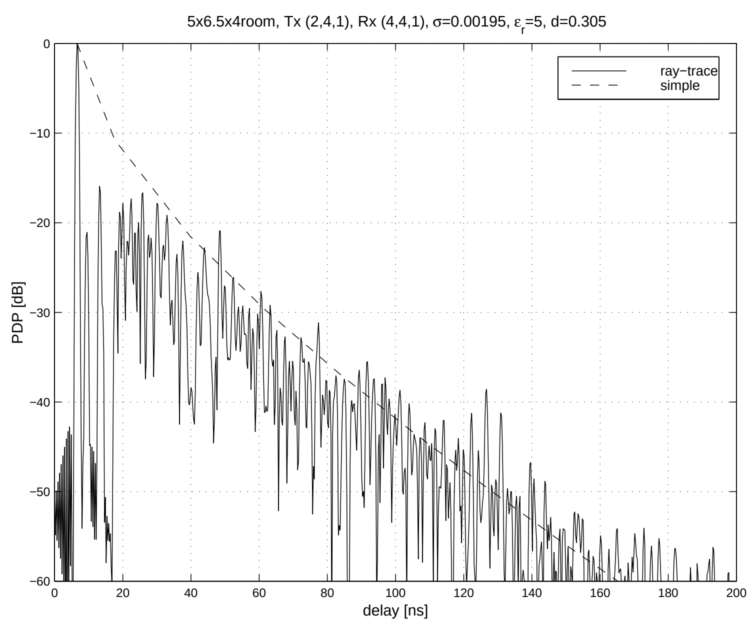


Figure 1. Calculated impulse response estimates from both ray-tracing and the simple model.

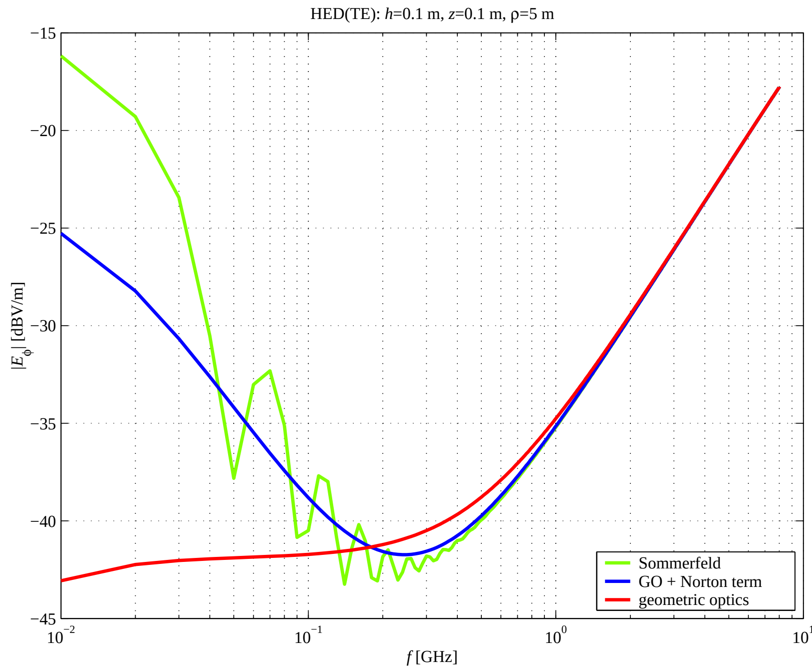


Figure 2. Near-surface effects on field strength of an elementary horizontal electric dipole above a concrete half space.

Figure 3. Antennas for measuring the impulse response of the in-corridor scenario.

The Institute is also involved in measurement efforts for various indoor propagation scenarios. 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 (see Figure 3). In addition to propagation effects, measurement results also provide statistical parameters for empirical models. The generality of these statistical models are limited by inherent assumptions. The Institute has investigated those limitations and is developing data analysis techniques to present the data concisely and with limited ambiguity.

For more information, contact:
Michael G. Cotton
(303) 497-7346
e-mail mcotton@its.bldrdoc.gov

Support to Private Sector Telecommunications Activities:

Cooperative Research with Industry

Outputs

- PC-based tools that measure 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 (NGI) and Internet 2 (I2) technologies.
- Measurements to validate the theoretical capacity study of the Bell Labs Layered Space-Time (BLAST) 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. ITS has participated for a number of years in CRADAs with private sector organizations to design, develop, test, and evaluate advanced telecommunication concepts. Research has been conducted under agreements with Bell South Enterprises; Telesis Technology Laboratories; US WEST Advanced Technologies; Bell Atlantic Mobile Systems; GTE Laboratories Inc.; US WEST New Vector Group; General Electric Company; Motorola Inc.; Hewlett-Packard Company (HP); Integrator Corporation; AudioLogic, Inc.; Industrial Technology, Inc.; Netrix Corporation; Lucent Technologies; ARINC; Lehman Chambers; Lucent Digital Radio; Intel Corporation; the American Automobile Manufacturers Association; the University of Pennsylvania; and East Carolina University's Brody School of Medicine. 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 entered into a CRADA to conduct cooperative research and development in the area of telecommunications and multimedia for development of test equipment and products. The areas of interest include subjective and objective video quality, subjective and objective audio quality, and wireless communications.
- ITS is conducting a CRADA 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.
- ITS has been a premier laboratory in millimeter-wave research for two decades. Now ITS is applying this unique expertise while conducting research into radio propagation considerations for local multipoint distribution service (LMDS). ITS has initiated CRADAs with HP and Lucent Technologies for LMDS research. Under these agreements, ITS has developed propagation models for the LMDS channel, conducted field measurements to characterize radio frequency propagation of an LMDS system, and developed a three-dimensional signal coverage map of the area of interest for LMDS transmission.

- Lucent Technologies, Bell Laboratories, and ITS have entered into a CRADA to measure the transmission coefficient matrix associated with two 16-element arrays located above a ground plane. The purpose of this experiment is to validate Lucent Technologies' theoretical capacity study of the Bell Labs Layered Space-Time (BLAST) 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 have entered into a CRADA to conduct 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.

ITS engineer performing measurements of a multi-element antenna array built for 3G services (photograph by F.H. Sanders).

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, LMDS, 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.

For more information, contact:
Ronald L. Ketchum
(303) 497-7600
e-mail rketchum@its.bldrdoc.gov

ITU Standards Activities

Outputs

- Leadership of ITU 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 ITU-R develops Recommendations and contributes to Regulations addressing radio spectrum use, interference, propagation, and radio services. The ITU-T and ITU-R work programs are conducted in Study Groups whose responsibilities are distinguished on the basis of particular technical specialties and standards development needs. The Recommendations developed in these international organizations strongly impact 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 call processing and data transfer 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. ITS participants are currently working to extend the performance description principles and framework to integrated IP and telephony networks, and are developing objective, perception-based quality metrics for voice, video, and multimedia services.

The Institute's ITU-T leadership activities in 2001 were focused in two groups: Study Group 13 Working Party 4 (Network Performance and Resource Management) and Study Group 9 Working Group 2 (Quality Assessment). The former group develops performance Recommendations for high-speed synchronous digital hierarchy (SDH), broadband ISDN, ATM, wave division multiplexing (WDM), and IP-based network technologies. The latter group defines quality objectives for integrated broadband cable networks and television and sound transmission. During FY 2001, ITS also provided leadership and technical contributions to related work in the American National Standards Institute (ANSI) accredited T1 (Telecommunications) Committee's T1A1 (Performance and Signal Processing) Subcommittee. With strong input from T1A1, Working Party 4/13 completed a new Recommendation (Y.1541) that defines QoS Classes for IP-based networks supporting real-time services (e.g., Voice over IP). This Recommendation and its associated parameter definition standard (Recommendation I.380) are the first ITU-T Recommendations developed to deal specifically with IP network performance. They will be important in defining service level agreements (SLAs) among independent network operators collectively providing assured quality services over IP-based networks. The Y.1541 QoS Classes are summarized in the accompanying table. Recommendation Y.1541 also describes the kinds of applications that would typically use each QoS Class and indicates the node and transmission mechanisms that could be used to implement them. The node mechanisms include separate queues (with or without weighting or preferential servicing), traffic grooming (for example, to separate real-time streams from bulk file transfers), and drop priorities (to separate loss sensitive traffic from other IP flows). The transmission mechanisms include constraints on routing and distance.

Recommendation Y.1541 IP QoS Classes and Objectives

		QoS Classes and Objectives					
Network Performance Parameter	**Nature of Objective**	Class 0	Class 1	Class 2	Class 3	Class 4	Class 5
IP packet transfer delay (IPTD)	Upper bound on the mean IPTD	100ms	400ms	100ms	400ms	1 s	Unspec.
IP packet transfer delay variation (IPDV)	Upper bound on the $1\text{-}10^{-3}$ quantile of IPTD minus the minimum IPTD	50ms	50ms	U	U	U	Unspec.
IP packet loss ratio (IPLR)	Upper bound on the packet loss probability	$1*10^{-3}$	$1*10^{-3}$	$1*10^{-3}$	$1*10^{-3}$	$1*10^{-3}$	Unspec.
IP packet error ratio (IPER)	Upper bound	$1*10^{-4}$					Unspec.

ITU-R Recommendations provide the technical basis for spectrum allocation decisions and spectrum use both globally and regionally. They help ensure compatibility between radio systems operated by U.S. government and industry organizations and those operated in other countries. The agreements reached at ITU-R sponsored World Radiocommunication Conferences ultimately become international treaties for the United States. These impacts make it vital that U.S. interests and positions be effectively represented in ITU-R Recommendations and conference negotiations. Institute staff members have played a central role in the development of ITU-R (previously CCIR) Recommendations for over three decades, and a substantial proportion of existing ITU-R/CCIR Recommendations are based on ITS research. Experimental results and mathematical models developed at ITS are used throughout the world in the prediction of radio wave propagation, noise and interference, and area coverage. They provide technical information used by the Federal Communications Commission (FCC) and other regulatory agencies in controlling the locations, frequencies, and power levels of radio and television broadcast transmitters and in regulating terrestrial mobile communications.

ITS staff currently represent the U.S. in the activities of ITU-R Study Group 3 (Propagation) and its Working Parties, WP-3J (Propagation Fundamentals), WP-3K (Point-to-Area Propagation), WP-3L (Ionospheric Effects) and WP-3M (Point-to-Point, Earth-Space Propagation and Interference). During 2001, ITS staff members participated in WP-3M and WP-3J meetings and chaired Drafting Groups responsible for numerous WP 3 results. ITS assumed leadership of a special Task Group, TG 3/2, formed at the urgent request of several Administrations and other participants to accelerate progress on a proposed new Recommendation, ITU-R P.[BLM], "Method for point-to-area predictions for terrestrial services in the frequency range 30 to 3 000 MHz." The Task Group was asked to prepare the new Recommendation under tight time constraints to meet the need for international frequency coordination supporting the deployment of third generation (3G) wireless networks. To accelerate progress, ITS arranged for most of the group's work to be conducted by correspondence; provided an electronic repository for the Correspondence Group; and prepared detailed comments on all submissions. The Task Group met its objective on time, and the proposed new Recommendation (designated P.1546) was adopted at a special Study Group 3 meeting arranged specifically for that purpose. The new Recommendation extends, integrates, and supercedes existing ITU-R Recommendations P.370 and P.529, which were previously used separately in coordinating frequency use in broadcast and land mobile radio services.

For more information, contact:
Neal B. Seitz
(303) 497-3106
e-mail nseitz@its.bldrdoc.gov

The new ITS 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 ITS to consolidate efforts in several areas, such as the RF/network interface (photographs by S. Wolf).

ITS Tools and Facilities

Adaptive Antenna Testbed

The adaptive antenna testbed (ATB) is a multi-channel test facility based on ITS digital sampling channel probe technology (see also "Adaptive Antenna Testbed," pp. 52-53). The system can simultaneously characterize eight wideband radio channels (expandable to 16 with multiplexing). The received signals are digitized for flexible post processing. The table below summarizes the range of permissible values for the testbed, as well as giving an example of a third-generation wireless (3G) band configuration.

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 a common reference 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.

A well-characterized cell site in Boulder, Colorado, serves as a known platform for evaluating 3G components and systems. Alternately, the ATB transmitting and receiving systems may be van-mounted for site mapping studies at any required location.

Contact: Peter B. Papazian (303) 497-5369
e-mail: ppapazian@its.bldrdoc.gov

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 switchers 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.

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.

Contact: Stephen D. Voran
(303) 497-3839
e-mail: svoran@its. bldrdoc.gov

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 both a transmitter and receiver, is used to make complex impulse response measurements. Unlike the analog sliding correlator equivalent, the DSCP digitizes the received signal at an intermediate frequency (IF) and then processes the data, thus providing the advantages of digital processing. Relative to the sliding correlator, the time over which the impulse is generated is also less, and therefore, can characterize the communication channel over a shorter period of time. Historically the DSCP has been employed extensively for characterization of cellular and PCS channels. 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 ITS web site: http://flattop.its.bldrdoc.gov/rcirms/

Contact: Peter B. Papazian (303) 497-5369
e-mail: ppapazian@its.bldrdoc.gov

ITS Home Page: http://www.its.bldrdoc.gov

ITS Internet Services

ITS provides public Internet access to NTIA/ITS publications, program 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
- *Telecom Glossary 2000*. Available at http://www.its.bldrdoc.gov/projects/telecomglossary2000/
- 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

Contact: Jeanne M. Ratzloff (303) 497-3330
e-mail: webmaster@its.bldrdoc.gov

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.

Contact: Gregory R. Hand (303) 497-3375
e-mail: netmgr@its.bldrdoc.gov

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.

Contact: John M. Vanderau (303) 497-3506
e-mail: jv@its.bldrdoc.gov

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 at 450 MHz, 1350 MHz, 1920 MHz, 2.3 GHz, 5.8 GHz, and 30.3 GHz. Impulse response measurement capability at 30.3 GHz with 2ns resolution has been enhanced with the addition of a wideband digital recording system. During the past year ITS increased its mobile channel measurement capability with the addition of a phased array antenna 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.

Contact: Peter B. Papazian (303) 497-5369
e-mail: ppapazian@its.bldrdoc.gov

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.

Contact: Arthur A. Webster (303) 497-3567
e-mail: awebster@its.bldrdoc.gov

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. Other agencies anticipate using the generator in their radar research programs.

Contact: Brent Bedford (303) 497-5288
e-mail: bbedford@its.bldrdoc.gov

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.

Contact: Robert J. Achatz (303) 497-3498
e-mail: rachatz@its.bldrdoc.gov

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 system, is a vehicularly mounted, self-contained facility for measurements between 1 MHz and 24 GHz. A fourth-generation RSMS (RSMS-4) is expected to be designed and built in FY 2002. ITS also has available a number of suitcase-deployable systems called Compact Radio Spectrum Measurement Systems (CRSMS). RSMS and CRSMS facilities incorporate a combination of commercial off-the-shelf hardware, hardware designed by ITS, and software written by ITS. The RSMS is RF-shielded, and includes two 30-ft masts, an on-board 10-kW generator, air conditioners, dual measurement systems in four full-height equipment racks, and storage for accessory equipment and spares. CRSMS capabilities utilize the same software but typically include only as much hardware as is required for a specific measurement task. Local arrangements must be made for CRSMS shelter and power.

Both RSMS and CRSMS 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, ISM devices, broadcast signals, and special-purpose transmitter systems can be measured and analyzed. For a complete description of the RSMS, go to ITS on-line publications (http://www.its.bldrdoc.gov) and download applicable appendices from any RSMS measurement report (e.g., Appendix A of NTIA Report 97-334; see Publications Cited, pp. 96).

Contact: Frank H. Sanders (303) 497-5727
e-mail: fsanders@its.bldrdoc.gov

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.

Contact: Brent Bedford (303) 497-5288
e-mail: bbedford@its.bldrdoc.gov

Spectrum Compatibility Test and Measurement Sets

The introduction of new radio technologies in close physical and frequency proximity to older ones often causes electromagnetic compatibility (EMC) problems. Although 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 an interfering signal with known characteristics in environments where the candidate interferer may be unavailable for use. This includes situations such as laboratory tests using interference from ship- or aircraft-mounted radars or communication systems. In both situations a system is needed which can simulate the spectral emissions of other devices with a wide range of latitude.

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 the system under test or they can be transmitted into the 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 emissions can be digitized using high-speed samplers. The digitized waveforms (in bandwidths up to 30 MHz and at frequencies as high as 26 GHz) are stored for later use. When needed, the exact amplitudes, frequency components, and phase components of the signals can be played back using arbitrary waveform generators and selected RF signal generators. The advantage of this arrangement is that very complex waveforms can be replicated with complete confidence that the simulated signal exactly matches the original signal from which it was derived.

Contact: Frank H. Sanders (303) 497-5727
e-mail: fsanders@its.bldrdoc.gov

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.

Contact: Val M. O'Day (303) 497-3484
e-mail: voday@its.bldrdoc.gov

Telecom Glossary 2000 Web Page

Telecom Glossary 2000 (see pp. 30-31) is available free to the public on the web at the URL http://www.its.bldrdoc.gov/projects/telecomglossary2000/

The glossary is an update of FED-STD-1037C, *Glossary of Telecommunication Terms* (1996). The completed, up-to-date, hyperlinked, web-accessible *Telecom Glossary 2000* is now an American National Standard, ANS T1.523-2001. It is available free to the public also on the ATIS/T1 web site http://www.atis.org/tg2k/

The new *Telecom Glossary 2000* provides 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),

Web page for ANS T1.523-2001, Telecom Glossary 2000.

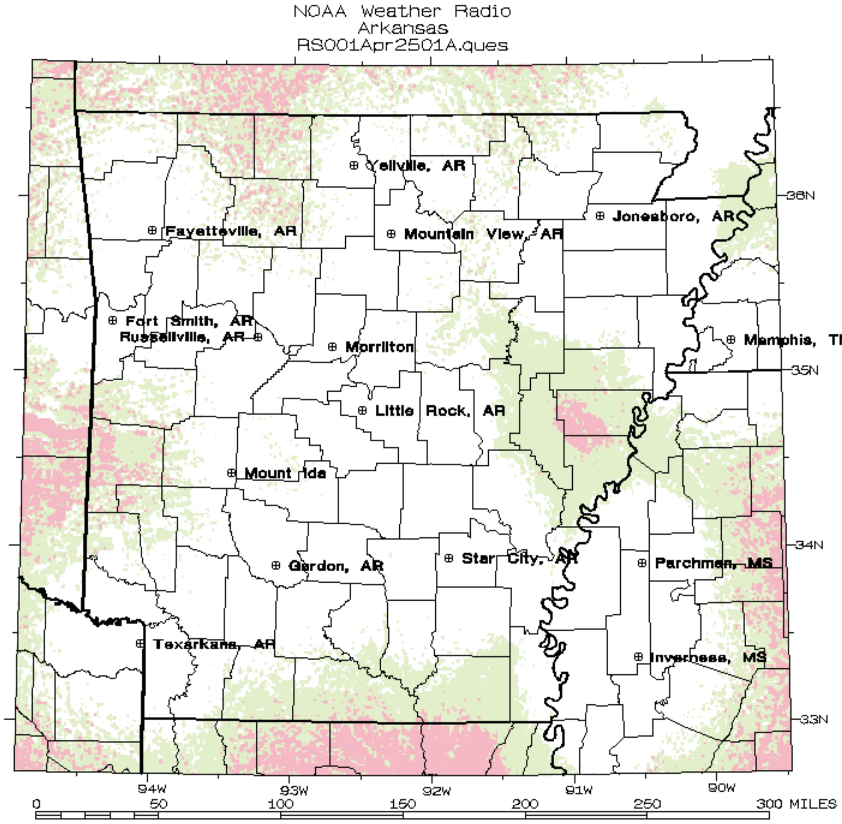
communications security, data processing, premises wiring, grounding and bonding, telegraphy, and video. Recently added disciplines include web terminology, T1 Standards, information assurance/security, and photonics. The glossary is presented in hypertext with clickable graphics and 69,000 hyperlinks to defined terms. The web site 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 glossary is 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.

Contact: Evelyn M. Gray (303) 497-3307
e-mail: egray@its.bldrdoc.gov

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 some 1-arc-second (30 m) and 3-arc-seconds (90 m) resolution for much of the world and GLOBE (Global Land One-km Base Elevation) data for the entire world; 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 was



Example of a composite coverage analysis using CSPM.

recently upgraded and is now ten times faster than before with about 210 gigabytes of storage capacity (three times the previous capacity). Recently obtained 1-arc-second (30 m) terrain data for CONUS with some data at 10 m resolution will become available later in FY 2002. 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.
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 above. Plotted outputs can be faxed to the user, plotted on clear plastic for overlaying on geopolitical

maps, or downloaded to the user site (in HPGL, GIF, or TARGA format). This program uses 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 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.
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.

Contact: Gregory R. Hand (303) 497-3375
e-mail: ghand@its.bldrdoc.gov

Ultrawideband (UWB) Interference Testing Laboratory

The Ultrawideband (UWB) Interference Testing Laboratory has been assembled for the purpose of evaluating the performance of radio systems when exposed to varying levels of UWB signal power. Over the past year, this fully-automated laboratory was configured for measuring the effects UWB signals may have on Global Positioning System (GPS) receivers. ITS, in cooperation with NTIA's Office of Spectrum Management, has performed these measurements to provide input for timely policy and regulatory decisions by NTIA and the Federal Communications Commission. Three signal sources — the desired GPS signal, the undesired UWB signal, and white noise — are attenuated, combined, and then injected (by conducted means) into various GPS receivers while the values for various performance metrics for each receiver are measured simultaneously. To maintain a controlled environment and thus ensure repeatable measurements, the GPS signals are generated using a simulator. UWB signals are produced by a narrow pulse generator driven by an arbitrary waveform generator or by custom driver circuits. A variety of UWB signal structures can be generated by varying the pulse dithering process (pulse spacing), the pulse repetition frequency (PRF), and signal gating. In addition, an aggregate of up to six UWB signals can be generated and combined for investigating the effects this signal may have on other radio systems. Currently the UWB Interference Testing Laboratory is being configured to investigate UWB interference effects on public safety radio systems.

Contact: Randy Hoffman (303) 497-3582
e-mail: rhoffman@its.bldrdoc.gov

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.

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.

Contact: Christopher J. Behm (303) 497-3640
e-mail: cbehm@its.bldrdoc.gov

Audio quality research is performed in a state-of-the-art laboratory at ITS. Researchers identify and respond to selected open questions surrounding quality issues in digital speech and audio compression and transmission, especially Internet transmission of compressed audio (photograph by S. Wolf).

ITS Projects in FY 2001

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. Deliverables include technical publications, algorithms, software, and technical presentations and laboratory demonstrations as requested.
Project Leader: Stephen D. Voran (303) 497-3839
e-mail svoran@its.bldrdoc.gov

Broadband Wireless Research Provide radio-wave propagation data between 100 MHz and 100 GHz, in order to promote the use of this portion of the radio spectrum and new signal processing methods that increase spectrum utilization and channel capacity, as well as the development of new wideband wireless data services. Deliverables include a CD-ROM of channel measurement data.
Project Leader: Peter B. Papazian (303) 497-5369
e-mail ppapazian@its.bldrdoc.gov

Broadband Wireless Standards Develop technical means to improve predictions of signal coverage and interference for 3G wireless services through support to ITU-R (e.g., SG 3/Working Party 3K) 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
e-mail pmckenna@its.bldrdoc.gov

Network Interoperability Evaluate a preliminary (systems engineering-oriented) framework constructed in FY 2000 for analyzing and understanding interoperability issues; quantify levels of interoperability achievable through techniques such as signaling and control technologies; validate alternative approaches via analysis and simulation.
Project Leader: Randall S. Bloomfield (303) 497-5489
e-mail rbloomfield@its.bldrdoc.gov

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

Networking Technology Continue research into network planning and analysis technologies to address Government needs for better network performance, reliability, and cost effectiveness. Deliverables include an NTIA Report.
Project Leader: Val Pietrasiewicz (303) 497-5132
e-mail valp@its.bldrdoc.gov

Policy Support Provide engineering and technical support to NTIA in telecommunications policy development. Provide support in various technical analyses including broadband wireless access, 3rd generation wireless systems, privacy issues, information technology advances, and critical infrastructure protection.
Project Leader: Val M. O'Day (303) 497-3484
e-mail voday@its.bldrdoc.gov

Potential Interference from UWB Signals to GPS Receivers Investigate potential interference to Global Positioning System (GPS) receivers from ultrawideband (UWB) devices and assist NTIA/OSM as necessary in completing the formulation of Part 15 UWB regulations.
Project Leader: J. Randy Hoffman (303) 497-3582
e-mail rhoffman@its.bldrdoc.gov

Propagation Model Support Provide propagation model support to NTIA/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
e-mail pmckenna@its.bldrdoc.gov

Re-write of ITU Document 1177 Re-write the ITU-R Draft Recommendation M.1177-1B, Working Party 8B, “Techniques for Measurement of Unwanted Emissions of Radar Systems,” (Question ITU-R 202/8), and represent the U.S. Administration as a delegate at the ITU in Geneva for the purpose of supporting this document.
Project Leader: Frank H. Sanders (303) 497-5727
e-mail fsanders@its.bldrdoc.gov

RSMS Operations Provide NTIA with critical measurement support to determine broadband spectrum occupancy across the U.S.; resolve interference problems involving Government radio systems; and determine the emission characteristics of radio transmitter systems that may affect Government operations or that may be acquired by Government agencies.
Project Leader: Frank H. Sanders (303) 497-5727
e-mail fsanders@its.bldrdoc.gov

RSMS Enhancements Develop new capabilities for the fourth generation of the Radio Spectrum Measurement System (RSMS), including new techniques, algorithms, and hardware.
Project Leader: Frank Sanders (303) 497-5727
e-mail fsanders@its.bldrdoc.gov

Third Generation Wireless Develop accurate attenuation, frequency selective fading, noise, and interference radio channel models for proposed 3G wireless standards. Deliverables include articles, reports, and presentations.
Project Leader: Robert J. Achatz (303) 497-3498
e-mail rachatz@its.bldrdoc.gov

Third Generation Wireless Interference Modeling and Characterization Building on previous ITS work, develop interference models for each PCS technology, and apply the models in characterizing one-on-one, one-on-many, and many-on-one PCS interference for 3G architectures. 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
e-mail triley@its.bldrdoc.gov

Unintentional Part 15 Radiator Emission Measurements Measure and document broadband radio-frequency (RF) emissions from a variety of personal computers. Use these data to compare these unintentional emissions (regulated by FCC CFR 47 Part 15 Rules) with those from ultrawideband (UWB) emitters measured previously by ITS.
Project Leader: Frank H. Sanders (303) 497-5727
e-mail fsanders@its.bldrdoc.gov

Video Quality Research Develop the required technology for assessing the performance of advanced television and other digital video transmission systems (e.g., HDTV and video teleconferencing), and actively transfer this technology to other Government agencies, standards bodies, and the U.S. telecommunications industry. Deliverables include software, conference and journal papers, and technical standards contributions.
Project Leader: Stephen Wolf (303) 497-3771
e-mail swolf@its.bldrdoc.gov

Voice Over IP (VoIP) Provide engineering and technical support to NTIA/OSM’s Public Safety Program. Evaluate the requirements and restrictions of current VoIP technology.
Project Leader: Robert Stafford (303) 497-7835
e-mail rstafford@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 for the Department, provide engineering services and technical assistance consistent with the current priorities of the 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

International Symposium on Advanced Radio Technologies Develop the 2002 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: William A. Kissick (303) 497-7410
e-mail wkissick@its.bldrdoc.gov

PCS/LMDS for DoD Enhance the ITS PCS/LMDS model (developed in the Geographic Information System (GIS) environment) by adding interference capability and converting the model to run on an NT-based system.
Project Leader: Robert O. DeBolt (303) 497-5324
e-mail rdebolt@its.bldrdoc.gov

Department of Justice

LMR Usage Statistics and Engineering Studies Assist DOJ's Wireless Management Office (WMO) with 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

Public Safety Wireless Network (PSWN) Support Provide support for the PSWN in public safety standards efforts with the Telecommunications Industry Association (TIA) TR-8 process, and 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

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

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

Investigation of Potential Interference from UWB Signals to GPS Receivers Accelerate and expand the project to provide an initial assessment of ultra-wideband (UWB) interference to Global Positioning System (GPS) receivers.
Project Leader: J. Randy Hoffman (303) 497-3582
e-mail rhoffman@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 Wireless Communications Task Force (WCTF), to include providing technical review, support, and guidance related to FRA's plans to develop a radio communications experimental testbed facility.
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

Advanced HF Applications As the Federal representative to the MIL-STD-188-110B Working Group, review the standard and coordinate comments from the Federal users community. Write a final report on the low-cost ALE system developed by ITS in FY 1999, in order to provide documentation for users.
Project Leader: Christopher Redding (303) 497-3104
e-mail credding@its.bldrdoc.gov

Digital Land Mobile Radio Standards Development Assist NCS in developing a comprehensive set of interoperability standards for digital land mobile radio, for public safety applications, by leading the Project 25 Encryption Task Group, providing systems engineering support to other Task Groups, developing security standards, and participating on various steering committees.
Project Leader: William J. Pomper (303) 497-3730
e-mail wpomper@its.bldrdoc.gov

Mobile IP Network Access Technologies
Enhance NS/EP responder access to network-based information by evaluating and demonstrating emerging technologies for mobile access to IP networks. Deliverables include a wireless network data collection system.
Project Leader: Christopher J. Behm (303) 497-3640
e-mail cbehm@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; apply computer simulation and other reliability analysis and traffic engineering tools to assess and optimize public network reliability, identify network disruptions, and restore services, in support of Critical Infrastructure Protection (CIP) initiatives.
Project Leader: Arthur A. Webster (303) 497-3567
e-mail awebster@its.bldrdoc.gov

Priority Services in Converging Networks
Assist NCS in extending GETS-like priority access capabilities to wireless and broadband infrastructures, selected international services, and IP-based networks through technical contributions and leadership in telecommunication standards committees, prototype testing and evaluation of advanced NS/EP technologies, and the development of a system for displaying commercial wireless service coverage and associated NS/EP infrastructures.
Project Leader: Christopher J. Behm (303) 497-3640
e-mail cbehm@its.bldrdoc.gov

Standards Promulgation Support Update key standards and Recommendations to maintain their value; prepare web, CD-ROM, and search-engine equipped versions of selected documents to facilitate their distribution; help prepare open literature publications to expand public awareness and use of NCS standards products; and provide leadership and administrative support for selected standards development activities.
Project Leader: Neal B. Seitz (303) 497-3106
e-mail nseitz@its.bldrdoc.gov

Tandem Vocoder Objectively evaluate tandem vocoding systems, by measuring the voice quality of various combinations, to establish the feasibility (from a voice quality perspective) of tandeming vocoders in order to relay voice communications between disparate systems. Deliverables include an NTIA Report.
Project Leader: Christopher Redding (303) 497-3104
e-mail credding@its.bldrdoc.gov

USSG B Standards Support Provide administrative focal point and support for ITAC-T U.S. Study Group B – Network Infrastructure Study Group.
Project Leader: Marcia L. Geissinger

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 help develop and validate interoperability standards for the justice and public safety communities. Provide technical assessments and evaluations of products and services. Deliverables include standards, reports, guides, guidelines, handbooks, white papers, and other products.
Project Leader: Val J. Pietrasiewicz (303) 497-5132
e-mail valp@its.bldrdoc.gov

US Air Force

Assessment of UWB and GPS Compatibility Provide an initial assessment of ultrawideband (UWB) interference to Global Positioning System (GPS) receivers, through the measurement of specified GPS receiver parameters which are used to determine the performance of the receivers when exposed to various UWB signals.
Project Leader: J. Randy Hoffman (303) 497-3582
e-mail rhoffman@its.bldrdoc.gov

US Army

Signature Management and Deception Support Assist the Night Vision Electronic Sensors Directorate (NVESD) in defining an updated signature management communication system.
Project Leader: Edmund A. Quincy (303) 497-5472
e-mail equincy@its.bldrdoc.gov

US Coast Guard

US Coast Guard Measurements Assess the protection ratios and separation distances between AIS transponders and PC mobile units that are operating on the same ship; generate measured data for input into a future RTCM marine handheld receiver standard.
Project Leader: Brent L. Bedford (303) 497-5288
e-mail bbedford@its.bldrdoc.gov

Cooperative Research and Development Agreements (CRADAs)

American Automobile Manufacturers Association

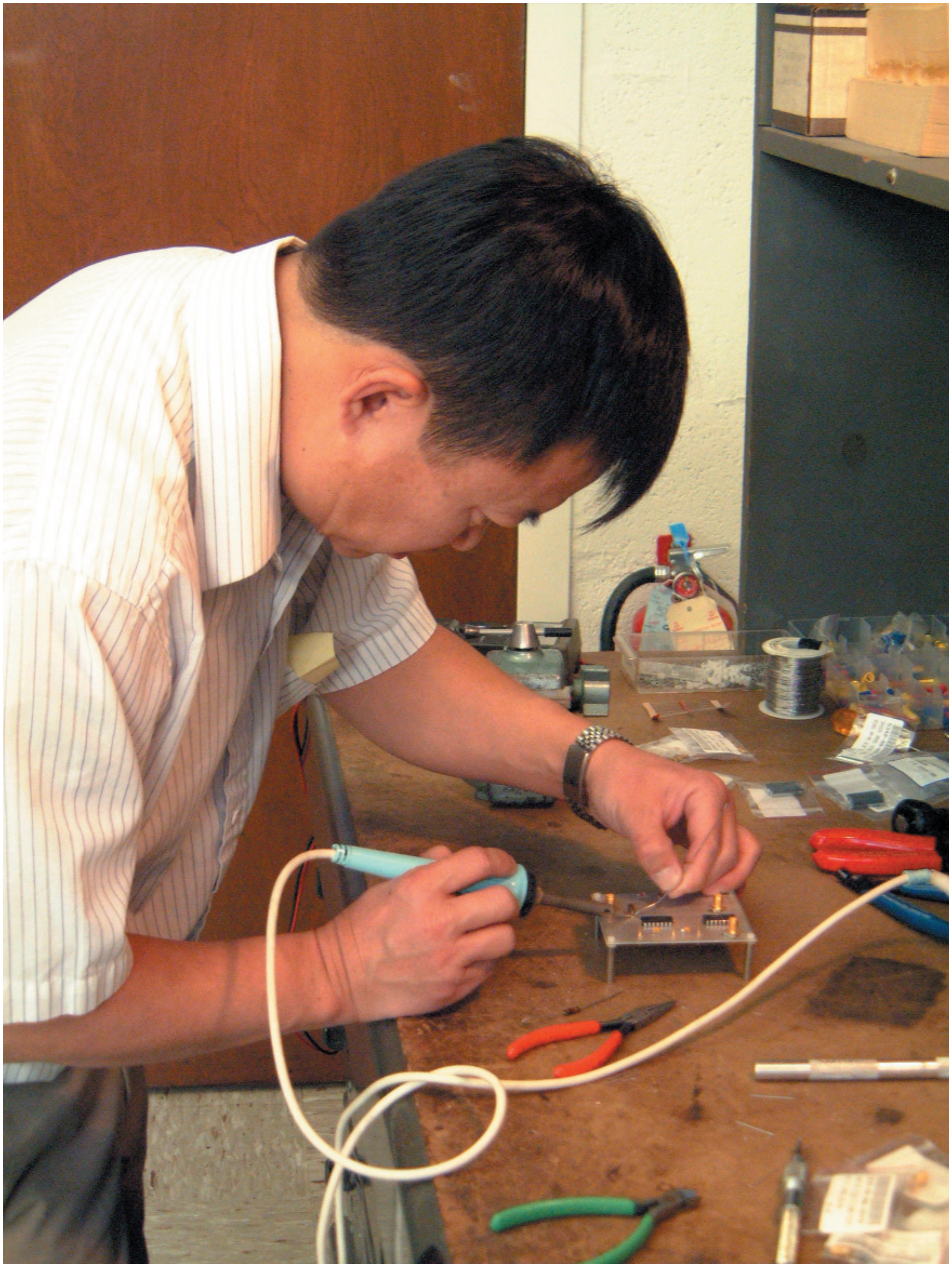
RF Environmental Measurements Provide data on the maximum field strengh levels encountered within the vicinity of high power radar transmitters. Deliverables include a report to the sponsor.
Project Leader: Frank H. Sanders (303) 497-5727
e-mail fsanders@its.bldrdoc.gov

ARINC

Spectrum Planning Tool Set Support and enhance the Spectrum Management Toolset (SMTS) software developed by ITS for ARINC, which predicts the coverage of a wide range of communication systems.
Project Leader: Robert O. DeBolt (303) 497-5324
e-mail rdebolt@its.bldrdoc.gov

Lucent Technologies

BLAST Capacity Measurements Validate Lucent's theoretical capacity study of the Bell Labs Layered Space-Time (BLAST) theory.
Project Leader: Peter Papazian (303) 497-5369
e-mail ppapazian@its.bldrdoc.gov



ITS engineer assembling custom-designed hardware for measurements at the ITS Boulder Laboratories (photograph by F.H. Sanders).

ITS Outputs in FY 2001

NTIA Publications

J.R. Hoffman, M.G. Cotton, R.J. Achatz, R.N. Statz, and R.A. Dalke, “Measurements to determine potential interference to GPS receivers from ultrawideband transmission systems,” NTIA Report 01-384, Feb. 2001.

> This report describes laboratory measurements of Global Positioning System (GPS) receiver vulnerability to ultrawideband (UWB) interference. The laboratory measurements were performed by inserting increased levels of UWB interference until an operating GPS receiver lost lock. At each interference level leading up to loss of lock, reacquisition time, fundamental GPS measurements (e.g., pseudorange and carrier phase), status flags (e.g., potential cycle slips), and position data were sampled. A variety of UWB signals were tested, including aggregates of as many as six UWB sources. Two GPS receivers with different receiver architectures were tested.

J.R. Hoffman, M.G. Cotton, R.J. Achatz, and R.N. Statz, “Addendum to NTIA Report 01-384: Measurements to determine potential interference to GPS receivers from ultrawideband transmission systems,” NTIA Report 01-389, Sep. 2001.

> This addendum to NTIA Report 01-384 describes laboratory measurements on two additional Global Positioning System receivers to quantify the effects of ultrawideband interference on those receivers. The laboratory measurements were performed by inserting increased levels of UWB interference until an operating GPS receiver lost lock. At each interference level leading up to loss of lock, reacquisition time was determined. When possible, fundamental GPS measurements (e.g., pseudorange and carrier phase), status flags (e.g., potential cycle slips), and signal-to-noise ratio were also sampled.

C.L. Holloway, F.H. Sanders, and P.M. McKenna, “Predicted and measured field strengths in the Boulder, Colorado, area from two proposed terrestrial digital television tower sites,” NIST Technical Note 1519 and NTIA Report 01-387, May 2001.

> A study was performed to determine the increase in ambient electromagnetic field strengths that would result from a proposal to locate a cluster of terrestrial digital television (DTV) transmission towers in proximity to the Department of Commerce (DOC) Laboratories in Boulder, Colorado. The primary objective of this study was to assess the impact on a broad range of Federal Government research and metrology programs that depend upon the relatively quiet radio-frequency electromagnetic environment. Radio-wave propagation measurements were performed for two terrestrial DTV frequencies (533 MHz and 772 MHz), and used to verify predicted DTV electric field strengths obtained from the DOC Irregular Terrain Model (ITM). The measured data were also used to determine the variation in received signal strength over small distance intervals. Radio-wave propagation measurements were performed at both frequencies using two possible mountaintop transmitter locations, Eldorado Mountain and Squaw Mountain. The first (Eldorado Mountain) affords substantial line-of-sight coverage over the Boulder area, and the second (Squaw Mountain) affords only indirect (diffractive) coverage over the same area. The two propagation conditions from each site, direct and indirect, respectively, are compared to the ITM predictions. The relative variations in measured and predicted signal strengths are compared as a function of frequency and of propagation conditions. Measured and predicted data were found to be in close agreement. This provides confidence that the theoretical predictions of received signal strengths at given locations in the Boulder area are accurate. It was found that in some locations, the ambient field strengths for 1 MW of transmitter power from a single station will exceed 1 V/m.

W.J. Ingram and E.M. Gray, “On-line development of an interactive web glossary,” NTIA Report 01-385, Apr. 2001.

This report describes the electronic, computer-based processes of creating an on-line, Web-based glossary of telecommunication terms — American National Standard, T1.523-2001, *Telecom Glossary 2000*. These e-mail processes or Web-based processes constituted electronic meetings or “virtual meetings” to solicit public review comments for updating the glossary. The programming design, structure, and some of the code used to gather e-mail comments and to build the glossary Web pages are discussed in the report. With the exception of the kickoff meeting and the resolution meeting, all interim meetings of the glossary-development Ad Hoc Group consisted of e-mail exchanges or Web-page modifications. This electronic meeting forum allowed a broader participation in the revisions, wider distribution of comments, speedier development of the glossary, and economy of resources. The completed product is scheduled to be available free of charge to the public on the ATIS (Alliance for Telecommunications Industry Solutions)/T1 Web site.

W.A. Kissick, Ed., “The temporal and spectral characteristics of ultrawideband signals,” NTIA Report 01-383, Jan. 2001.

Ultrawideband (UWB) technology, useful for both communication and sensing applications, uses the radio spectrum differently than the vast majority of radiocommunication technologies. UWB systems make use of narrow pulses and time-domain signal processing. Questions regarding how these systems, with their potentially very wide emission bandwidths, might affect the efficient use of the radio spectrum or cause interference to conventional radio and wireless systems must be answered before there is any large-scale deployment of UWB systems. The investigation reported here examined both the temporal and spectral characteristics of UWB signals, since all radio signals exist in both the time and frequency domains. The investigation was approached with theoretical analyses, measurement of actual UWB devices, and computer simulations. The emissions of several UWB transmitters were measured under controlled, and repeatable, laboratory conditions. Those measurement methods useful for routine measurements using commercially-available test equipment were identified. The characteristics of an aggregate of several UWB signals were examined. An initial assessment of the effects of UWB signals on several Federal Government systems was accomplished through field measurements. This report provides a basis for an assessment of the effects of UWB signals on other communication and radar systems, the study of the spectrum efficiency of UWB technologies, and the development of spectrum sharing policies and regulations.

P. Papazian, P. Wilson, M. Cotton, and Y. Lo, “Flexible interoperable transceiver (FIT) program test range I: Radio propagation measurements at 440, 1360 and 1920 MHz, Edwards Air Force Base, CA,” NTIA Report 00-380, Oct. 2000.

Radiowave propagation measurements at Edwards Air Force Base, CA are described. These measurements were made as part of the Flexible Interoperable Transceiver (FIT) Program. The objective of the measurements is to define communication link requirements at 440, 1360, and 1920 MHz. Simultaneous wideband measurements at three frequencies were made using fixed transmitters and a mobile fitted with a multi-channel receiver. The system measured the radio channel impulse response. Data outputs include delay spread and basic transmission loss. These parameters are compared at the three measurement frequencies to determine additional propagation impairments military systems will suffer due to frequency translation from 440 MHz to 1360 MHz and 1920 MHz.

P. Papazian, P. Wilson, M. Cotton, and Y. Lo, “Flexible interoperable transceiver (FIT) program test range II: Radio propagation measurements at 440, 1360 and 1920 MHz, Ft. Hood, Texas,” NTIA Report 00-381, Oct. 2000.

Radiowave propagation measurements at Ft. Hood, Texas are described. These measurements were made as part of the Flexible Interoperable Transceiver (FIT) Program. The objective of the measurements is to define communication link requirements at 440, 1360, and 1920 MHz. Simultaneous wideband measurements at three frequencies were made using fixed transmitters and a mobile fitted with a multi-channel receiver. The system measured the radio channel impulse response. Data outputs include delay

spread and basic transmission loss. These parameters are compared at the three measurement frequencies to determine additional propagation impairments military systems will suffer due to frequency translation from 440 MHz to 1360 MHz and 1920 MHz.

C. Redding, N. DeMinco, and J. Lindner, "Voice quality assessment of vocoders in tandem configuration," NTIA Report 01-386, Apr. 2001.

This report describes the objective testing of various vocoders, both singly and in different combinations of tandem configurations, to evaluate overall voice quality in an objective manner. The objective test evaluation was performed using a standardized (and patented) objective voice quality estimation algorithm developed by the Institute for Telecommunication Sciences (ITS). This method determines an auditory distance (AD) and converts it to a finite scale that can be related to the mean opinion score (MOS) scale commonly used in subjective voice quality tests. This testing establishes the feasibility (from a voice quality perspective) of using vocoders in a tandem configuration in order to relay voice communications between disparate systems.

J.A. Wepman and J.R. Hoffman, "Implementation and testing of a software defined radio cellular base station receiver," NTIA Report 01-388, Jul. 2001.

Software defined radios (SDR's) represent a departure from traditional radio design. There is some mystique about what SDR's are, how they are designed, how they operate, and how performance is determined or verified. This report provides insight into some of these SDR aspects by presenting a detailed example SDR receiver design along with a set of performance measurements at various stages of the receiver. For this example, an Advanced Mobile Phone System (AMPS) cellular B-band base station receiver was configured using SDR technology. The architecture consists of a cellular B-band analog downconverter and digitizer, a digital downconverter that operates in a personal computer, a first-in, first-out (FIFO) buffer memory board, and an analog audio processor. The modular architecture permits signals to be observed at several stages of processing: the digitized IF output, the digitally downconverted and filtered baseband output, the digital FM demodulator output, and the analog audio output. A wide variety of measurements under various RF input signal conditions were made at each of the processing stages. Results of particular interest include the effects of aliasing and the ability to detect a low-level desired signal in the presence of a high-level, in-band interfering signal. The SDR AMPS receiver, while possessing the inherent flexibility advantages of SDR's, easily met the TIA/EIA-712 cellular base station standards for adjacent and alternate channel desensitization, intermodulation spurious response attenuation, and protection against spurious response attenuation.

P. Wilson, E. Haakinson, and R. Dalke, "Vulnerability of wireline and cellular telecommunications networks to high power radio frequency fields," NTIA Report 01-382, Nov. 2000.

High level electromagnetic fields can upset and damage electronics, as well as disrupt or disable computer software. Thus, high power radio frequency (RF) fields pose a threat to critical infrastructures such as telecommunications. This report examines the vulnerability of public and emergency telecommunications networks to high power RF fields, at the network and nodal levels. The assessment of network level vulnerability requires an examination of the system architecture and how redundancy and robustness are used to compensate for nodal loss or overload. The overall public telecommunications network has sufficient redundancy and capacity to withstand the loss of even multiple nodes. A full system collapse is not envisioned as a possible scenario. However, large local blackouts are possible. The assessment of nodal level vulnerability involves estimating the coupling of high level RF fields to sensitive equipment located at a node. Neither public network switching stations nor cellular base stations are intentionally hardened against high level RF fields. Typical steel reinforced concrete walls provide little shielding for frequencies above a few hundred MHz. Thus, a switching station could be disrupted (10 to 100 thousand users) by a high power RF device in this frequency range, although the probability of disruption is difficult to assess due to the variety and complexity of building layouts. Wireless base stations are highly vulnerable to high power fields coupling via the antennas.

Outside Publications

Articles in Conference Proceedings

W. Ashmawi, R. Guerin, S. Wolf, and M. Pinson, "On the impact of policing and rate guarantees in Diff-Serv networks: A video streaming application perspective," in *Proc. ACM SIGCOMM 2001* (Assoc. for Computing Machinery, Special Interest Group on Data Communications), Aug. 2001.

> Over the past few years, there have been a number of proposals aimed at introducing different levels of service in the Internet. One of the more recent proposals is the Differentiated Services (Diff-Serv) architecture, and in this paper we explore how the policing actions and associated rate guarantees provided by the Expedited Forwarding (EF) translate into perceived benefits for applications that are the presumed users of such enhancements. Specifically, we focus on video streaming applications that arguably have relatively strong service quality requirements, and which should, therefore, stand to benefit from the availability of some form of enhanced service. Our goal is to gain a better understanding of the relation that exists between application level quality measures and the selection of the network level parameters that govern the delivery of the guarantees that an EF based service would provide. Our investigation, which is experimental in nature, relies on a number of standard streaming video servers and clients that have been modified and instrumented to allow quantification of the perceived quality of the received video stream. Quality assessments are performed using a Video Quality Measurement tool based on the ANSI objective quality standard. Measurements were made over both a local Diff-Serv testbed and across the QBone, a QoS enabled segment of the Internet2 infrastructure. The paper reports and analyzes the results of those measurements.

S. Wolf and M.H. Pinson, "The relationship between performance and spatial-temporal region size for reduced-reference, in-service video quality monitoring systems," in *Proc. 5th World Multiconf. on Systemics, Cybernetics, & Informatics (SCI) and 7th Internat. Conf. on Information Systems Analysis & Synthesis (ISAS)*, Orlando, FL, Jul. 2001.

> This paper presents objective-to-subjective correlation results for a reduced-reference, in-service, video quality monitoring system. This reduced-reference system utilizes quality parameters that are computed by comparing features extracted from spatial-temporal (S-T) regions of the input video stream with identical features extracted from the output video stream. The amount of reduced-reference information that is required to compute the quality parameters is inversely related to the size of the S-T region. Smaller amounts of reference information (i.e., larger S-T regions) are desired since less transmission or storage bandwidth is required for the reference information. However, objective-to-subjective correlation drops off if the S-T region size becomes too large. In this paper we examine the tradeoffs between objective-to-subjective correlation results and S-T region size. Correlation results for S-T region sizes from 8 vertical lines x 8 horizontal pixels x 2 video frames to 128 x 128 x 24 are presented. These results utilized a total of nine subjectively rated data sets that span an extremely wide range of bit rates and compression techniques. Thus, designers of television video systems as well as Internet video streaming systems may use the results.

Journal Articles

R.A. Dalke, C.L. Holloway, P. McKenna, M. Johansson, and A.S. Ali, “Effects of reinforced concrete structures on RF communications,” *IEEE Trans. on EMC*, v. 42, n. 4, pp. 486-496, Nov. 2000.

> The proliferation of communication systems used in and around man-made structures has resulted in a growing need to determine the reflection and transmission properties of various commonly used building materials at radio frequencies typically used in businesses and residential environments. This paper describes the calculation of reflection and transmission coefficients for reinforced concrete walls as a function of wall thicknesses and rebar lattice configuration over a frequency range of 100-6000 MHz. The transmission and reflection coefficients were calculated using a finite-difference time-domain (FDTD) solution of Maxwell's equations. The rebar structures analyzed include both a two-dimensional (2-D) trellis-like structure and a one-dimensional (1-D) structure, where the reinforcing bars are all oriented in the same direction. In general, the results show that the reinforced concrete structures severely attenuate signals with wavelengths that are much larger than the rebar lattice and that the transmitted signal has a complex structure with resonances and nulls that strongly depend upon the geometry of the reinforcing structure and the concrete wall thickness.

C.L. Holloway, D.A. Hill, R.A. Dalke, and G.A. Hufford, “Radio wave propagation characteristics in lossy circular waveguides such as tunnels, mine shafts, and boreholes,” *IEEE Trans. on Antennas and Prop.*, vol. 48, no. 9, pp. 1354-1366, Sep. 2000.

> In this paper, we present the characteristics of radio propagation in a circular lossy waveguide whose walls are composed of earth soil materials with frequency-dependent properties. This type of structure is used to represent a radio link for an underground wireless communication channel such as a tunnel, mine shaft, or borehole. We present calculated results of the attenuation constant for various propagation modes in the soil waveguide structure for various soil constituents and moisture levels. Transverse field plots of the various modes for different soil types are also presented. Finally, it is shown that for small $|k_2a|$ (where k_2 is the wavenumber in the soil and a is the radius of the waveguide) some modes in the waveguide disappear and a discussion of this behavior and how it relates to excitation problems is given.

C.L. Holloway and E.F. Kuester, “Impedance-type boundary conditions for a periodic interface between a dielectric and a highly conducting medium,” *IEEE Trans. on Antennas and Prop.*, vol. 48, no. 10, pp. 1660-1672, Oct. 2000.

> Using the homogenization method, we derive a generalized impedance-type equivalent boundary condition for the electromagnetic (EM) field at a two-dimensional (2-D) periodic highly conducting rough surface with small-scale roughness. The results obtained in this paper generalize ones obtained previously for the case of a perfectly conducting rough surface. We will show that the coefficients in this equivalent boundary condition can be interpreted in terms of electric and magnetic polarizability densities. We also show that when the roughness dimensions are small compared to a skin depth of the conducting region (a smooth interface), the generalized impedance boundary condition given here reduces to the standard leontovich condition. Results for the reflection coefficient of a plane wave incident onto a 2-D conducting interface are presented. We show the importance of the boundary-layer fields (as used in this study) over that of classical methods when calculating the reflection coefficient from a highly conducting rough interface. This work will lead to an analysis of the effects of surface roughness on power loss in MIMIC circuits.

C.L. Holloway and E.F. Kuester, “Power loss associated with conducting and superconducting rough interfaces,” *IEEE Trans. on Microwave Theory and Tech.*, vol. 48, no. 2, pp. 1601-1610, Oct. 2000.

> In recent work, a generalized impedance boundary condition for two-dimensional conducting rough interfaces was derived. In this study, the impedance boundary condition is used to calculate the power loss associated with conducting rough interfaces. Results for two-dimensional conducting and superconducting roughness profiles are shown in this paper, and comparisons to other results in the literature are given. The importance of these roughness effects in microwave and millimeter-wave integrated circuits is also discussed. Suggestions are made to extend this study to three-dimensional random rough interfaces.

P. Wilson, P. Papazian, M. Cotton, Y. Lo, and S. Bundy, "Simultaneous wide-band four-antenna wireless channel-sounding measurements at 1920 MHz in a suburban environment," *IEEE Trans. on Vehicular Tech.*, vol. 50, no. 1, pp. 67-78, Jan. 2001.

> Simultaneous four-antenna wide-band mobile channel-sounding measurements were made in two areas at 1920 MHz. The received signal strength and transmission loss were examined. Path-loss exponents for the two sectors were found to be 4.0 and 4.1. Root mean square delay spreads for the two sectors were found to be less than 1.38 and 0.65 μs for 90% of the data and less than 3.14 and 1.35 μs for 99% of the data. Fast fading reduction using antenna diversity and increased channel bandwidth (19.6 kHz, 1.25 MHz, 5.0 MHz, and 10.0 MHz) were examined. Three signal combining methods were considered: selection diversity, equal gain combining, and maximal ratio combining. The measured results show that increasing the number of diversity antennas or the channel bandwidth significantly reduces fading. Maximal ratio combining yields the largest diversity gain, exceeding 11.0 and 17.0 dB at the 90% and 99% fast fade depth probability levels, respectively, for the 19.6-kHz narrow-band signal and 6.7 and 6.9 dB for the 10.0-MHz broad-band signal when all four channels are used.

Other Publications

W.A. Kissick, W.J. Ingram, J.M. Vanderau, and R.D. Jennings, "Antenna system guide," NIJ Guide 202-00, Apr. 2001.

Unpublished Presentations

K. Allen, "Review of neural network-based propagation models," presented at the National Radio Science Meeting (URSI), Boulder, CO, Jan. 2001.

R. Dalke, "Man-made radio noise in the VHF and UHF bands," presented at the Naval Postgraduate School Conference on Factors Affecting the Reception of Radio Signals, Monterey, CA, Mar. 2001.

R. Dalke, "Statistical characteristics of individual and aggregate ultrawideband communication signals," presented at the 2001 IEEE EMC International Symposium, Montreal, Canada, Aug. 2001.

N. DeMinco, "Modeling antennas on automotive vehicles in the FM broadcast band," presented at the National Radio Science Meeting (URSI), Boulder, CO, Jan. 2001.

C. Holloway and P. McKenna, "Numerical modeling for anechoic and semi-anechoic chambers for emissions and immunity testing of digital devices," presented at the National Radio Science Meeting (URSI), Boulder, CO, Jan. 2001.

J. Lemmon, "Wideband model of HF noise and interference," presented at the Naval Postgraduate School Conference on Factors Affecting the Reception of Radio Signals, Monterey, CA, Mar. 2001.

R. Matheson, "Broadband spectrum surveys," presented at the Naval Postgraduate School Conference on Factors Affecting the Reception of Radio Signals, Monterey, CA, Mar. 2001.

R. Matheson, "Extended emission spectra," presented at the Naval Postgraduate School Conference on Factors Affecting the Reception of Radio Signals, Monterey, CA, Mar. 2001.

R. Matheson, "UWB signal characteristics," presented at the Naval Postgraduate School Conference on Factors Affecting the Reception of Radio Signals, Monterey, CA, Mar. 2001.

P. Papazian and P. Wilson, "Phase calibration of a PCS antenna array," presented at the National Radio Science Meeting (URSI), Boulder, CO, Jan. 2001.

E. Quincy, "Channel effects on wireless FM shipboard speech performance," presented at the National Radio Science Meeting (URSI), Boulder, CO, Jan. 2001.

S. Voran, "Wired, wireless, or VoIP: Objective estimations of speech quality," invited talk presented at Supercomm '01, Atlanta, GA, Jun. 2001.

P. Wilson and P. Papazian, "Direction-of-arrival measurements in a suburban area at 1920 MHz," presented at the National Radio Science Meeting (URSI), Boulder, CO, Jan. 2001.

Standards Leadership Roles

Evelyn M. Gray, Senior Editor of ANSI X3.172-1996, "American National Standard Dictionary of Information Technology" (4300 entries), and participant, with NCITS Technical Committee K5, in the revision to develop the Millennial Edition; Convener, T1A1 Ad Hoc Glossary Group, to develop *Telecom Glossary 2000*, an 8000-entry technical glossary adopted as American National Standard T1.523-2001.

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 3J-6 and 3M-3B.

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

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

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

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

Representative Technical Contributions

ANSI-accredited TIA TR-8 (Mobile and Personal Private Radio Standards) and APCO Project 25.

- "Conventional voice throughput delay."
- "ISSI performance description framework."
- "Informal observations on VoIP quality and SIP call setup delay."
- "SIP call setup measurements."

Reliability/Availability of IP-based Networks and Services

- A. Webster, "Proposed revision to draft technical report on reliability/availability of IP-based networks and services," T1A1.2/2000-072, Oct. 2000, and other proposed revisions, including T1A1.2/2001-014, Jan. 2001.
- A. Nguyen and A. Webster, "Text for TR on IP reliability/availability, Section 2: NSTAC and NCC portions," T1A1.2/2001-058, Jul. 2001; A. Webster, "Text for TR on IP reliability/availability: 'Section 2 Related Work'," T1A1.2/2001-052, Jun. 2001;
- A. Webster, "Traffic analysis sections for TR on IP reliability/availability," T1A1.2/2001-031, Apr. 2001.
- A. Webster and E. Gray, "Revisions to Appendix B for TR on IP reliability/availability," T1A1.2/2001-049, Jun. 2001; A. Webster, "Revisions to Appendix C for TR on IP reliability/availability," T1A1.2/2001-050, Jun. 2001; A. Webster and E. Gray, "Revisions to Glossary for TR on IP reliability/availability," T1A1.2/2001-051, Jun. 2001.
- A. Webster, "Definitions for baseline document T1A1.2/2000-002," T1A1.2/2000-069, Oct. 2000, and T1A1.2/2000-069R1, Nov. 2000; A. Webster, R. Paterson, O. Avellaneda, R.A. Canaday, and F. Kaudel, "Revised framework diagram for baseline document T1A1.2/2001-002," T1A1.2/2001-012, Jan. 2001.

Telecom Glossary 2000

- E. Gray and W. Ingram, "Announcement of Draft *Telecom Glossary 2000* on the Web," T1A1/2000-052, Oct. 2000.

- N. Seitz, "T1A1 Telecommunications Glossary Ad Hoc Group," T1A1/2000-066, Nov. 2000.

- N. Seitz and E. Gray, "Consideration of ANS T1.523-2001, *Telecom Glossary 2000*, in Study Group 13 Work on General Network Terminology," ITU-T Contribution B01-04-115, May 2001.

- N. Seitz and E. Gray, "Announcement of the availability of *Telecom Glossary 2000* as a resource for the Global Standards Collaboration (GSC)," T1A1/2001-053, Sep. 2001.

Video Quality

- ANSI T1A1.1/2001-051, "Draft Technical Report A1, 'Methodological framework for specifying accuracy and cross-calibration of video quality metrics'," (contributors included M. Pinson, S. Voran, and S. Wolf).

- S. Voran and S. Wolf, "Proposed informative annex entitled 'A description of classification errors' for Technical Report A1 (contribution T1A1.1/2001-027)," T1A1.1/2001-036, Apr. 2001.

- A. Webster, "Comments regarding draft new recommendation J.144 (J.fullref) — Perceptual video quality measurement techniques for digital cable television in the presence of a full reference," Delayed Contribution D.134 presented to ITU-T SG9, Nov. 2000.

- A. Webster, "Proposal for draft FRTV objective video quality assessment document," T1A1.1/2001-018, Jan. 2001.

- S. Wolf, "Draft Technical Report for 'Objective video quality measurement using a peak-signal-to-noise-ratio (PSNR) full reference technique'," T1A1.1/2001-026R1, Mar. 2001 (and subsequent revisions).

Abbreviations/Acronyms

1-D	one dimensional
2-D	two dimensional
3G	third generation
3GPP2	third generation partnership project 2

A

A/D	analog to digital
AAMA	American Automobile Manufacturers Association
ACK	acknowledge
AD	auditory distance
AGILE	Advanced Generation of Interoperability for Law Enforcement
AIS	automatic identification system
ALE	automatic link establishment
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
ASIC	application specific integrated circuit
ATB	antenna testbed
ATIS	Alliance for Telecommunications Industry Solutions
ATM	asynchronous transfer mode
AWG	arbitrary waveform generator

B

BAWT	broadband arbitrary waveform transmitter
BBNG	broadband noise generator
BER	bit error rate
BLAST	Bell Labs Layered Space-Time theory
BPSK	binary phase shift keying

C

CBD	component-based design
CCIR	International Radio Consultative Committee (now ITU-R)
CD	compact disk
CD-ROM	compact disk read-only memory
CDMA	code division multiple access
CDS	communication deception system
CECOM	Communications-Electronics Command (U.S. Army)
CIA	Central Intelligence Agency
CIP	critical infrastructure protection
CONUS	continental U.S.
COTS	commercial off-the-shelf
CRADA	cooperative research and development agreement
CRPL	Central Radio Propagation Laboratory
CRSMS	Compact Radio Spectrum Measurement System
CSPM	Communication System Performance Model
CSPT	Communication System Planning Tool
CW	continuous wave

D

dB	decibel
DGPS	differential GPS
Diff-Serv	Differentiated Services
DOC	Department of Commerce
DOD	Department of Defense

DOJ	Department of Justice
DSCP	digital sampling channel probe
DTV	digital television

E

EF	expedited forwarding
EIA	Electrical Industries Association
EM	electromagnetic
EMC	electromagnetic compatibility
ESSA	Environmental Science Services Administration
ETS	emergency telecommunication service

F

FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FDMA	frequency division multiple access
FDTD	finite-difference time domain
FED	Federal
FED-STD	Federal Standard
FFT	fast Fourier transform
FH-FSK	frequency hopping-frequency shift keyed
FIFO	first in first out
FIT	flexible interoperable transceiver
FM	frequency modulation
FPGA	field programmable gate array
FRA	Federal Railroad Administration
FRTV	full reference television
FTP	file transfer protocol
FTTA	Federal Technology Transfer Act
FY	fiscal year

G

GBgigabyte

GETS	Government Emergency Telecommunications Service
GHz	gigahertz
GIF	graphics interchange format
GIS	geographic information system
GLOBE	global land one-km base elevation
GO	geometric optics
GPS	Global Positioning System
GSC	Global Standards Collaboration
GSM	Global System for Mobile
GWEN	Ground Wave Emergency Network

H

HAAT	height above average terrain
HDTV	high definition television
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
IPDV	IP packet transfer delay variation
IPER	IP packet error ratio
IPLR	IP packet loss ratio
IPTD	IP packet transfer delay
ISART	International Symposium on Advanced Radio Technologies
ISDN	integrated services digital network
ISSI	inter-RF subsystem interface
IT	information technology
ITAC-T	International Telecommunications Advisory Committee - Telecommunications
ITM	Irregular Terrain Model
ITS	Institute for Telecommunication Sciences
ITS	Intelligent Transportation System
ITSA	Institute for Telecommunication Sciences and Aeronomy
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union-Radiocommunication Sector
ITU-T	International Telecommunication Union-Standardization Sector

K

kHz	kilohertz

L

LAN	local area network
LB	letter ballot
LMDS	local multipoint distribution service
LMR	land mobile radio
LOS	line of sight
LULC	land use/land cover

M

MHz	megahertz
MIL-STD	military standard
MILCOM	Military Communications Conference
MIMIC	millimeter wave integrated circuit
MIMO	multiple input multiple output
MOS	mean opinion score
MPEG	Motion Picture Experts Group
MPLS	multiprotocol label switching
MS	mobile set
MSC	mobile switching center
MSTV	Association for Maximum Service Television, Inc.
MW	megawatt

N

NASTD	National Association of State Telecommunications Directors
NCC	National Coordinating Center for Telecommunications
NCITS	National Committee for Information Technology Standards
NCS	National Communications System
nDGPS	nationwide differential GPS
NE	network element
NGI	next generation Internet
NGN	next generation network
NI	network interoperability
NII	national information infrastructure
NIJ	National Institute of Justice
NIST	National Institute of Standards and Technology
NRA	no radio available
NS/EP	National Security and Emergency Preparedness

NSA	National Security Agency
NSTAC	National Security Telecommunications Advisory Committee
NSTISSI	National Security Telecommunications and Information Systems Security Instruction
NTIA	National Telecommunications and Information Administration
NVESD	Night Vision Electronic Sensors Directorate

O

O&M	operations and maintenance
OATS	open area test site
OJP	Office of Justice Programs
OLES	Office of Law Enforcement Standards
OMB	Office of Management and Budget
OMNCS	Office of the Manager, National Communications System
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
PC	personal computer
PCS	Personal Communications Services
PDO	Program Development Office
PN	pseudo-random
PPI	plan position indicator
PPS	precise positioning service
PQR	picture quality rating
PRF	pulse repetition frequency
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 Advisory Committee

Q

QoS	quality of service

R

R&D	research and development
RDBMS	relational database management system
RF	radio frequency
RFIMS	Radio Frequency Interference Monitoring System
RFSS	radio frequency subsystem
RMS	root mean square
RSMS	Radio Spectrum Measurement System
RTCM	Radio Technical Commission Marine
RTCP	real time control protocol
RTP	real time protocol

S

S-T	spatial-temporal
SDH	synchronous digital hierarchy
SDMA	space division multiple access
SDR	software defined radio
SIP	session initiation protocol
SLA	service level agreement
SLP	service logic process
SMR	specialized mobile radio

SMTS spectrum management toolset

SNR signal-to-noise ratio

SONET synchronous optical network

SPS standard positioning service

SRD standard requirements document

SYN synchronize

T

TA Services Telecommunications Analysis Services

TB terabyte

TCP transmission control protocol

TDMA time division multiple access

TEAM Telecommunications Engineering, Analysis, and Modeling Division

TIA Telecommunications Industry Association

TV television

U

UDP user datagram protocol

UHF ultra high frequency

UML unified modeling language

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

USSG U.S. study group

UTP unshielded twisted pair

UTRA UMTS terrestrial radio access

UWB ultrawideband

V

VHF very high frequency

VoIP voice over Internet protocol

VQEG Video Quality Experts Group

W

W-CDMA wideband CDMA

W3C World Wide Web Consortium

WCTF Wireless Communication Task Force

WDM wave division multiplexing

WIN wireless intelligent network

WLAN wireless LAN

WMO Wireless Management Office

WNRC Wireless Networks Research Center

WP working party

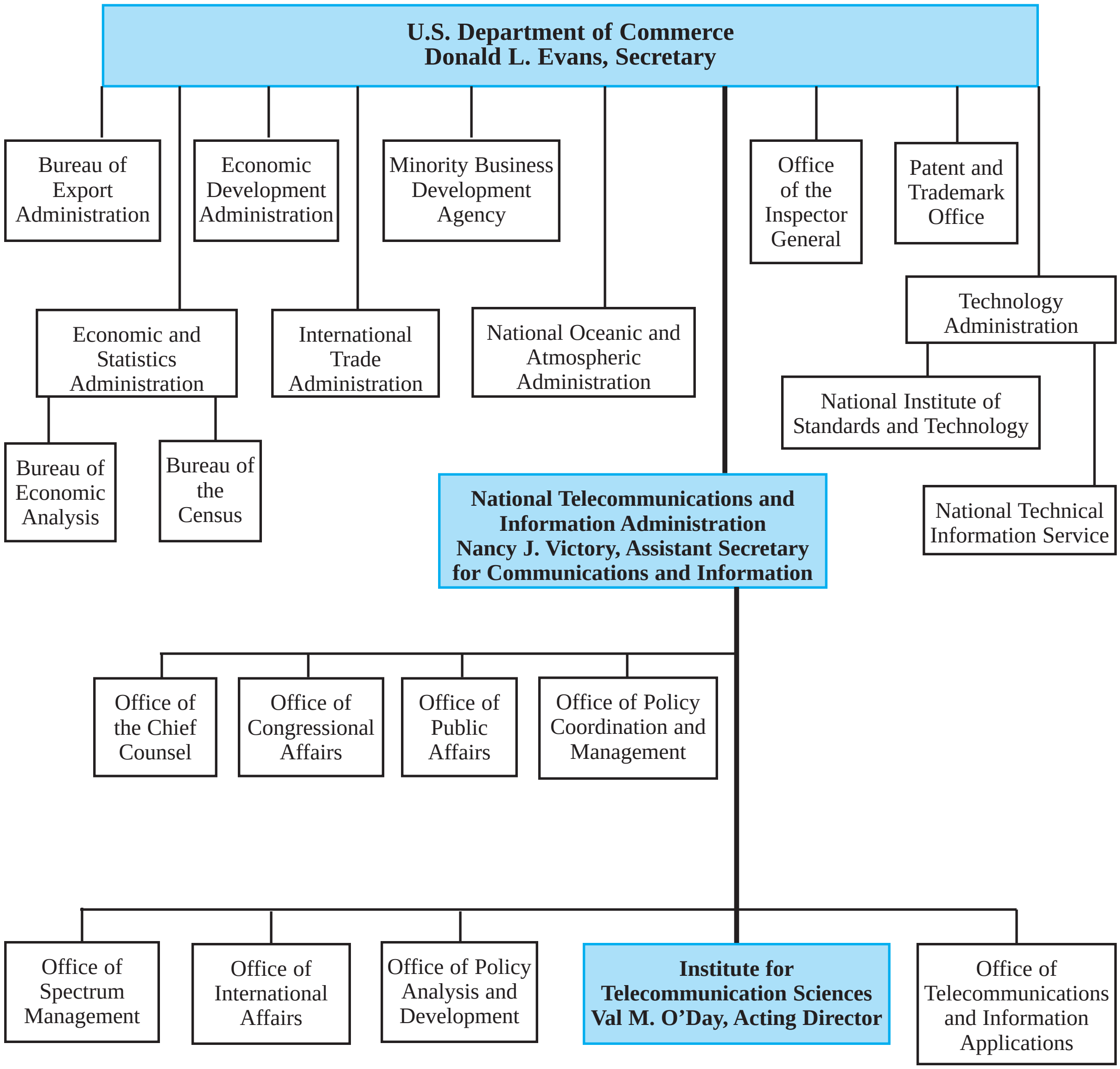
X

XML eXtensible Markup Language

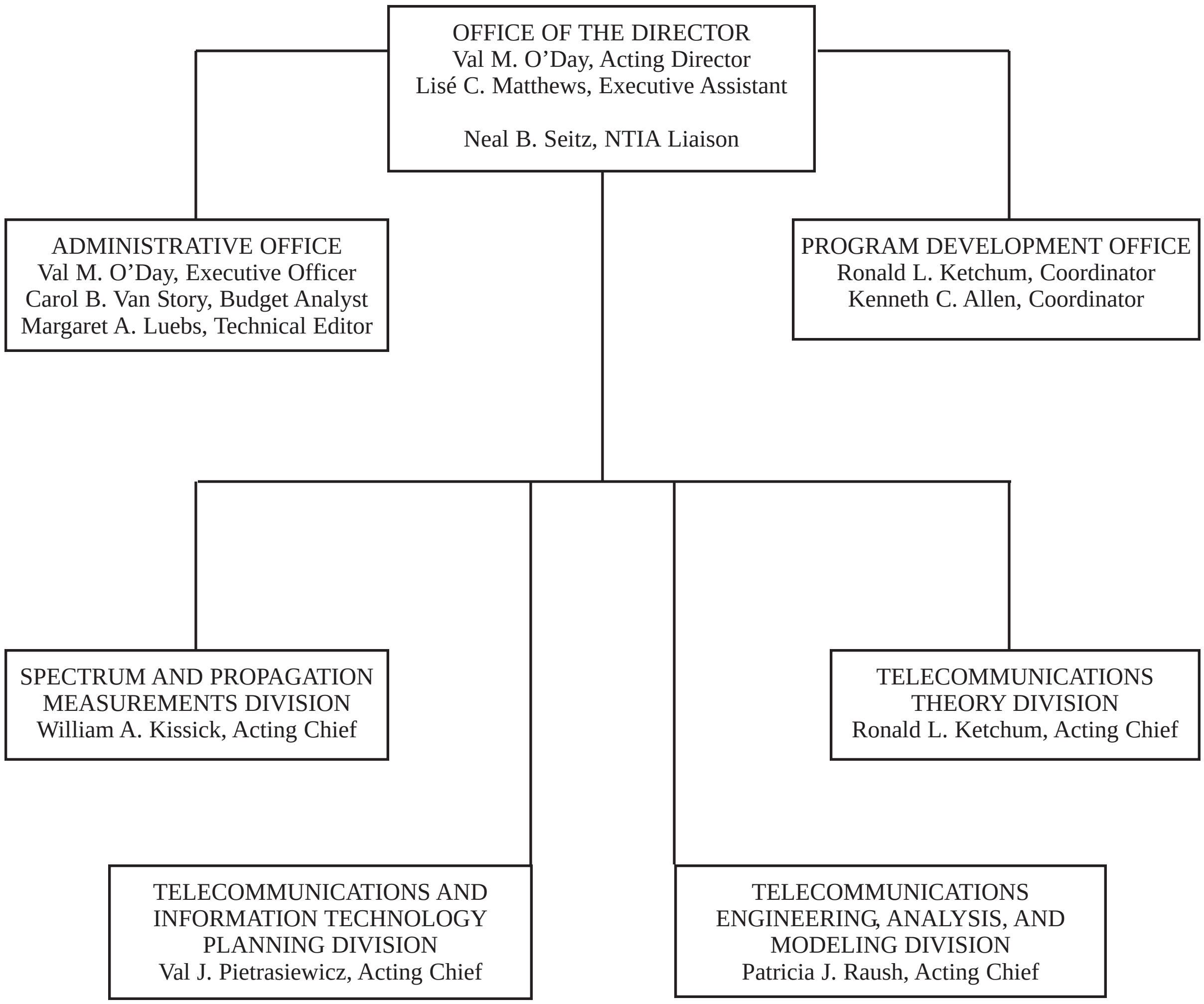
Y

YIG yttrium iron garnet

DOC/NTIA Organization Chart



ITS Organization Chart



NTIA/ITS
Dept. of Commerce
325 Broadway
Boulder, CO 80305-3328

303-497-5216

http://www.its.bldrdoc.gov