Telecommunications Engineering, Analysis, and Modeling

The Telecommunications Engineering, Analysis, and Modeling Division conducts studies in these three areas for wireless and wireless-wireline hybrid applications.

Engineering encompasses technical assessment of telecommunications systems, their components, and their performance, including impact of access, interoperability, timing and synchronization, and susceptibility to noise, jamming, and interfering signals on system effectiveness in national security/emergency preparedness (NS/EP), military, and commercial operational environments.

Analysis is often performed in association with the TA Services project, which offers analytical tools via an on-line cooperative research and development agreement. ITS can customize these tools and analyses for specialized applications. Propagation prediction models are being incorporated into GIS formats and web-based access.

Modeling is one of ITS's core strengths. Propagation models are incorporated with terrain databases and other data. Adaptations of historic models, and those for specialized situations have been developed, enhanced, and compared. ITS engineers contribute to international and national standards bodies, such as ITU-R SG3, 8F, and ATIS WTSC-RAN.

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Areas of Emphasis

ENGINEERING

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

Public Safety Video Quality (PSVQ) The PSVQ project is conducting a series of subjective tests illustrating different types of video compression and artifacts. These are shown to expert viewers and then the data are analyzed and correlated. From this analysis NTIA/ITS has made recommendations for a new video standard based on applications in the public safety arena, Rec. ITU-T P.912. This project is funded by NIST/OLES.

ANALYSIS

Telecommunications Analysis Services The Institute provides network-based access to research results, models, and databases supporting applications in wireless system design and evaluation. These services are available to government and non-government customers and are funded by fee-for-use and fee-for-development charges through an on-line CRADA. ITS is examining migration of TA Services to a web-based system.

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

MODELING

Broadband Wireless Standards The Institute develops radio propagation algorithms and methods to improve spectrum usage of wireless systems. Technical standards are prepared that support U.S. interests in 3G broadband wireless systems and are fed into ITU-R SG 3, WPs 3J, 3K, 3L, 3M. ITS is active in path specific model development in WP 3K and its development of ITU-R Recommendation P.1812. Work is funded by NTIA.

Low and Medium Frequency Propagation Modeling The Institute has developed a unique software model for performance and interference analysis. ITS has integrated this model into a GIS-based application so that the analysis outputs can be be presented with more detailed and illustrative graphics.

Short-Range Mobile-to-Mobile Propagation Model Development and Measurements The Institute is developing a model for short-range (1 m to 2 km) propagation between mobile radios. The propagation work consists of both modeling and field measurements. With a new customized propagation measurement system, field measurements were performed in FY 2008. This project is funded by NTIA/OSM.

Interference Issues Affecting Land-Mobile Systems

Outputs

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

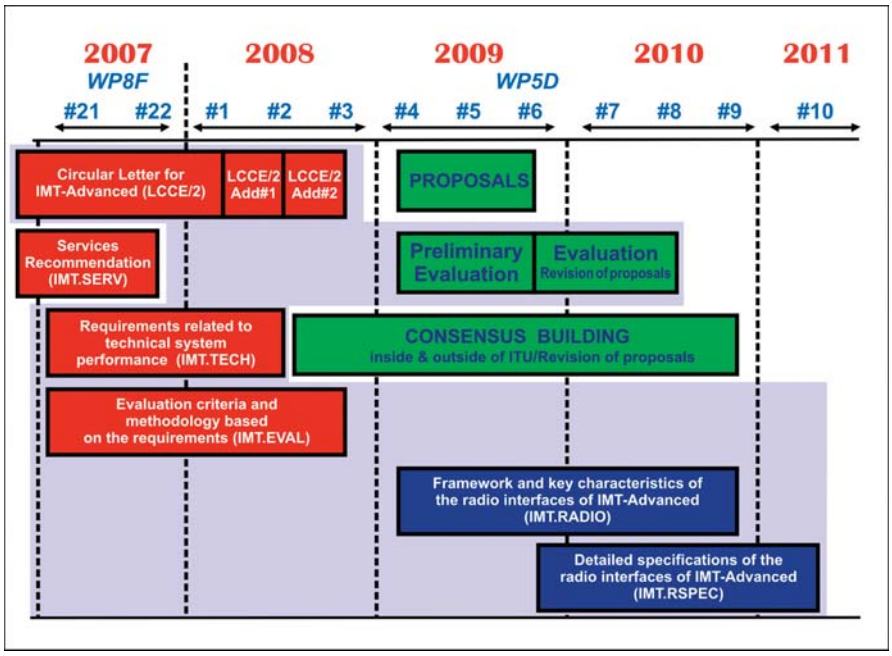
As next-generation commercial communication systems are deployed and future-generation technologies are developed, the demand for additional spectrum increases and the lack of available spectrum becomes an issue. The desire, and need, to implement true universal coverage (worldwide roaming) places different demands on spectrum allocations depending on the geographic and political location of the user and provider. Aside from the commercial uses of spectrum, the increasing needs of civil and Federal users place additional demands on the finite amount of spectrum. Spectrum dedicated to systems supporting emergency responders must be allocated from that already in use. Spectrum sharing by multiple users is necessary to accommodate all proposed and existing systems.

Until the planned, interoperable, communication systems for emergency services are deployed, Commercial Mobile Radio Services (CMRS) will remain an important asset in establishing emergency communications. As a result, wired and wireless communication services will experience usage rates significantly greater than average during emergency situations. This sudden influx of traffic by private, commercial, civil, and Federal users will result in system overloads, a decrease in signal quality, and further disruption of service in affected areas. Beyond the physical damage caused by events, additional factors will contribute to diminished channel capacity of wireless networks, such as co- and adjacent-channel interference and the operation of multiple, independent, non-interoperable systems servicing the same geographical area, often using the same frequency bands and infrastructure (base station sites and towers). One way of coping with damaged or destroyed infrastructure is to deploy temporary equipment to supplement the surviving system. To make efficient use of limited resources, responders need to know what equipment needs to be deployed in which locations. Knowledge of interference issues, system dynamics, and load patterns is key to effective, post-disaster support by national security/emergency preparedness (NS/EP) planners and network operators in an overloaded environment.

ITS is actively applying its expertise in propagation and interference areas through its participation in national and international standards development organizations. ITS contributed to the understanding of inter-PCS interference by participating in the Telecommunications Industry Association (TIA) committee TR46.2 (Mobile & Personal Communications 1800-Network Interfaces). As a member, ITS helped develop the Technical Service Bulletin "Licensed Band PCS Interference" (TSB-84A). This bulletin was a first step in characterizing the interfering environment caused by large numbers of active users and competing technologies. Since the completion of this work, coverage of interference issues concerning all mobile communication systems has been adopted by the Alliance for Telecommunications Industry Solutions (ATIS) subcommittee WTSC-RAN (Wireless/Mobile Standards – Radio Access Networks). Work on the successor to TSB-84A is currently underway as Issue P0017, "Proposed Joint ATIS/TIA Standard on Coexistence and Interference Issues in Land Mobile Systems." ITS continues to be involved in these activities as issue champion and editor.

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

The increase in the demand for mobile communications capacity requires that limited spectrum



Detailed schedule for the development of the IMT-Advanced process. The shaded area indicates the areas where ITS has been involved in the past and will continue to be involved in the future. (Adapted from the Working Party 5D Chairman's Report, R07-WP5D-C-0327!H02!MSW-E).

resources be shared by different users and utilized as efficiently as possible. Spread spectrum technologies, which make efficient use of allocated spectrum and are relatively unaffected by noise, are used in current cellular systems and will become even more prevalent in next-generation systems. The capacity of these technologies, such as code division multiple access (CDMA), is limited primarily by the number of other users occupying the same frequency band. These legitimate users appear to each other as an increase in the noise floor and are referred to as co-channel interferers. Most automatic power control schemes in spread spectrum systems increase power levels when the level of interference/noise is unacceptable. This increases the interference level for all users of a common frequency band and can cause an exponential effect where all users of the spectrum are operating at maximum power levels and experiencing a diminished Quality of Service (QoS). With the increasing dependence on spread spectrum technology, a clear understanding of the effects of interference is essential to increase the efficiency of spectrum use.

Work in detecting, identifying, and mitigating co-channel interference requires tools to characterize the interference experienced by air-interface signals. An interference model is a tool that can be used to predict levels of interference and identify sources of interference. To improve our understanding of how well spread spectrum systems can tolerate congested environments and how well multiple systems can coexist in the same environment, ITS has developed an interference model capable of implementing two CDMA-based systems: the TIA/EIA-95B standard and W-CDMA (Wideband CDMA). The model produces a representation of an instantaneous air interface signal; this signal contains outputs of multiple base stations with variable numbers of mobile users for each base station and can assign relative power levels for each individual mobile user. Both forward and reverse link processes are included in the model.

This system-specific interference model is used to determine the level of co-channel interference from both immediate and adjacent cells. The model calculates each channel's sampled QPSK or OQPSK signal contribution separately, then sums all signals identified in a specified scenario together to form a composite output signal. The power level for a single channel is a gain factor of the baseband filter and is set separately for each channel. There is no error correction added to the input sequence; only spreading codes and modulation processes are used. Software- and hardware-based simulations can use the sampled signal from the model to evaluate system designs. These simulations can characterize one-on-one, one-on-many, and many-on-one interference. As a result, potential solutions to congestion can be proposed to solve existing problems or to anticipate and avoid potential problems.

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Public Safety Video Quality

Outputs

- Test results from six phases of testing.
- Technical contributions to standards bodies to establish video quality measurements and standards for the public safety community.
- Technical contributions on video quality standards to the sponsor.

Police and fire agencies often purchase radios, cameras, and other communications equipment based on their local needs. Unfortunately, this equipment may not be of high enough quality for certain applications or be able to communicate with other agencies with specific needs. Until recently, there were no technical standards for emergency communications equipment. ITS is conducting audio and video quality research to determine standard parameters for levels of quality of communication systems based on the specific needs of public safety practitioners and their applications. ITS is working on behalf of the Department of Homeland Security (DHS) and the National Institute of Standards and Technology's Office of Law Enforcement Standards (NIST/OLES) to ensure that first-responder video systems communicate clearly and accurately with each other.

The PSVQ project started with a single video quality study, conducted at ITS in December 2005. This test focused on the application of tactical video with a narrow field of view (i.e., the area of video frame of interest, the "target," was relatively large). Over the next two years ITS expanded testing to include four additional study phases:

- Tactical, small target (wide field of view)
- Observed (live) surveillance, large target (narrow field of view)
- Observed (live) surveillance, small target (wide field of view)
- Recorded surveillance, large target (narrow field of view)
- Recorded surveillance, small target (wide field of view)

The resulting recommendations from the studies of these applications are given in Section 4 of the Public Safety Statement of Requirements (PS SoR) Volume II, Versions 1.1 and 1.2.[1,2]

In order to develop useful standards for video quality parameters, accurate measurements for video quality assessment must be employed, usually through subjective data collected from human subject testing. The ITU-T has a series of Recommendations that address methodology for performing subjective tests in a rigorous manner.[3,4] These Recommendations prescribe tests in which subjective viewers are asked to watch video that has been impaired to various degrees. The viewers are then asked to report their perceived quality of the video using a given rating system, usually consisting of a scale (e.g., Excellent, Good, Fair, Poor, Bad). These standard methods are generally targeted at the entertainment application of video, such as broadcast television. However, public safety agencies utilize video to help them perform their jobs, such as security, surveillance, remote command and control, and forensic evidence analysis. These applications fall into the class of video that is used to perform a specific task. The methods developed to assess a person's perceptual opinion of entertainment quality are not appropriate for task-based video. Task-based video is used to recognize objects, people or events. Methods that rely on a viewer's rating of quality may not capture the answer to the underlying question — that is, at what level of impairment does video data become unable to carry the information necessary to make decisions regarding the task at hand.

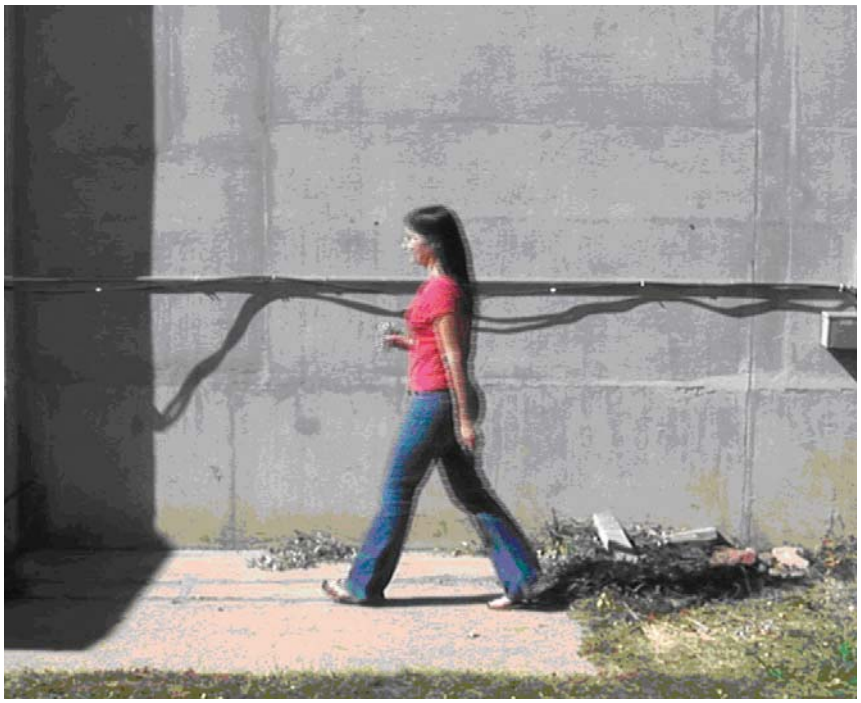
The first series of tests in FY 2007 highlighted a need to develop new quality assessment methods for video used to perform tasks for specific applications.

1 *Public Safety Statement of Requirements for Communications & Interoperability*, Volume II: Quantitative, Version 1.1, Nov. 2007.

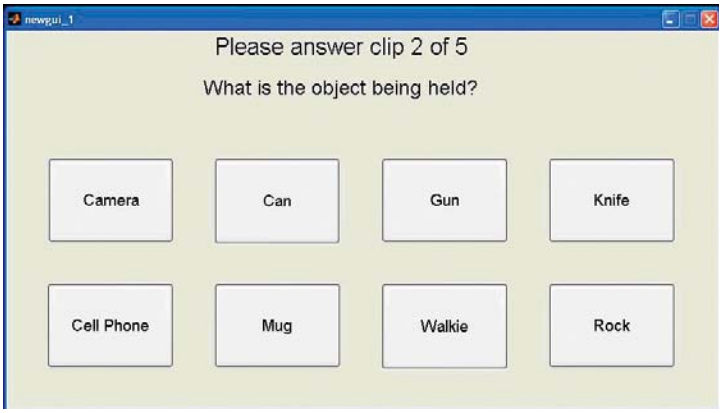
2 *Public Safety Statement of Requirements for Communications & Interoperability*, Volume II: Quantitative, Version 1.2, Sep. 2008.

3 ITU-R, 2002. Recommendation BT.500-11. Methodology for subjective assessment of the quality of television pictures. Recommendations of the ITU, Radiocommunication Sector.

4 ITU-T. 1999 September. Recommendation P.910. Subjective video quality assessment methods for multimedia applications. Recommendations of the ITU, Telecommunication Standardization Sector.



— forensic video analysis and live surveillance. Instead of being asked to report an opinion of quality, subjects were asked to perform specific recognition tasks, such as identify an object or read an alpha-numeric sequence. For example, practitioners were asked to watch a video clip and identify the object being held or used by a person, recognize if a certain object appeared in the video, read a license plate, or a read a hazmat sign. The subjective test viewers were experts in their fields of forensics or law enforcement. For the forensic test, the subjects were allowed to pause and replay the video, as they would during the performance of their jobs. The live surveillance test subjects were required to perform recognition tasks in real time. The results of this testing determined the percentage of experts (first responders) able to perform the desired task at a certain video impairment level. The results were categorized by the size of the target (object or alpha-numeric character) of interest. The two task-based tests were the first tests to employ the methods in P.912, and allowed for an evaluation of these methods for future studies.



An example of a task-based video quality assessment method.

Research was conducted in the area of military target recognition, computer object recognition, and human facial recognition. The results were adapted for development of video quality tests for public safety applications. A new standard was developed for video quality assessment for recognition tasks, and has been adopted by ITU-T Study Group 9 as Recommendation ITU-T P.912.[5]

Two task-based tests were designed for the PSVQ project using this new assessment method. These tests focused on two different application areas

In February 2009, ITS will host the first annual conference on Video Quality in Public Safety (VQiPS). VQiPS aims to bring together all users of video in the public safety community. The goal is to coordinate efforts in establishing quality requirements for video used in public safety applications.

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5 ITU-T. 2008 August. Recommendation P.912. Subjective video quality assessment methods for recognition tasks. Recommendations of the ITU, Telecommunications Standardization Sector.

Telecommunications Analysis Services

Outputs

- Internet access on a cost reimbursable basis for U.S. industry and Government agencies to the latest ITS engineering models and databases.
- Contributions to the design and evaluation of broadcast, mobile, and radar systems, personal communications services (PCS), and local multipoint distribution systems (LMDS).
- Standardized models and methods of system analysis for comparing competing designs for proposed telecommunication services.
- On-line CRADAs that allow users to task ITS to develop special models or perform special analysis tasks.

Telecommunications Analysis Services (TA Services) gives industry and Government agencies access to the latest ITS research and engineering outputs 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.

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

Some currently available databases and services are: on-line terrain data with 1-arc-second (30m) for CONUS and 3-arc-second (90m) resolution for much of the world, and GLOBE (Global Land One-km Base Elevation) data for the entire world; the U.S. Census data for 2000, and 1990; Federal Communications Commission (FCC) databases; and geographic information systems (GIS) databases (ArcInfo). For more information on available programs, see p. 74 of the Tools and Facilities section or call one of the contacts listed below.

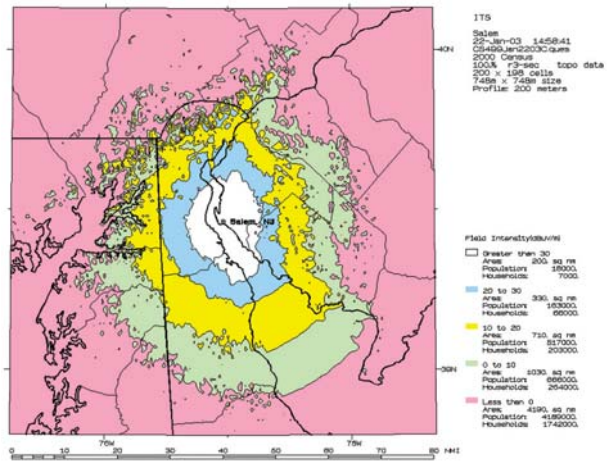

Figure 1. Sample output of the CSPM model of a broadcast transmitter in New Jersey.

Over the past 20 years, TA Services has developed both generic propagation models for a wide variety of applications in many frequency bands and application specific models used for a particular type of analysis such as High Definition Television (HDTV). These models are placed on the TA Services Web access system for use by customers with active accounts on the system. These customers can activate models, enter information about their broadcast equipment and produce a generic transmitter coverage such as that shown in Figure 1 for a typical broadcast application using the Communications System Performance Model

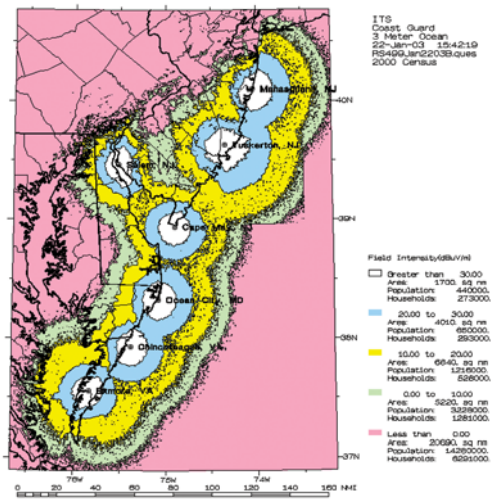

Figure 2. Composite coverage of several Coast Guard Stations located along the east coast.

(CSPM) application program. These coverages follow FCC guidelines and requirements in order to show both the signal coverage and the population that resides within the various analysis contours. Users can also combine many individual transmitter coverages into a composite coverage such as that shown in Figure 2. This allows the user to determine both single transmitter performance and integrated system performance.

TA Services has assisted the broadcast television providers of the U.S. with their transition to digital television (DTV) by providing an application specific model for use in advanced television analysis (high-definition television, advanced television, and digital television). This model allows the user to create scenarios of desired and undesired station mixes. The model maintains a catalog of television stations and advanced television stations from the FCC from which these analyses are made. The results of these studies show those areas of new interference and the population and number of households within those areas so that designers can mitigate possible interference situations before they become a problem. The model can also determine the amount of interference a selected station gives to other stations. This allows the engineer to make modifications to the station and then determine the effect those modifications have on the interference that station gives other surrounding stations. In addition to creating graphical plots of signal levels, the program creates tabular output which shows the distance and bearing from the selected station to each potential interfering station as well as a breakdown of the amount of interference each station in the study contributes to the total interference.

TA Services has also assisted the Public Broadcasting System of the U.S. and the National Weather Service in the determination of their system coverage and public outreach. These two major public providers ensure that more than 95% of all Americans have access to potentially life-saving information in the event of a national crisis of any kind. With the use of the TA Services system and databases, these two national systems were able to improve and verify the coverage of their large diverse systems.

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

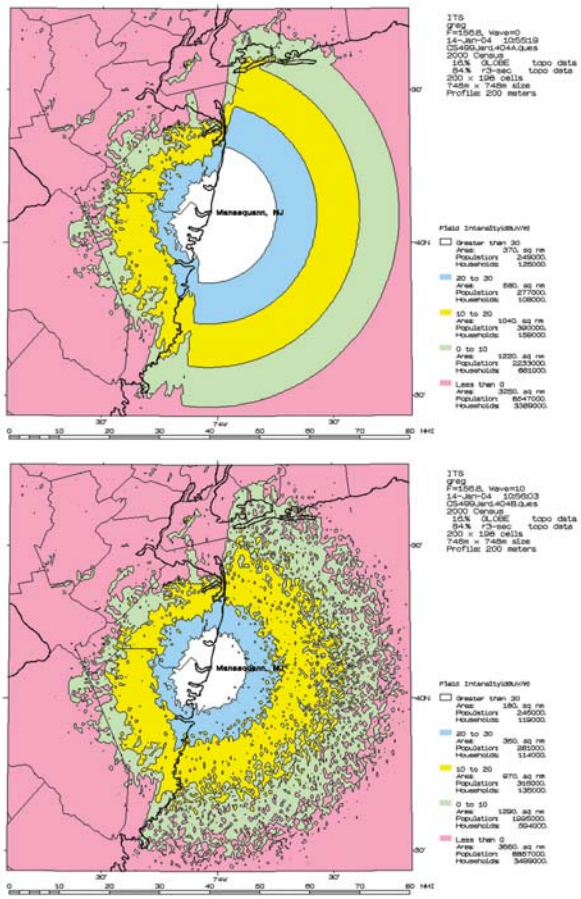

Figure 3. Coverage studies without (top) and with (bottom) an ocean clutter loss addition to CSPM.

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

ITS has begun the effort to upgrade the TA Services System to a new Geographic Information System (GIS) Web-based interface that will place the power of state of the art GIS functions and features in the hands of TA Services customers.

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Geographic Information System (GIS) Applications

Outputs

- Propagation coverages (LFMF, HF, and VHF) for one or more transmitters draped over surfaces.
- Composite, interference, overlap, point-to-point, and coupled outdoor/indoor coverages (VHF).
- 2D and 3D visualization environments.
- FCC database downloads.
- Fly-through visualization capabilities.
- Web-based propagation models and frequency coordination in development.

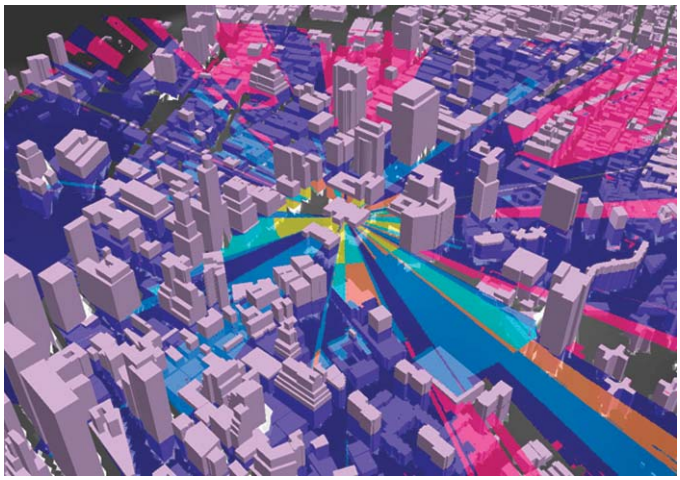

Figure 1. A CSPT-VHF study for New York showing both 2D (top) and 3D (bottom) results.

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

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

Two other extensions of CSPT allow the user to incorporate the ITS HF ICEPAC model, which provides sky-wave analysis capabilities from 2 to 30 MHz, and the ITS LFMF System 3 model, which provides analysis capabilities from 150 kHz to 2

MHz for areas as large as the entire world. The CSPT tools can download FCC FM and TV databases, perform overlap, composite, and interference studies and can report demographic information from the 1990, 2000, and 2007 (estimated) Census Population databases.

Over the last year, the Institute has been upgrading the CSPT stand-alone software into a cutting-edge web-based GIS solution. Two products are simultaneously being developed: 1) the TMFCW (Table Mountain Frequency Coordination Website) and the PMW (propagation modeling website) — shown in Figure 3. The TMFCW uses Longley-Rice propagation analysis to identify potential interference from organizations transmitting within an 80-mile radius of the Table Mountain Radio Quiet Zone. The PMW allows users to perform TIREM and Longley-Rice analysis via the web in either single or batch transmitter mode. Both GIS websites allow users to log into one center server site and use one central database server for data storage, retrieval, and analysis. The solution integrates COTS (commercial off the shelf) GIS, database, and web-development products in a fully-customizable software programming environment that can be tailored to meet individual customer needs. Both the TMFCW and the PMW display 2D propagation analyses; these displays will become 3D as customizable GIS web technology becomes available.

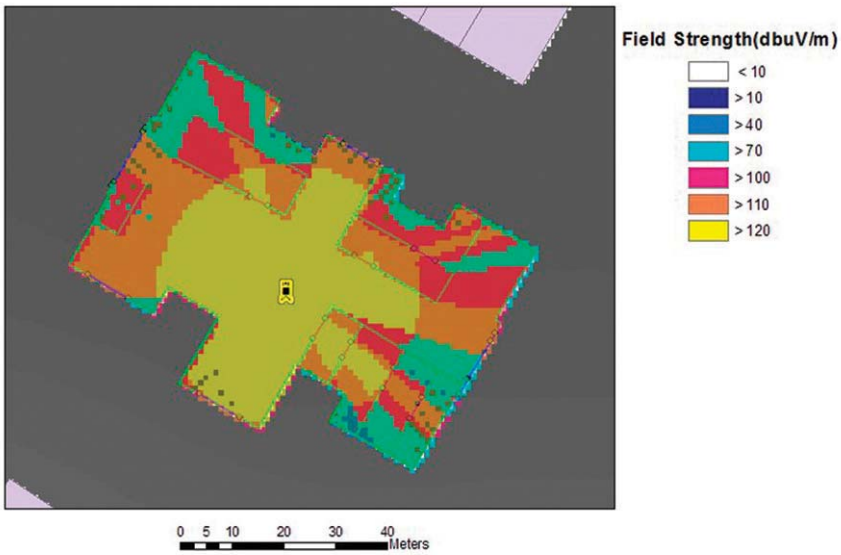

Figure 2. A CSPT-VHF indoor/outdoor study in New York.

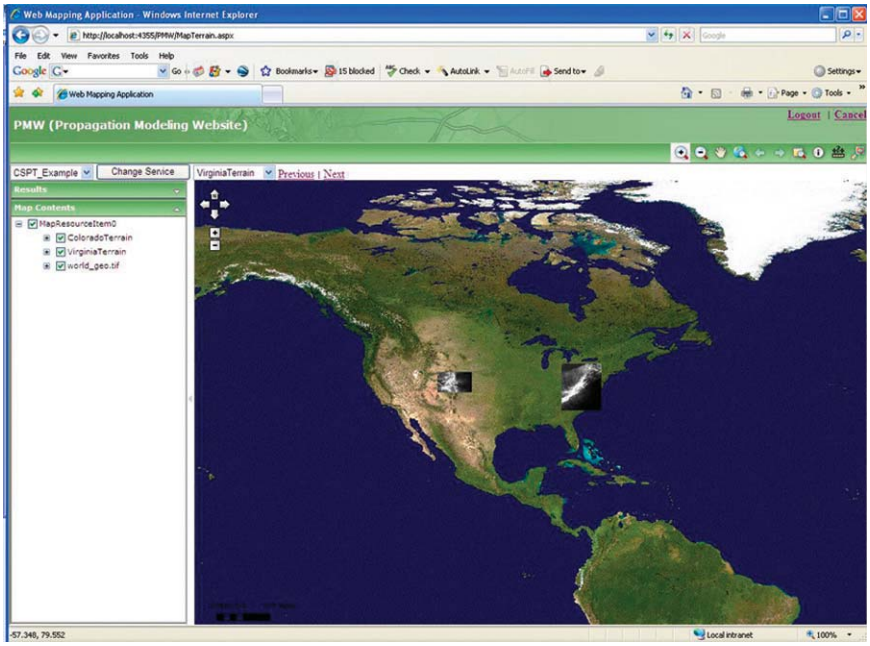

Figure 3. The PMW with user-selectable Virginia or Colorado terrain imagery.

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Broadband Wireless Standards

Outputs

- Hosting/Supporting the 2008 Block Meetings of ITU-R Working Parties 3J, 3K, 3L, and 3M, ISART 2008, and ClimDiff 2008.
- Support of ongoing efforts in various Correspondence Groups, formal and informal, conducting studies between meetings of the Working Parties.

Much of the work on the Broadband Wireless Standards project in FY 2008 centered on hosting and supporting the Block Meetings of the ITU-R Working Parties 3J (propagation fundamentals), 3K (point-to-area propagation), 3L (ionospheric propagation) and 3M (point-to-point and earth-space propagation), which were held at the Hotel Boulderado in Boulder, Colorado, in June 2008. The Block Meetings are held outside Geneva, Switzerland, on a biennial basis, typically in years when a subsequent meeting of ITU-R Study Group 3 is not required. Although the meetings are held outside of Geneva, a great deal of the preparatory work involved in formulating draft new Recommendations and revising existing Recommendations, Handbooks and Reports is accomplished at these venues. The Boulder meetings were no exception to this rule.

In addition to hosting the Block Meetings of the Working Parties, ITS sponsored two concurrent conferences, the International Symposium on Advanced Radio Technologies (ISART) 2008 and ClimDiff 2008, just prior to the Block Meetings at the same venue in Boulder. ISART provides a forum that brings together technical researchers, business leaders, government policy makers, and regulators for the purpose of forecasting the development and application of radio frequency technologies. ISART 2008 had five half-day sessions: Topics in Spectrum Management; Communications in Various Noise Environments; Propagation Prediction Models; Wireless in Mobile Environments; and Emerging Wireless Technologies. The ClimDiff 2008 conference covers topics in radio-climatological and diffraction effects on radio propagation. ClimDiff 2008 had three half-day sessions: Measurement and Modelling of Climatic Effects; Measurement and Synthesis of Rain Parameters; and Effects Due to Buildings and Terrain.

In addition to these activities, ITS personnel were heavily involved in supporting ongoing studies being carried out in the Subgroup 3K-1 Correspondence Group (3K-1 CG). Subsequent to the adoption of Recommendation ITU-R P.1812, the Rapporteur convened a third Special Workshop for this 3K-1 CG at Ofcom, London, UK in March 2008. This Special Workshop provided an opportunity for members of the 3K-1 CG to present and discuss, in detail, various alternative methods for combining single knife-edge diffraction results to approximate multiple knife-edge diffraction and, in particular, to consider the

Figure 1. As part of the U.S. Delegation, NTIA/ITS hosted the working party meetings this year for ITU-R Study Group 3 in Boulder, Colorado, June 5-13, 2008. Here, in a joint plenary session, the Working Party Chairs and Counselor discuss the input documents with the various delegations from all over the world.

implications of these methods for the real-world problem of radio signal propagation by diffraction over irregular terrain, relative to other propagation mechanisms. To this end, ITS re-engineered, implemented, and validated the Fresnel-Kirchhoff based approach to numerical solution of the multiple knife-diffraction problem outlined in NTIA Reports 81-86 and 83-124 by L.E. Vogler.

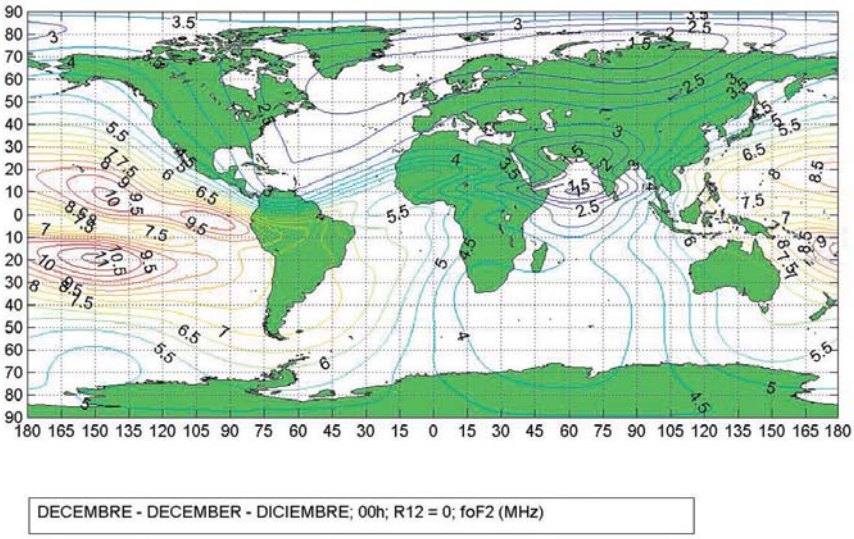

Figure 2. An example of an ionospheric map discussed in ITU-R Working Party 3L.

ITS has supported the correspondence group which produced the vocabulary list from the ITU-R recommendations maintained by Study Group 3. The ITU-R Coordination Committee for Vocabulary (CCV) has accepted the vocabulary list into the web-based ITU Terms and Definitions page.

ITS is also giving support to handbook publications from the ITU that are based on Study Group 3 recommendations. ITS participated in the final review of a new edition of the ITU "Handbook on Radiometeorology." The last edition of this handbook was published in 1996. In addition, ITS is corresponding with NASA to begin work on a new handbook on interference of radiowave transmission which will cover the information from Recommendations ITU-R P.452 (Prediction Procedure for the Evaluation of Microwave Interference Between Stations on the Surface of the Earth at Frequencies Above About 0.7 GHz) and ITU-R P.620 (Propagation Data Required for the Evaluation of Coordination Distances in the Frequency Range 100 MHz to 105 GHz).

In support of Working Party 3L, ITS is implementing revisions of the Recommendations ITU-R P.533 (Method for the Prediction of Performance on HF Circuits) and P.1239 (Ionospheric Characteristics). The latter Recommendation is based on methods developed at ITS and ITS' predecessor organizations after the 1958 International Geophysical Year. The longstanding models of the F2 layer penetration frequency, foF2, and M Factor at 3000 km, M(3000)F2 are based on measurements that are now over 40 years old. Many administrations have been collecting data from that time to the present and need a way to augment foF2 and M(3000)F2. ITS is working within ITU-R Working Party 3L to find a way to enhance ionospheric maps to take into account the wealth of contemporary measurements. ITS is working with other members of WP 3L to coordinate a new set of coefficient files that are used to generate these maps. Through the work of the German delegation and others, a new set of coefficients based on several implementations of ionospheric mapping software will soon be available through the ITU. ITS has been instrumental in this effort since these coefficient sets and models were developed here in Boulder. ITS has made every effort to assure the HF community that this effort is both accurate and true to the original models.

A new version of ITU-R Recommendation P.533 is available that takes into account digital modulation, equatorial scattering, and circuit reliability. With the advent of Digital Radio Mondiale (DRM) and a variety of digital modulation techniques it had become apparent that a new method to determine the reliability of HF digital communications needed to be developed. ITS has been working with other international HF experts to devise such a method. After several years of work the new algorithm is now available in the HF propagation software suite that ITS maintains.

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Low and Medium Frequency Propagation Modeling

Outputs

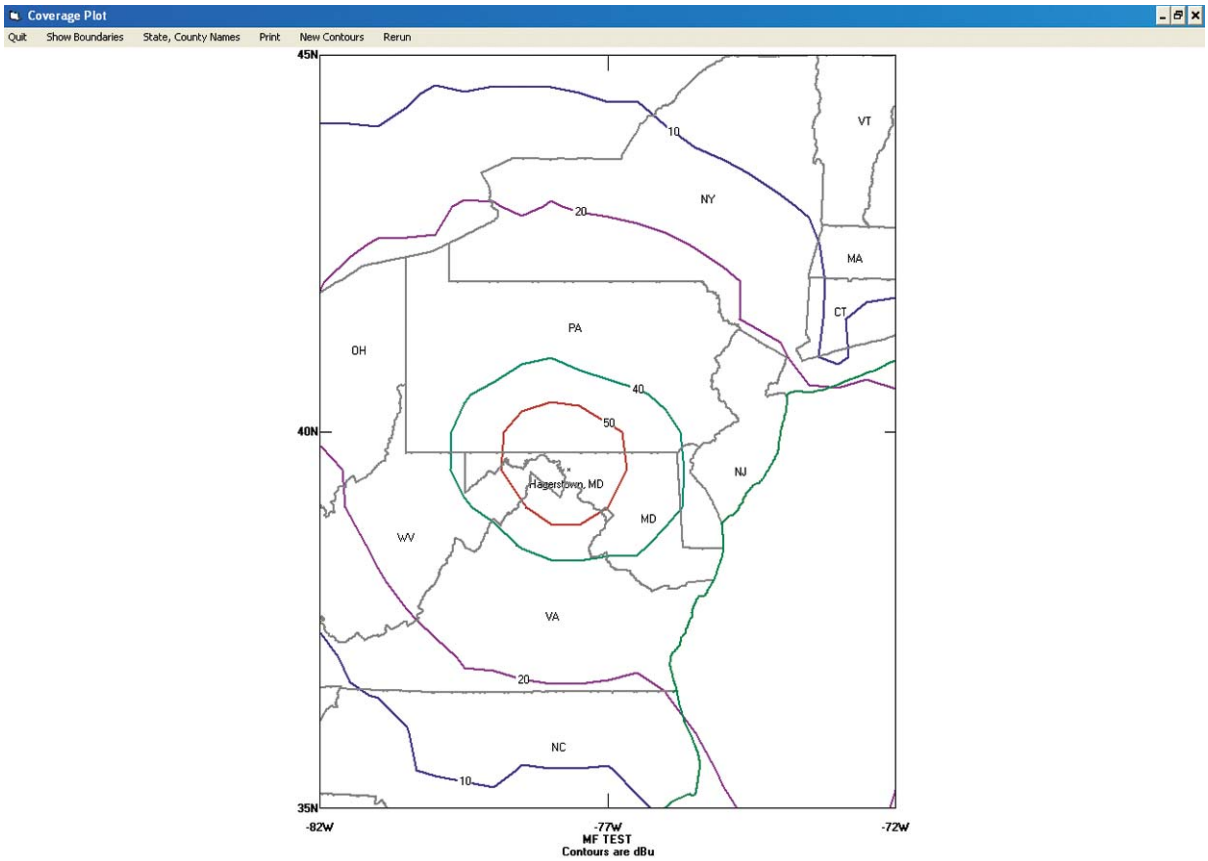
- Unique low and medium frequency ground-wave and sky-wave propagation models.
- Antenna models specific to LF/MF frequencies incorporated into analyses.
- Interference analysis used to allocate frequencies for DGPS station sites and AM broadcast stations.

The Institute has developed and continues to improve a propagation model to be used for analysis of coverage and interference in the medium frequency (MF) and low frequency (LF) bands. This is a Windows®-based communication/broadcasting system performance model designed for a PC that includes three ground-wave and three sky-wave propagation loss prediction methods. The models perform radio-wave propagation and antenna analysis in addition to interference prediction analysis. The sky-wave propagation models are valid from 150 to 1705 kHz, and the ground-wave models are valid from 10 kHz to 30 MHz. This model has been used for interference and coverage analysis for two versions of the Nationwide Differential Global Positioning System (NDGPS) in the two bands of frequencies from 285 to 325 kHz and 435 to 495 kHz, and for coverage and interference analysis of the AM broadcast band of 150 to 1705 kHz.

For the frequency band of 150 to 1705 kHz, the propagation of radio waves at night includes both a ground wave and a sky wave. The expected sky-wave signal combined with the ground-wave signal may be compared with the expected radio noise environment (consisting of atmospheric, galactic, and man-made noise components) to predict the likelihood that the communication link will operate satisfactorily or whether interference will occur. The presence of the sky wave at night could create potential interference problems between distant stations on the same frequency or frequencies that are near each other. The sky-wave models provide some means of estimating the expected field strengths of signals to assist in frequency allocation and to avoid potential interference problems. At night the undesirable interference from the sky wave can manifest itself as adjacent and co-channel interference to stations that it would not normally reach in the daytime. The absence of the sky wave during the day precludes the use of systems in this band for reliable long distance communication, since the sky wave at frequencies from 150 to 1705 kHz is strongly attenuated by the electron density in the D region during the daytime. Long distance radio-wave propagation during the daytime is limited by how far the surface-wave component of the ground wave can diffract around the Earth and its terrain features.

Antenna modeling in this band is also quite unlike that in other bands, since the performance of an antenna on or near the surface of the Earth is very dependent on the interaction with the lossy Earth, so specific antenna models have been included that correctly launch the ground wave at the horizon angle and the sky wave at the appropriate elevation angle.

This model consists of three distinct analyses called System 1, System 2, and System 3. While the analyses are related in function, each is independent of the others. System 1 treats the broadcast circuit from a proposed transmitter to a particular receiver site as a point-to-point problem. The user selects transmitter characteristics, receiver characteristics, site characteristics, and a propagation model. System 2 continues to treat the desired transmitter and the desired receiver site as a point-to-point problem, but interference effects are included. All adjacent and co-channel transmitters (referred to as the interfering transmitters) within a user-defined search radius are used to compute signal-to-interference ratios at the receiver location. For each adjacent and co-channel transmitter, the model lists the computed signal-to-interference ratio as well as the amount that the ratio exceeds or fails to exceed the required signal-to-interference ratio for the adjacent or co-channel case. System 3 evolves from the System 2 analysis by treating the broadcast situation as an area problem. The System 3 output is a map of the user-selected area showing contours of signal coverage or signal-to-interference ratios.



NDGPS coverage plot for Hagerstown, Maryland, at 454 kHz.

ITS has integrated the low and medium frequency model into a Geographic Information System (GIS) based application, the Communication Systems Planning Tool Low and Medium Frequency (CSPT-LFMF) model which provides the user with a GIS input capability so that low and medium frequency analyses can be run and displayed with more detailed and illustrative graphics. The GIS-based model makes use of GIS databases that include terrain, satellite and aircraft imagery, roads and other transportation infrastructure layers, building data, and population data. Additional efforts in the planning stages for future modifications to the low and medium frequency model include extending the frequency capability below 150 kHz by adding additional propagation models.

The figure shown above is an actual output of the low and medium frequency propagation model developed by ITS. It shows the coverage for an NDGPS site in Hagerstown, Maryland, at 454 kHz using the System 3 analysis of the low and medium frequency model. The contours are electric field strength in dB micro-volts per meter.

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

Outputs

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

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

In an Executive Memorandum from the President dated November 30, 2004, the Department of Commerce was asked to submit a plan to implement recommendations to ensure that our spectrum management policies are capable of harnessing the potential of rapidly changing technologies. The recommendations included (1) providing a modernized and improved spectrum management system; (2) developing engineering analysis tools to facilitate the deployment of new and expanded services and technologies; (3) preserving national security and public safety; and (4) encouraging scientific research and development of new technologies. To implement these recommendations, it is necessary to determine the best practices in engineering for spectrum management, and address the EMC analysis process.

ITS was tasked by NTIA/OSM to review and evaluate the current propagation models and ITU-R Recommendations to determine which could be used to perform propagation analyses to facilitate EMC analyses of mobile wireless devices. After performing an exhaustive review of current models, ITS determined that none was entirely suitable for use in analyzing mobile-to-mobile (MTOM) interference interactions. Although the models had their own regions of validity with respect to frequency, separation distance, and antenna heights, they were all inadequate for the short-range MTOM model requirements of: 1 m to 2 km separation distances, 1–3 m antenna heights, and a frequency range of 150–3000 MHz. Existing radio-wave propagation models are valid only for much higher antenna heights (4 m or greater) and larger separation distances (greater than 1 km). It was therefore necessary to initiate an analysis and measurement effort to develop and validate models in this parameter range.

In FY 2008, ITS conducted a measurement campaign in and around the Denver-Boulder metroplex to provide an initial set of measurements in real-world environments ranging from the dense urban high-rise environment of downtown Denver to the open, rural environment to the east of Table Mountain along N. 63rd St. in Boulder County, CO. The measurements were conducted using pseudo-mobile-to-mobile protocol, with the transportable transmitter truck driven to fixed sites and the transmitting antennas deployed near the ground on tripod supports, and the receiver van was driven through the surrounding environment at normal traffic speeds. At certain sites, measurements were collected using both the wideband impulse response-based receiver system, described in the ITS FY 2007 Technical Progress Report, and a narrowband, spectrum analyzer based receiver system. When the receiver system was deployed in narrowband mode, the pseudo-noise code based modulation of the (wideband) transmitter system was turned off.

There are theoretical and practical advantages and disadvantages to both the wideband and narrowband receiver systems. The wideband system is able to obtain channel impulse response information over the bandwidth of the transmitted signal, with the disadvantage of limited dynamic range and ability to tolerate ambient interference, while the narrowband system cannot collect channel impulse responses, but has the advantages of increased dynamic range and tolerance to ambient interference when a sufficiently narrow resolution bandwidth is chosen.

An important issue is the extent to which the wideband and narrowband systems give comparable results. The fading/enhancement observed by the narrowband system is that which occurs for a very small frequency range (approximately ±1.5 kHz) about the carrier frequency, while the frequency

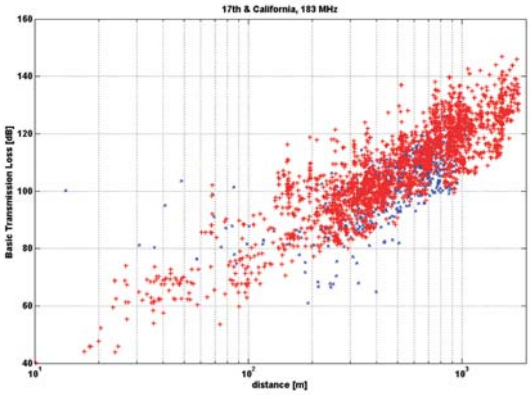

Figure 1. Comparison of wideband, x's, and narrowband, +'s, measured basic transmission losses in the dense urban high-rise region of downtown Denver, CO at 183 MHz.

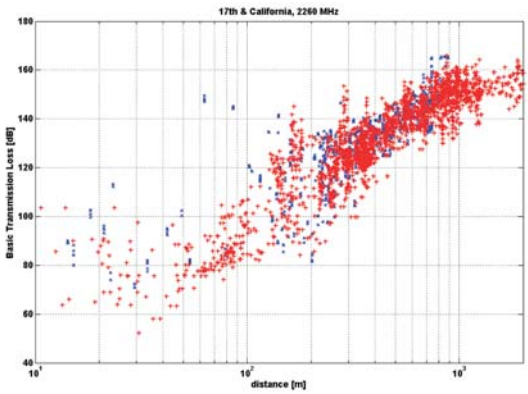

Figure 2. Comparison of wideband, x's, and narrowband, +'s, measured basic transmission losses in the dense urban high-rise region of downtown Denver, CO at 2260 MHz.

range about the carrier for the wideband system is as large as ±10 MHz and may include frequency selective effects. Figures 1 and 2 show comparisons of measurements taken with the two systems on drive routes in the dense urban high-rise environment in downtown Denver at 183 MHz and 2260 MHz, respectively. The wideband measurement results are represented by x's and the narrowband results are represented by +'s. In view of the fact that both datasets show comparable values of the basic transmission loss versus distance, it appears that frequency selective fading is not a dominant mechanism in the measurements obtained using the wideband system.

Simple slope-intercept models have been obtained using linear regression fits to the existing measurement data. The values obtained by the narrowband system are listed in Table 1.

Table 1. Results for All Measured Data

Slopes

	183	430	915	1350	1602	2260	5750
Rys	37.3	35.4	40.1	39.5	42.1	48.9	44.9
NCA	22.3	0.0	34.5	0.0	36.1	33.9	39.1
DTC	40.3	45.4	42.4	44.5	43.8	44.2	42.7
Fed	34.6	33.5	33.0	38.0	36.0	40.0	41.6
Bro	38.4	42.2	41.1	0.0	43.0	51.3	58.5
Aur	38.0	39.8	39.9	39.8	45.2	41.1	47.5
17t	39.1	43.3	46.1	43.0	45.7	48.0	50.1

Intercepts

	183	430	915	1350	1602	2260	5750
Rys	1.1	2.4	-6.6	-10.2	-15.2	-31.3	-3.8
NCA	48.4	0.0	28.4	0.0	24.8	37.0	33.9
DTC	0.8	-12.8	11.6	-1.1	5.5	7.2	41.0
Fed	9.2	12.0	26.9	5.1	32.8	6.3	16.7
Bro	12.7	3.2	22.6	0.0	15.8	-0.0	-6.6
Aur	4.6	-1.2	14.8	8.0	0.4	25.6	21.0
17t	2.0	-4.0	3.8	6.8	3.6	6.1	24.3

Standard Deviations

	183	430	915	1350	1602	2260	5750
Rys	5.4	5.8	7.0	7.7	7.4	7.8	9.2
NCA	7.9	0.0	8.9	0.0	9.9	9.6	9.1
DTC	7.4	8.2	7.4	8.1	7.6	7.6	8.4
Fed	7.5	7.4	9.2	9.9	10.6	9.5	9.7
Bro	8.0	8.2	8.8	0.0	8.7	10.0	10.6
Aur	6.6	7.5	7.5	7.1	7.5	7.4	7.9
17t	7.8	8.6	8.3	8.6	8.9	9.1	10.2

Number of Points

	183	430	915	1350	1602	2260	5750
Rys	563	547	547	555	482	311	509
NCA	260	0	254	0	258	271	312
DTC	1527	1616	1379	1401	1302	1665	1381
Fed	1441	1467	1334	1502	1269	1468	1430
Bro	2289	2600	3304	0	2728	2494	2835
Aur	2059	2656	1981	2514	2024	2314	1561
17t	3069	2379	2840	2248	3152	2243	2257

Rys=Ryssby Church ; NCA=NCAR ; DTC=Belleview Promenade, Denver Tech Center ; Fed= Denver Federal Center ; Bro=Broadway and Spruce, downtown Boulder ; Aur=Auraria Campus, downtown Denver ; 17t=17th and California, downtown Denver.

Work on this project in FY 2009 will focus on obtaining measurements for additional environments as well as further work on model development and refinements.

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