Telecommunications Engineering, Analysis, and Modeling

The Telecommunications Engineering, Analysis, and Modeling Division conducts studies in the following 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 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.

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/G3GRA.

Areas of Emphasis

ENGINEERING

Interference Issues Affecting Land-Mobile Systems The Institute participates in the ATIS subcommittee WTSC/G3GRA (Wireless Technologies and Systems Committee — Radio Aspects of GSM/3G and Beyond). ITS is now developing PCS interference models for CDMA and W-CDMA. This project is funded by NTIA.

Public Safety Video Quality (PSVQ) The PSVQ project is conducting a series of subjective tests that illustrate different types of video compression and artifacts. These examples of video are shown to viewers and then the data is analyzed and correlated. From this analysis NTIA/ITS hopes to make recommendations for video standards based on applications in the public safety arena. This project is funded by DHS/SAFECOM.

Public Safety Architecture Framework (PSAF) The PSAF project is establishing a common framework for information databases from various branches of the public safety community. NTIA/ITS is leading a large collaborative effort to ensure the ability to share information across many agencies — local, State, and Federal. This project is funded by DHS/SAFECOM.

Analysis of HA-NDGPS The Institute has developed a unique software model for performance and interference analysis and is conducting an analysis of the High Accuracy Nationwide Differential Global Positioning System (HA-NDGPS) for the Federal Highway Administration of the U.S. Department of Transportation.

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 that improve spectrum usage of wireless systems. Technical standards are prepared that support U.S. interests in 3G broadband wireless systems and are then fed into the ITU-R SG 3, WPs 3J, 3K, 3L and 3M. ITS is active in path specific model development toward a draft new Recommendation. The project is funded by NTIA.

Short-Range Mobile-to-Mobile Propagation Model Development and Measurements The Institute is developing a model for short-range (less than 1 km) propagation between mobile radios. The propagation work consists of both modeling and measurements. A new propagation measurement system is under development, and preliminary measurements were performed in FY 2006. This project is funded by NTIA.

Interference Issues Affecting Land-Mobile Systems

Outputs

- Self-interference models for dominant CMRS technologies.
- Technical contributions to industry-supported efforts for predicting, identifying, and mitigating interference related problems.
- Adapted model for use in evaluating adjacent channel systems.

Recent natural disasters demonstrate how important Commercial Mobile Radio Services (CMRS) have become in establishing emergency communications. Damage to the terrestrial telecommunication infrastructure forces users to resort to cellular resources. Emergency responders find themselves unable to establish inter-agency communication links, especially with responders from outside of the affected area and, as a last resort, must rely on cellular systems to fulfill their missions. The sudden influx of traffic by private, commercial, civil, and Federal users results in system overloads, a decrease in signal quality, and further disruption of service in the affected area. Beyond the physical damage caused by events, additional factors contribute to diminished channel capacity of the wireless network, such as co- and adjacent-channel interference and the operation of multiple, independent, non-interoperable systems servicing the same geographical area, often using the same frequency bands and infrastructure (base station sites and towers).

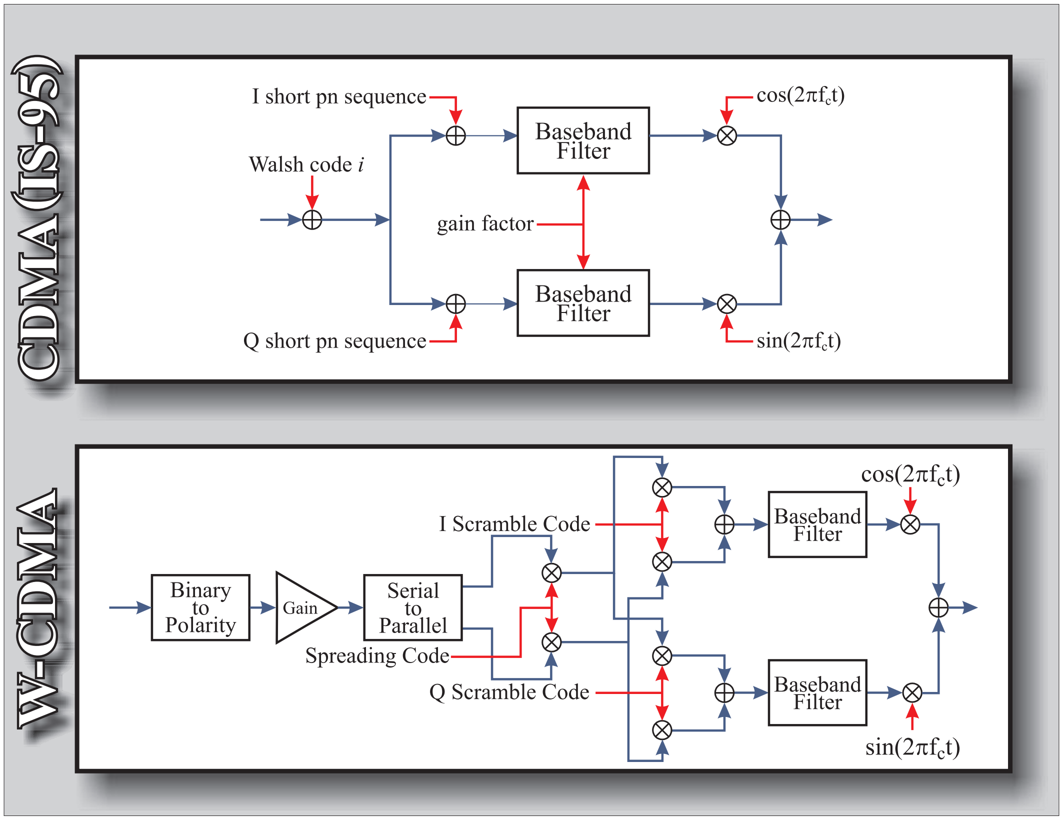
One way of coping with damaged or destroyed infrastructure is to deploy temporary equipment to supplement the surviving system. To make efficient use of limited resources, responders need to know what equipment needs to be deployed in which locations. Knowing the interference issues, dynamics and load patterns of the original system is key to effective, post-disaster support by national security/emergency preparedness (NS/EP) planners and network operators in an overloaded environment.

As plans for next- and future-generation communication systems develop, the lack of available spectrum becomes an issue. Also, spectrum dedicated to systems supporting emergency responders must be allocated from frequencies already in use. Spectrum sharing by multiple users will become absolutely necessary if all proposed systems are implemented.

ITS contributed to the understanding of inter-PCS interference by participating in the Telecommunication Industry Association (TIA) committee TR46.2 (Mobile & Personal Communications 1800-Network Interfaces). As a member of TR46.2, ITS contributed to the development of the Technical Service Bulletin "Licensed Band PCS Interference" (TSB-84A). This bulletin was a first step in characterizing the interfering environment caused by large numbers of active users and competing technologies. Since the completion of TR46.2's work, coverage of interference issues concerning all mobile communication systems has been adopted by the Alliance for Telecommunications Industry Solutions (ATIS) subcommittee WTSC/G3GRA (Wireless Technologies and Systems Committee — Radio Aspects of GSM/3G and Beyond). Work on the successor to TSB-84A is currently underway as Issue P0004, "Interference and Co-Existence Issues Affecting Land Mobile Systems." ITS continues to be involved in interference issues with this group as editor and contributor.

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

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. Several standard propagation models are accepted by industry members (i.e., Okumura and COST-231/Walfish/Ikegami) but no interference



Downlink diagram for IS-95 CDMA and W-CDMA as implemented in the co-channel interference model.

model has been developed or accepted. ITS is developing an interference model capable of implementing any cellular technology, including two CDMA-based systems: the TIA/EIA-95B standard and W-CDMA (wideband CDMA). The model involves system-specific interference modeling to determine the level of co-channel interference from both immediate and adjacent cells. The model produces a representation of an instantaneous air interface signal. The signal can contain outputs of multiple base stations with variable numbers of channels for each base station and can assign relative power levels for each individual channel. Both forward and reverse link processes are included in the model. The figure shows the block diagrams of the forward data paths for both technologies currently implemented.

The model calculates each channel's signal contribution separately from all other channel's signals and then adds the processed signal to the other signal contributions to form a composite output signal. The power level for a single channel is an arbitrary gain factor of the baseband filter which is set separately for each channel. The output of the model consists of a vector of numerical values representing a sampled QPSK or OQPSK signal. There is no error correction added to the input sequence; only spreading codes and modulation processes are used. This model does not check for recovery information contained in the input. Its only purpose is to determine how well the system can transmit the bits of an input binary sequence.

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

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Public Safety Video Quality

Outputs

- Test results from four phases of testing.
- Technical contributions to standards bodies to establish video quality standards for the public safety community.
- Statement of Requirements technical contributions on video quality standards to the sponsor.

Police and fire agencies often purchase radios, cameras and other communications equipment based on just their local needs. Unfortunately, this equipment may not always be of high enough quality for certain applications or be able to communicate with similar agencies with other specific needs. Until several years ago, 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 with the Department of Homeland Security (DHS) to ensure that first-responder video systems communicate clearly and accurately with each other.

The Public Safety Video Quality (PSVQ) project is a growing research effort. This project started with a single video quality test, the application of tactical video with a narrow field of view, conducted at ITS in December 2005. During the rest of FY 2006 and continuing through FY 2007, ITS has been expanding testing to include four additional test phases: wide tactical, narrow observed surveillance, wide observed surveillance, and narrow and wide recorded surveillance. “Wide” describes the field of view if the objects of interest are relatively small, for example, people in the stands at a football game. “Narrow” is used to describe the field of view in which the objects of interest are large, for example, a close up of a person’s face. From these five tests, ITS researchers can develop specific technical requirements per each public safety video application.

A Video Quality Metric (VQM) is a tool that can be used to objectively predict levels of quality based on subjective tests. ITS engineers have developed several standard video quality metrics which are used to analyze the video quality of various public safety applications, such as in-car cameras and surveillance cameras. Shown in the figure on the next page is an example of an in-car camera application with relatively poor video quality.

ITS is developing a model to predict what a subjective viewer would think. How would a first responder evaluate the quality of the video necessary for him to do his job? Can the in-car camera read the license plate of a vehicle in front of the police car? A subjective viewer would rate the quality of such video on a scale ranging from good to bad. Public-safety practitioners — first responders — volunteer to participate in the subjective video quality tests at ITS in order to provide the necessary subjective data on acceptable video quality levels.

The resulting model produces correlation curves that provide the critical analysis to draw conclusions and make specific technical recommendations. The model calculates each viewer’s contribution (video quality scores) separately and then combines them together with the other viewers’ data to form a composite output result. Curves are fitted to the scatter plots created during the correlation analysis. The purpose of such analysis is to determine how high the video quality needs to be for public safety practitioners to do their job. The model is used to predict objectively a subjective viewer’s perception of video quality.

With a model that allows for this translation from subjective methods to objective methods, subjective testing would become unnecessary. This resulting model could be used as an objective test method to determine the same video quality information without the need for subjective testing. Subjective testing is very time consuming and hence very expensive. This new method, an objective alternative, would provide savings of both time and money. This modeling tool could then be used by the public safety community to help evaluate and aid in the selection of video equipment.

The ITS VQM was developed by Margaret Pinson and Stephen Wolf of the ITS Telecommunications Theory Division. The Theory Division houses

The video from an in-car camera mounted on the dash of a police car illustrates how poor the quality can be from such a device especially given the harsh video environment such as night filming and high motion components with flashing lights.

long-term research programs in both video and audio quality. Pinson and Wolf's work is described in more detail on pp. 56-57 and has led to several international and national standards. In addition, ITS also houses a multimedia project in the Telecommunications and Information Technology Planning Division that brings many of these ITS technical products to national and international standards groups, such as the Video Quality Experts Group (VQEG). VQEG activities are supported by three of ITS's four Divisions. The multimedia project is described on pp. 28-29.

The goal of the PSVQ project is the identification of video quality standards. This identification of video quality parameters is part of a larger effort to develop a comprehensive Statement of Requirements (SoR) for public safety communications. ITS is developing the SoR for the public safety community, which reviews and approves the work and even participates in the research as incident experts and subjective test subjects. The public safety SoR is supported by representatives from various organizations: International Association of Chiefs of Police (IACP); International Association of Fire Chiefs (IAFC); Association of Public-Safety Communication Officials-International (APCO); National Association of State Emergency Medical Services (EMS) Directors; National Public Safety Telecommunications Council (NPSTC); and others. A number of Federal organizations are funding the work, most notably the U.S. Department of Homeland Security's SAFECOM Program and the National Institute of Standards and Technology (NIST) Office of Law Enforcement Standards (OLES).

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Public Safety Architecture Framework

Outputs

- Fully specified data model of a public safety radio communications system.
- PSAF data model populated with actual public safety land mobile radio (LMR) data.
- PSAF data model system view of an actual LMR network.

In FY 2006, the SAFECOM[1] sponsored Public Safety Architecture Framework (PSAF) Program began the first phase of actualizing the communications requirements outlined in the Public Safety Statement of Requirements (SoR).[2] The term "architecture framework" refers to the structured data used in comparing and integrating legacy communication systems to assess current resources and facilitate interoperability. In addition to characterizing current LMR system capabilities, the PSAF also allows "what if" scenarios to identify future system interoperability and functionality. The purpose of the PSAF is two-fold:

1) The PSAF program not only identifies key existing communication interface standards but also fleshes out newly emerging standards. Identifying these standards is essential to achieve SAFECOM's system-of-systems vision outlined in the SoR.

2) The PSAF serves as a guide for jurisdictional interoperability planning and functionality upgrades. It enables engineers and system planners to assess their current public safety communication capabilities and determine the level of interoperability between various jurisdictional systems.

To leverage current development, the ITS-led PSAF project has joined forces with the Communication Assets Survey and Mapping (CASM) project led by the Space and Naval Warfare Systems Center (SPAWAR), San Diego. CASM is sponsored by the Department of Homeland Security (DHS) under the ICTAP (Interoperability Communications Technical Assistance Program) umbrella. CASM is a web-based tool that agencies can use to store interoperable communications equipment inventory and current radio communications infrastructure information. The data resides in a secure SPAWAR database that is accessible only by the participating agencies.[3] The CASM tool was first released in July, 2005. It has 57 sites and 650 users. The PSAF project will extend the current CASM functionality into a new tool that will incorporate additional PSAF requirements. The joint ITS/SPAWAR development team has completed an initial PSAF data model, including the underlying database, relationships, and cardinality that provide the ability to evaluate public safety communications systems.

The PSAF data model, outlined in the PSAF definitions and guidelines documentation,[4] combines three different data perspectives (OV, SV, and TV) into one cohesive model. The OV (Operational View) identifies how public safety agencies perform their missions. The SV (Systems View) captures public safety systems of equipment and information flow. The TV (Technical Standards View) captures the technical interfaces that allow systems to interoperate. In order to create the PSAF data model, various scenarios, such as the radio subsystem, dispatch subsystem, etc., were diagrammed separately and then combined into a cohesive data hierarchy.

Figure 1 shows a high-level view of the SV portion of the PSAF data model. This diagram identifies the entities captured in the model and the relationships between entities. The data model also includes all of the critical public safety attributes that comprise each entity.

To validate the PSAF data model and to provide development feedback, a trial data collection effort was performed with Cobb County, Georgia, in

1 SAFECOM, a communications program of DHS's Office for Interoperability and Compatibility, with its Federal partners, provides research development, testing and evaluation, guidance, tools, and templates on communications-related issues to local, tribal, State, and Federal emergency response agencies (http://www.safecomprogram.gov/SAFECOM/).

2 The SOR defines future requirements for crucial voice and data communications in day-to-day, task force, and mutual aid operations (for more information visit http://www.safecomprogram.gov/SAFECOM/library/technology/1258_statementof.htm).

3 For more information visit the http://www.ojp.usdoj.gov/odp/docs/ICTAP_Fact_Sheet.pdf website.

4 See http://www.safecomprogram.gov/NR/rdonlyres/87C163DB-BF19-4E0D-B2DB-E9446E1151EC/0/ST06173PSAF1.pdf for additional PSAF documentation.

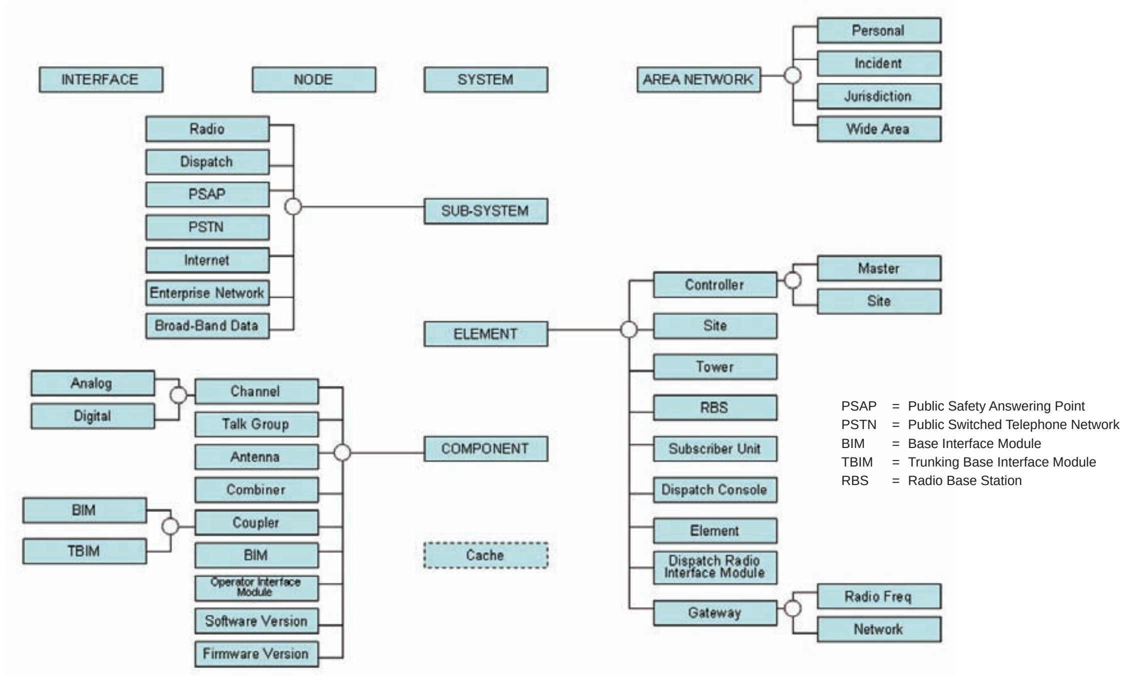

Figure 1. PSAF system view of a land mobile radio system.

November, 2006. The Cobb County site was selected to leverage the current data collection efforts already performed using the CASM tool. Figure 2 shows ITS personnel gathering LMR system information at an actual radio site.

Figure 2. ITS personnel gathering LMR system information at an actual radio site (photograph by C. Redding).

Prior to the trial, the PSAF data model was pre-populated with existing CASM data. An analysis was performed to determine the "delta" between PSAF and CASM and then a PSAF questionnaire was created to allow for entry of the additional PSAF data. The SV produced from the trial will show, as modeled in Figure 1, the system, subsystems, elements, and components of the Cobb County LMR network. The next phase of the project, slated for May 2007, will be a pilot data collection process that will expand the trail data collection effort into a more fully developed model and incorporate the results into a database storage mechanism.

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Analysis of the High-Accuracy Nationwide Differential Global Positioning System

Outputs

- Unique ITS-developed software model for performance and interference analysis.
- ITS interference analysis used to allocate frequencies for the HA-NDGPS station sites.

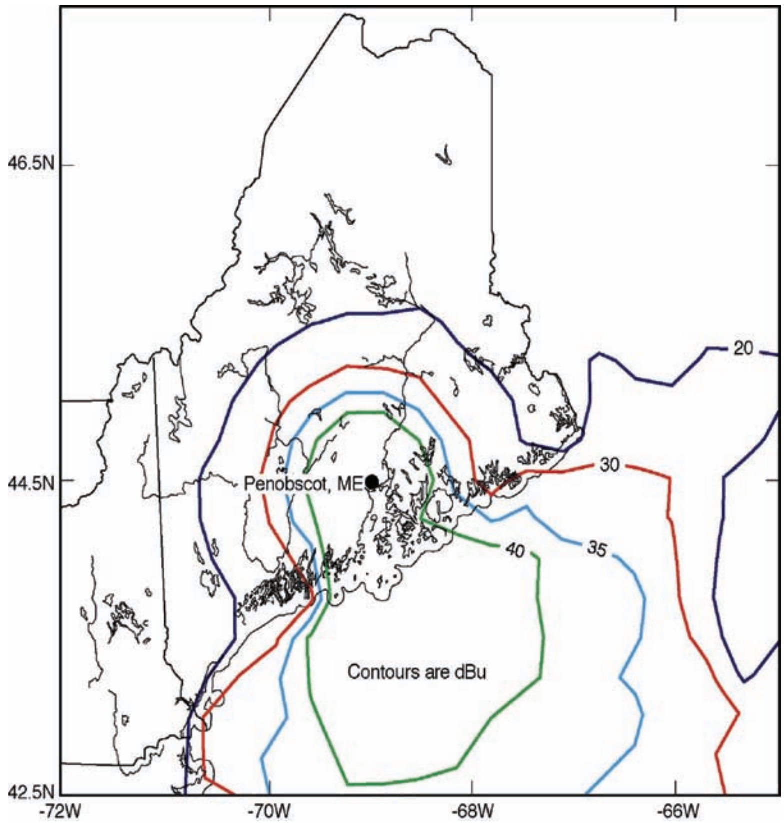
The Institute is performing an interference analysis of the High Accuracy Nationwide Differential Global Positioning System (HA-NDGPS) for the Federal Highway Administration (FHWA) of the U.S. Department of Transportation. The HA-NDGPS system can provide correction signals to the location provided by the Global Positioning System (GPS) satellites that will result in a position location more accurate than that provided by the GPS satellites alone. The HA-NDGPS differential-correction signal is computed by comparing the GPS satellite determined position of the HA-NDGPS reference station site with the surveyed geodetic position of the HA-NDGPS reference station site. The HA-NDGPS differential-correction signal is then broadcast over a wide area at medium frequencies from reference station sites geographically distributed over the United States to provide contiguous coverage. A HA-NDGPS receiver collects navigational information from all GPS satellites in view, and also receives differential correction signals from a local HA-NDPGS reference station site to determine a precise geographic location.

There are two versions of the Nationwide Differential Global Positioning System (NDGPS): the Legacy NDGPS operating in the 285–325 kHz band, and the HA-NDGPS operating in the 435–495 kHz band. Both of these systems provide correction signals to the locations given by GPS satellites. The Legacy NDGPS system can provide one meter position accuracy and the HA-NDPGS system can provide one-tenth meter position accuracy. The planned HA-NDGPS station sites will be collocated geographically with all of the Legacy NDGPS sites at a total of 130 sites when complete. ITS is performing the interference analysis for all of the planned 130 HA-NDGPS sites.

The NDGPS system was originally designed for use by the U.S. Coast Guard in harbor approach and navigation, vessel tracking, and buoy tracking, but the increased accuracy of the recently developed HA-NDGPS has expanded its use to land applications such as: mapping, precision surveying, positive train control, precision farming, smart vehicles, lane keeping, collision avoidance, snow plow management, accurate waterway dredging, and improved public safety emergency response. The FHWA in cooperation with other Federal, State, and local organizations is deploying both NDGPS and HA-NDGPS sites across the country to provide this service to cover the inland waterways and all land regions of the continental United States, Alaska, Hawaii, and Puerto Rico. Coverage of the coastal regions of these locations will also be included.

Prediction of coverage and interference for HA-NDGPS requires special analysis considerations. For the frequency bands 285–325 kHz and 435–495 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 communications link will operate satisfactorily. 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 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 HA-NDGPS interference analysis involves selecting frequencies for these systems so that they will not interfere with each other or other users of the bands. The planned HA-NDGPS sites are being analyzed for coverage and interference using the Low and Medium Frequency Ground-Wave and Sky-Wave model developed at ITS. The model can evaluate the broadcast circuit from a proposed transmitter to a particular receiver site as a point-to-point problem. The user selects the transmitter



Coverage of one HA-NDGPS site in Penobscot, Maine.

characteristics, receiver characteristics, site characteristics, and a propagation model. The model can also perform an interference analysis including all adjacent and co-channel transmitters (referred to as the interfering transmitters) within a user-defined search radius 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. One of the outputs of the model is a map of the user-selected area, showing contours of signal coverage or signal-to-interference ratios. An example is shown in the figure above.

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 dependent on the interaction with the lossy Earth. Therefore, specific antenna algorithms have been included in the model that correctly launch the ground wave at the horizon angle and the sky wave at the appropriate elevation angle. The model contains a special database that determines the interfering transmitters and susceptible receivers in the environment.

In FY 2006, most of the work effort was directed towards gathering information to build this extensive database. The interference analysis was performed for approximately one-fourth of the sites. The interference analysis for the remainder of the sites is planned for completion in FY 2007.

This ITS interference analysis will demonstrate that the HA-NDGPS system can conduct operations on an unprotected, non-interference basis in the 435–495 kHz band and provide a first look at frequency assignments for each of the 130 facilities located nationwide. Low and medium frequencies have been used for many years in maritime and aviation applications for coarse position location and navigation. A broadcast technique in the low and medium frequency bands is used to ensure coverage over a large geographic area and in the presence of obstructions such as terrain, forests, and buildings between the broadcast site and the user's location.

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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, 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 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.

Currently available are: on-line terrain data with 1-arc-second (30m) resolution 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, 1997 update, and 1990; Federal Communications Commission (FCC) databases; and geographic information systems (GIS) databases (ArcInfo). For more information on available programs, see the Tools and Facilities section (pp. 73-74) or call the contact listed below.

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 TA Services system. These customers can activate models, enter information about their broadcast equipment and produce a generic transmitter coverage map such as that shown in Figure 1 below for a typical broadcast television station using the Communications System Performance Model (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 U.S. broadcast television providers 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

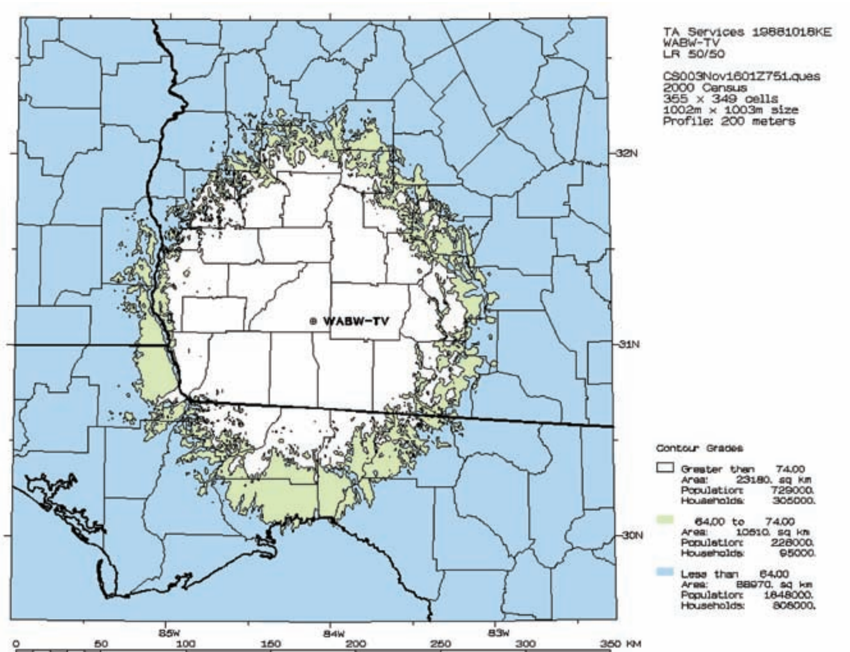

Figure 1. Sample output of the CSPM model of a TV transmitter located in Georgia.

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 (PBS) 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 and even determine where there is overlapped coverage of multiple transmitters, as shown in Figure 3. This provided invaluable services to the people of the southeastern portions of the United States in the severe hurricane season of 2005.

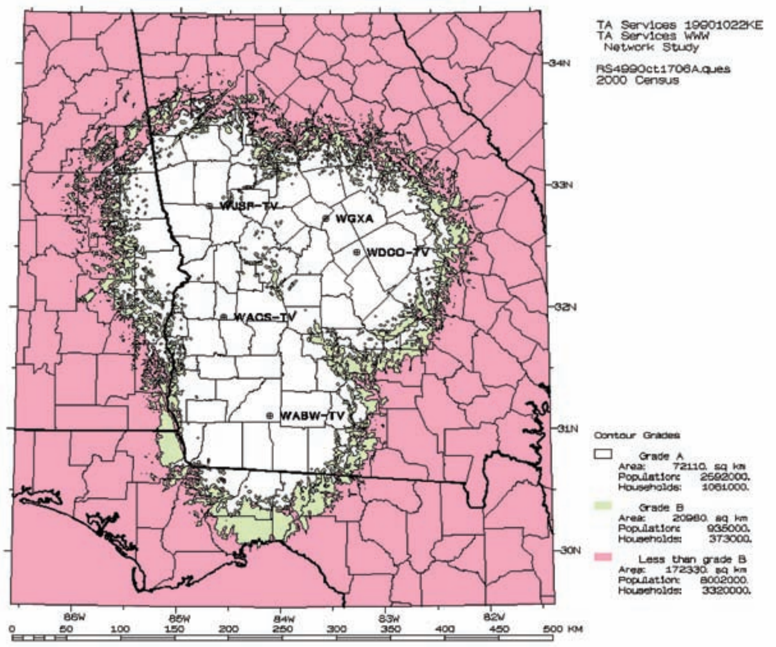

Figure 2. Composite coverage of several TV stations located in Georgia.

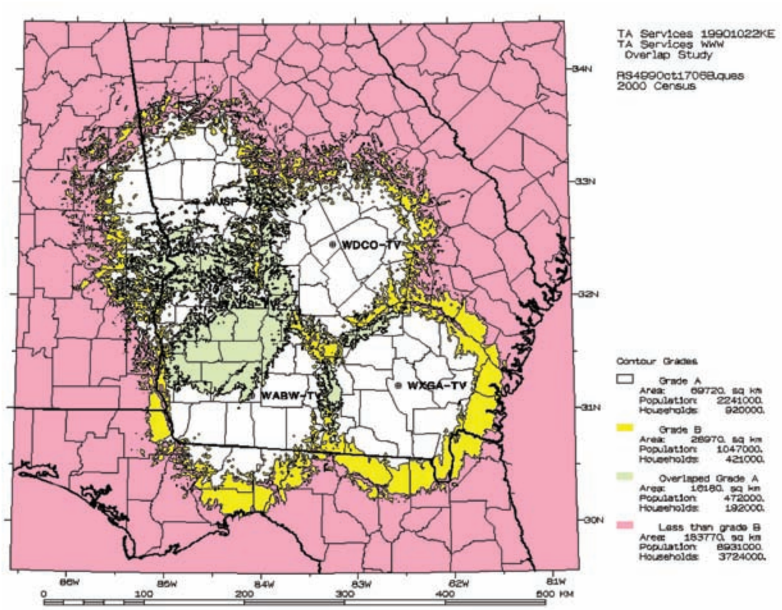

Figure 3. Overlap study of several TV stations located in Georgia.

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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.
- Fly-through visualization capabilities.

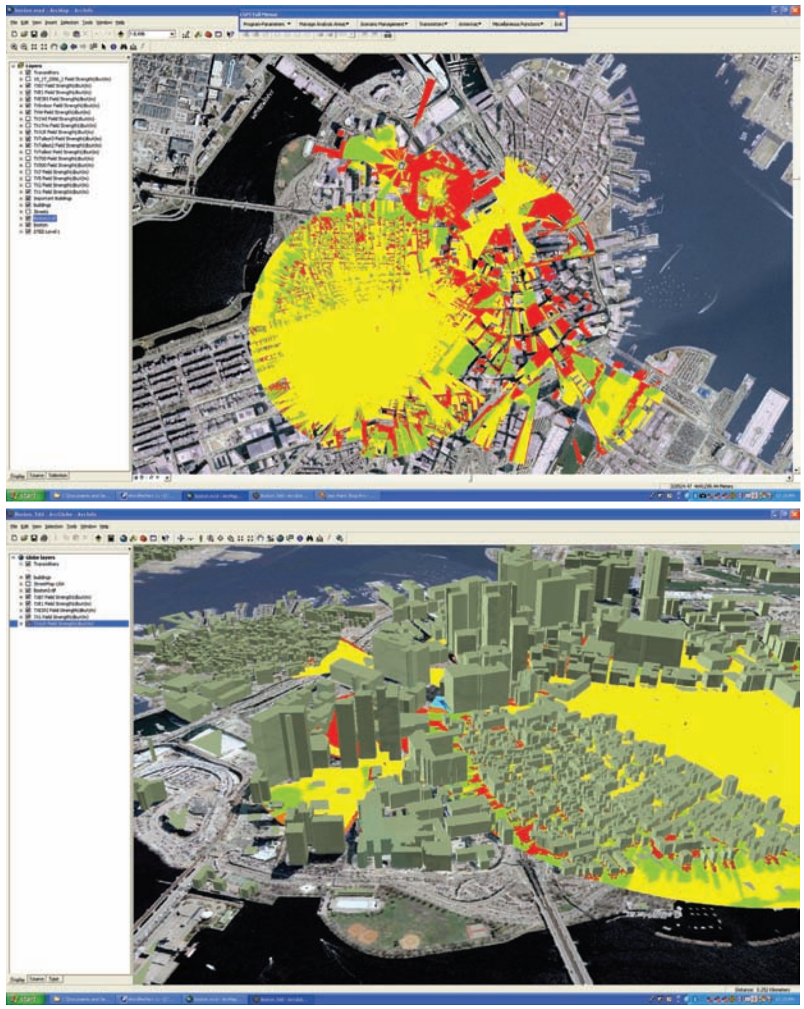

Figure 1. A CSPT-VHF study for Boston showing both 2D (top) and 3D (bottom) results.

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

The primary GIS-based tool developed by ITS is the Communication Systems Planning Tool (CSPT-VHF). CSPT is a menu and icon driven propagation model developed for frequencies from 20 MHz to 20 GHz that allows the user to connect to a variety of image catalogs and terrain libraries that cover most of the world. The user can create specific analysis areas using these catalogs and libraries and can then perform propagation scenarios for his/her application. These applications can range from outdoor coverage studies of large-scale areas of hundreds of square miles to indoor propagation studies of one building in an urban environment. Figure 1 shows a sample case of a transmitter coverage of the city of Boston. This coverage is shown in both 2D and 3D. CSPT allows the user to transition into 3D and fly through the environment.

A second tool is the CSPT-HF model, which provides the user with a GIS front end and back end to the ITS HF ICEPAC model, suitable for analyses from 2 MHz to 20 MHz. The GIS tool allows the

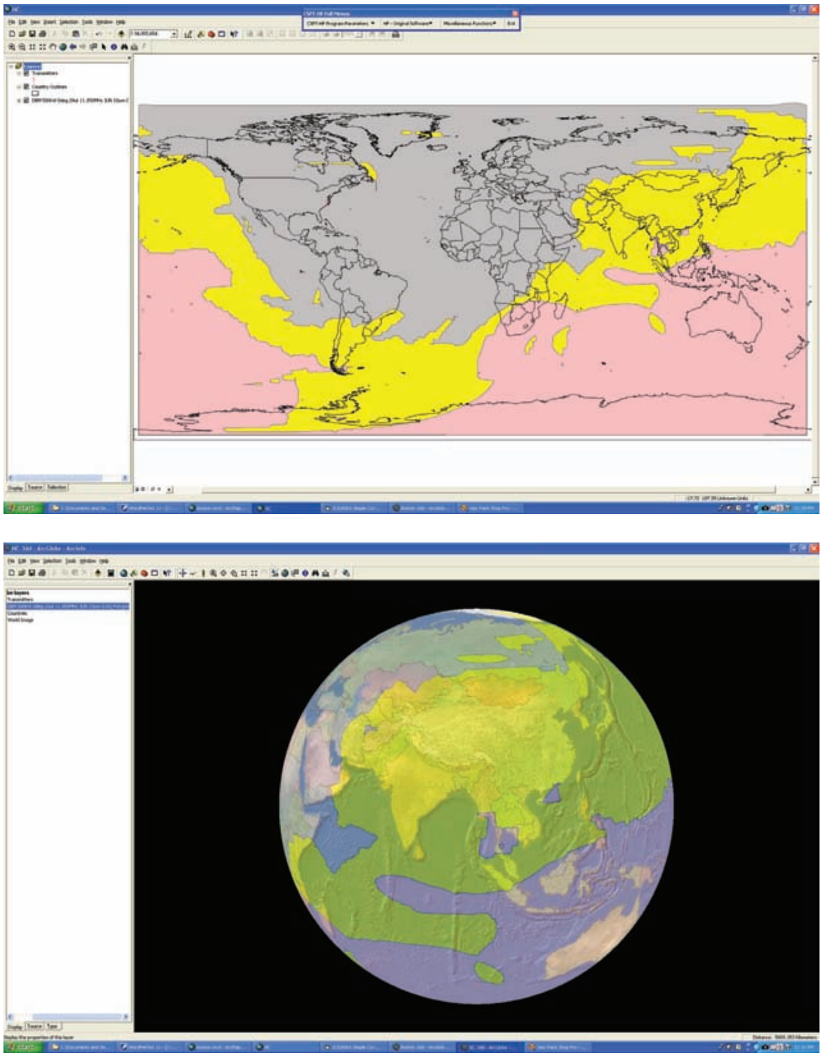

Figure 2. A CSPT-HF study for the entire earth showing both 2D (top) and 3D (bottom) results.

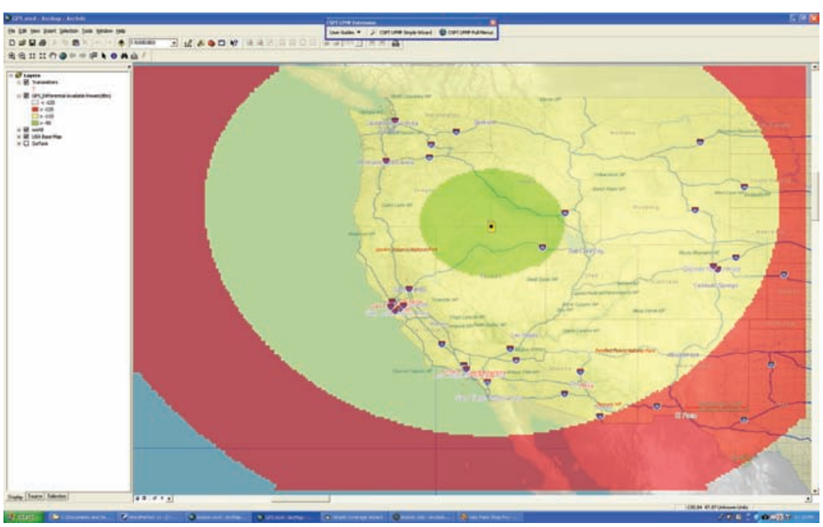

Figure 3. A CSPT-LFMF study for the western United States.

user greater flexibility in creating scenarios for HF area coverage studies and in viewing their results. Input parameters to the model can be incremented and run in a batch mode. The output results of ICEPAC are imported into the GIS and can be displayed in 2D or 3D as shown in Figure 2.

A third tool is the CSPT_LFMF model, which provides the user with an easy-to-use GIS input capability so that low frequency and medium frequency analyses (150 kHz to 2 MHz) can be run and displayed, as shown in Figure 3.

The general flow of the CSPT GIS Tool is as follows. The user defines an area within which a study will be performed. This area can be defined graphically by zooming into a map of the world or 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. After creating the analysis area, the user creates or imports transmitter, receiver, and antenna data. Lastly, the user selects the type of coverage and the propagation model to be used in the analysis.

Coverages, composites and interference analyses can be imported into GIS visualization tools, allowing the user to see and often fly through their studies so that a better understanding of the analysis results can be obtained.

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Broadband Wireless Standards

Outputs

- Studies of candidate standards for site general and site specific radio propagation models.
- Comparison of radio propagation models' predictions to measurements.

During FY 2006, the Broadband Wireless Standards Project focused on development and evaluation of site specific radio propagation models under consideration for standardization by ITU-R Working Party (WP) 3K. Testing of proposed modifications to Rec. ITU-R P.1546-2, a site general radio propagation model, was also undertaken. The culmination of these activities was a presentation to a special workshop on site specific and site general propagation models at ITU Headquarters in Geneva, Switzerland, on September 26-27, 2006, immediately preceding the Block Meetings of the Working Parties of ITU-R Study Group 3. The workshop was very successful in stimulating the work of subgroups 3K-1 and 3K-2 of WP 3K during these meetings.

Within the ITU-R, the requirement for a standardized site specific radio propagation model is pressing. The Regional Radio Conference, RRC-06, published the Final Acts of RRC-06 which contain the Regional Agreement GE06, adopted by RRC-06. The GE06 Agreement governs the use of frequencies by the broadcasting service and other primary terrestrial services in bands 174–230 MHz and 470–862 MHz in parts of ITU-R Regions 1 and 3. The Final Acts also contain frequency assignment and frequency allotment plans for the digital broadcasting service, the analog television plan applicable in the transition period, the coordinated list of assignments to other terrestrial primary services in these bands, and the Resolutions adopted by RRC-06. The GE06 Agreement is provisionally applicable from June 17, 2006.[1] One of the RRC-06 Resolutions highlights the urgent need for a site specific model for use in bilateral and multilateral planning and coordination activities to take place under the GE06 Agreement.

Six different site specific propagation models are being considered as candidates for a Draft New Recommendation (DNR) that will be developed by WP 3K at its next meetings (April 2007). If consensus is achieved within WP 3K, it is almost certain that Study Group 3 will approve the DNR for adoption. Three models are variants of Rec. ITU-R P.452, separately proposed by the European Broadcasting Union (EBU), China, and the UK. Of the remaining three models, one was proposed by Switzerland, and the last two were proposed by the United States: the ITS Irregular Terrain Model (ITM) in its point-to-point prediction mode and the Site Specific Model (SSMD). Since the latter two models were relatively unknown internationally, there was a need to increase their visibilities in this forum.

The ITM is a mature, general purpose radio propagation model, intended for use on tropospheric circuits with path lengths of 1–2,000 km, antenna heights above ground of 0.5–3,000 m and frequencies of operation of 20–20,000 MHz. When the link's radio climate is specified, it can be used to make predictions for the quantiles of attenuation relative to free space for long-term time variability, location variability and situation variability.

The SSMD, a less mature model, is a hybrid model: its median predictions are a weighted combination of the 50% time sea curves of Rec. ITU-R P.1546-2 and the Deygout three-edge diffraction method of Rec. ITU-R P.526-9, with the smooth earth component removed. When applicable, these predictions are limited to the troposcatter losses of Rec. ITU-R P.452-12. To obtain predictions for time percentages less than 50% and greater than or equal to 1%, the variability of the corresponding land curves of Rec. ITU-R P.1546-2 is applied to the median prediction described above. Because this model is heavily based on Rec. ITU-R P.1546-2, the distance, antenna height, and frequency limits of that Recommendation apply: path lengths of 1–1,000 km, effective antenna heights less than 3,000 m and frequencies of operation of 30–3,000 MHz.

One method that may be employed to evaluate site specific radio propagation models is to compare their predictions to measured propagation data. When this is done, the comparison results are stated in terms of the prediction error, i.e., the difference between the predicted and measured attenuations (dB), and the central moment statistics of the prediction errors. Five U.S. propagation measurement campaigns have data at least partially applicable to both of the models: the ITS Phase 1, Phase 2, and Low Antenna campaigns, and the Ft. Huachuca and

1 http://www.itu.int/pub/R-ACT-RRC.14-2006/en.

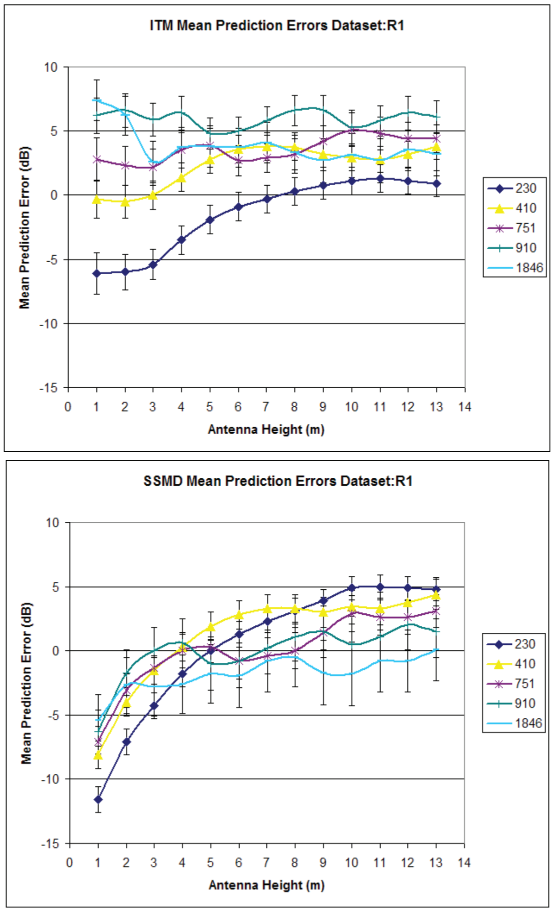

Figure 1. (Top) ITM and (bottom) SSMD mean prediction errors plotted as functions of antenna height and frequency for the Phase 2 R1 measurement dataset. The values of the measurement frequencies (MHz) are given in the legend.

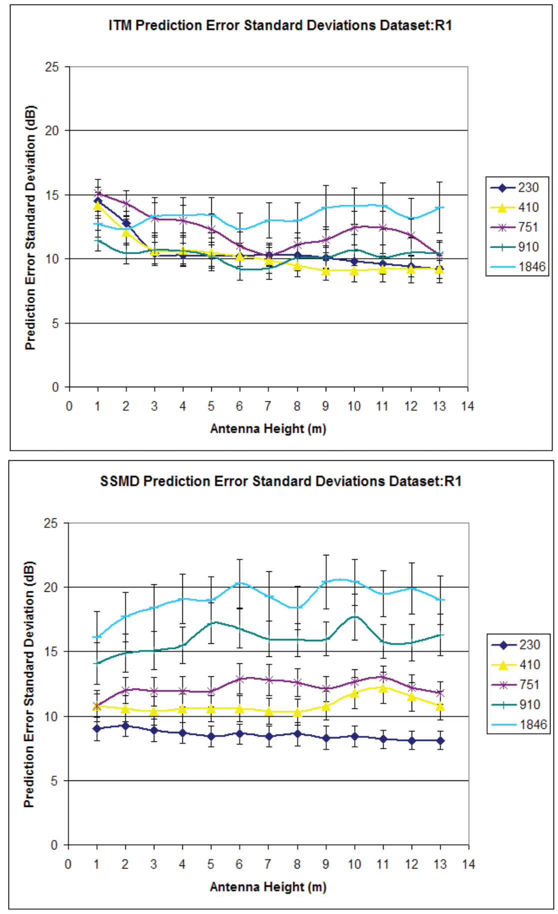

Figure 2. (Top) ITM and (bottom) SSMD prediction error standard deviations plotted as functions of antenna height and frequency for the Phase 2 R1 measurement dataset. The values of the measurement frequencies (MHz) are given in the legend.

FCC/TASO measurement campaigns. Both models' prediction errors and central moment statistics were computed for all the above measurements.

Figures 1 and 2 show examples of the prediction error means and standard deviations for the two models, respectively, for the Phase 2 R1 dataset, for frequencies below 3,000 MHz. In this dataset, measurements were attempted at multiple frequencies and antenna heights for each path. As a result, measurements made on the same path are correlated, as are the models' prediction errors. Therefore, the models' prediction error means and standard deviations are presented individually (i.e., for a given frequency and antenna height) with the error bars corresponding to the univariate standard error estimates for these quantities. Figure 1 shows that the variation of the models' mean prediction errors with height and frequency is markedly different. The fact that both models have roughly comparable mean prediction errors for heights above 10 m suggests that SSMD height extrapolations below the 10 m sea curves might benefit from additional refinements. Somewhat in contrast, Figure 2 shows that the models' prediction error standard deviations are roughly constant with antenna height, but that the frequency dependence of this quantity is more pronounced for SSMD's prediction errors.

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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 heavily on these mobile 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-wave propagation model is essential for meeting the needs of both the spectrum management process and the electromagnetic compatibility analysis process.

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. These 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 also address the electromagnetic compatibility (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 were 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 effort to develop models valid in this parameter range.

In FY 2006, ITS performed an initial analysis and determined that the development of a model that will satisfy the above requirements requires the use of mutual coupling predictions and should also include the effects of the surface wave, and the near-field effects of the antennas for these frequencies. The antenna patterns or gains of the antennas may not be valid at close separation distances, since they may not be in the far field of the antennas. In addition, for low antenna heights, the effects of the close proximity of the Earth to the antenna produces a strong interaction of the antenna with the ground, changing its impedance and thus affecting the efficiency and gain of the antennas.

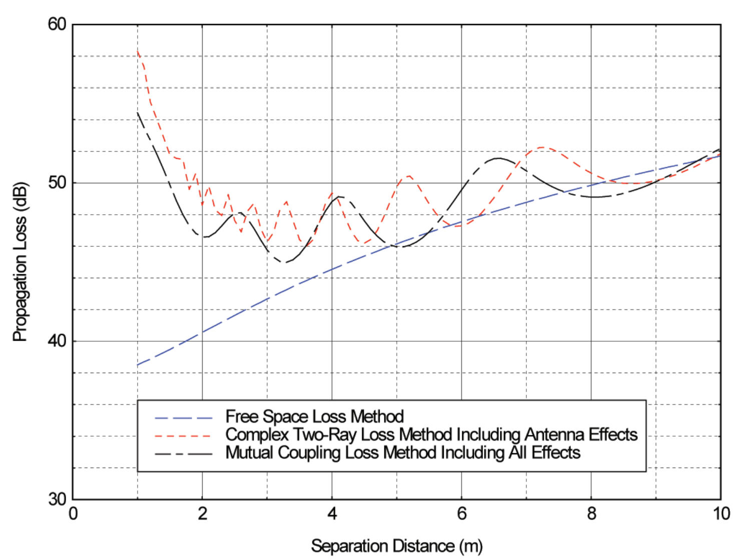

Figure 1. Three propagation loss prediction methods at 900 MHz for a transmitter height of 3 meters and receiver height of 1 meter.

Figure 2. Exterior view of the ITS propagation measurement receiver vehicle (foreground). The rear of the propagation transmitter vehicle is visible at the far right, with an NTIA logo (photograph by F.H. Sanders).

Investigations of propagation modeling techniques and the special considerations of a short-range propagation model with low antenna heights have resulted in the development of new approaches to accurately model propagation loss in an MTOM environment. This initial analysis addressed the line-of-sight (LOS) propagation environment in an open scenario for vertical polarization. Horizontal polarization will be addressed in future efforts. A hierarchy of approaches was utilized to develop the short-range MTOM model that would account for different levels of complexity. Figure 1 shows a comparison of propagation loss versus distance predicted by three analysis methods of increasing complexity and accuracy. Free-space loss is the least complex and least accurate method, and a mutual coupling method including all effects is the most complex and most accurate method. A method of intermediate complexity is the complex two-ray theory with complex reflection coefficient and antenna effects included.

In FY 2006, an initial radio-wave propagation measurement program was performed in conjunction with the ITS Telecommunications Theory Division to validate and refine the MTOM propagation models. Simultaneous wideband (~10 MHz bandwidth) measurements were made over the 150–5800 MHz band in various scenarios of antenna-height combinations and separation distances for comparison to propagation loss predicted by the analysis models. The program used a newly outfitted van as the receiver vehicle with data collection instrumentation, and the third-generation RSMS van as the pseudo-mobile transmitter vehicle (see Figure 2 above). The initial testing for a concept demonstration was performed in an environment where it was possible to make measurements at distances ranging from a few meters up to one kilometer. The measurements were performed in two very large parking lots for different filling conditions ranging from empty or sparse vehicle population (approximating a two-ray LOS condition) to completely full of vehicles (approximating a heavy traffic LOS and diffraction condition). The measured data is currently being processed.

In FY 2007, mathematical algorithms will be developed from the results of the FY 2006 analysis and measurement effort. Other analysis and measurement efforts to be performed will address LOS and non-LOS scenarios for: the urban/suburban canyon environment, the suburban/residential environment, the parking lot canyon, and the rural environment.

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