Telecommunications Engineering, Analysis, and Modeling

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

Engineering includes assessment of the components of telecommunications systems; evaluation of protocol and transport mechanism effects on network survivability and performance; and assessment of the impact of access, interoperability, timing, and synchronization on system effectiveness in national security/emergency preparedness (NS/EP), military, and commercial environments.

Analysis is often performed in association with Telecommunications Analysis (TA) Services, which offers analysis tools online via the Internet. In addition, ITS can provide custom tools and analyses for larger projects or specialized applications.

Modeling is one of ITS' core strengths. Propagation models are incorporated with various terrain databases and data from other sources, such as the U.S. Census. Adaptations of historic models, and those for more specialized situations have been developed, enhanced, and compared. ITS engineers contribute their propagation modeling expertise to the ITU as well.

Continuing to add to our wireless test facilities and research capabilities, ITS engineers have set up short and long range wireless test links to further research 2.5G and 3G technologies. The Wireless Networks Research Center (WNRC) in combination with these test links can accommodate studies of emerging technologies and PCS, analysis of wireless protocols, and studies of wireless network effects, e.g., congestion, and capabilities, e.g., priority access. (See page 79 for more information about the WNRC and page 71 for information about the wireless links at Green Mountain Mesa.)

Areas of Emphasis

ENGINEERING

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

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

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

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

ANALYSIS

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

Geographic Information System Applications The Institute continues to develop a suite of Geographic Information System (GIS) based applications for propagation modeling and performance prediction studies. This work is funded by the DoD.

MODELING

Broadband Wireless Standards The Institute develops new radio propagation algorithms and methods that improve spectrum usage of wireless systems. Technical standards are prepared that support U.S. interests in third generation (3G) broadband wireless systems. The project is funded by NTIA.

Propagation Model Development & Comparisons The Institute compares and harmonizes existing propagation models, to improve their predictive accuracies and reduce the differences between their predictions. This project is funded by NTIA.

Outdoor IEEE 802.11 Testbed

Outputs

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

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

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

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

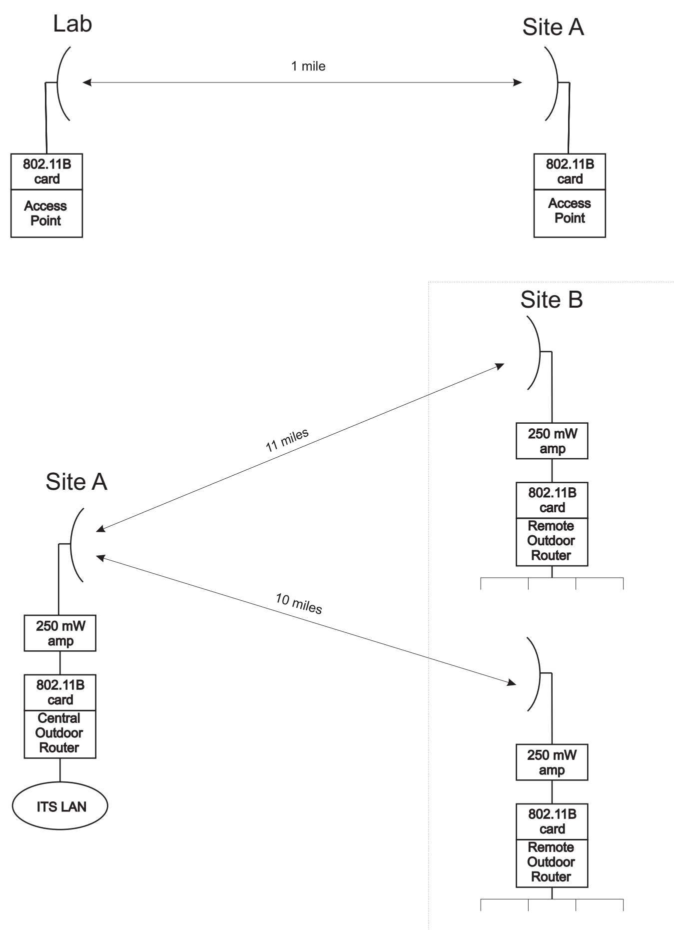

Figure 1. Long range outdoor links between the Green Mountain field site and the Table Mountain field site near Boulder, CO.

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

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

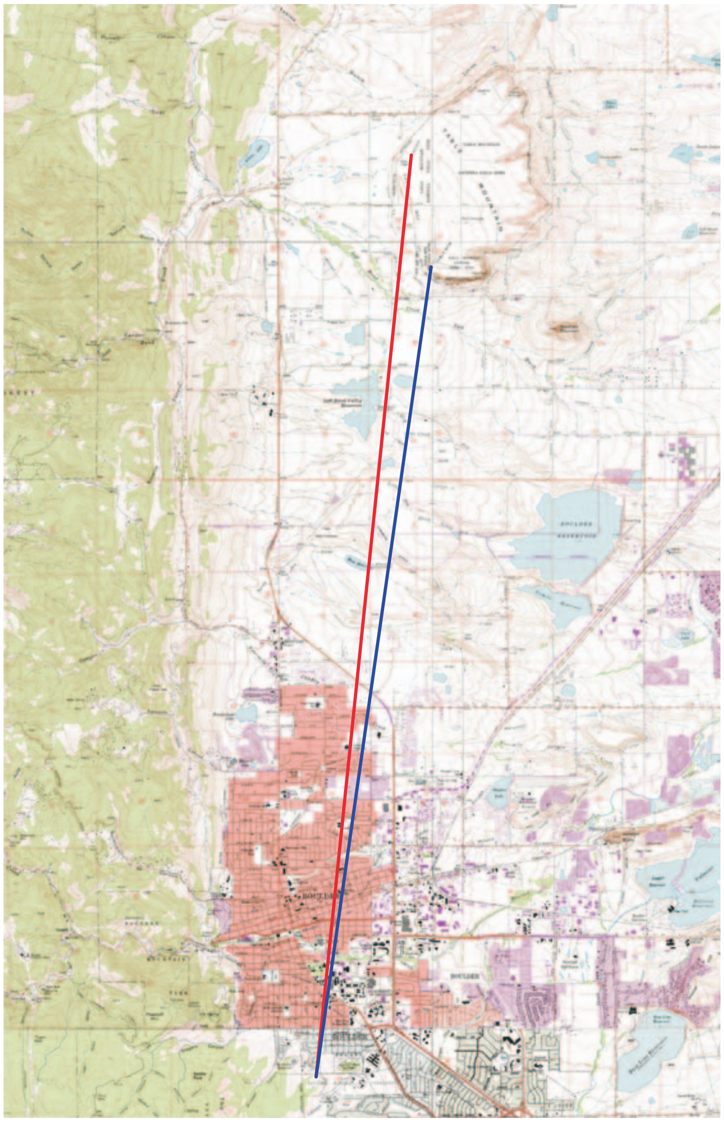

Figure 2. Long range outdoor links between the Green Mountain field site and the Table Mountain field site near Boulder, CO.

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

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PCS Applications

Outputs

- Self-interference models for current and proposed PCS technologies.
- Technical contributions to an industry-developed inter-PCS interference standard for predicting, identifying, and alleviating interference related problems.

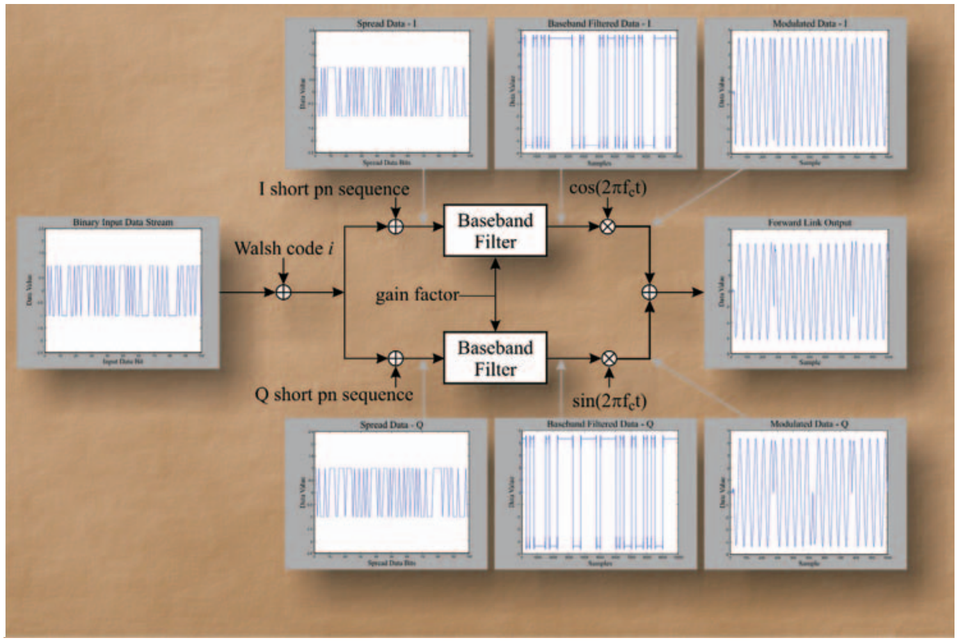
Personal Communications Services (PCS) has become an important resource for establishing emergency communication services following natural or man-made catastrophes. Such disasters can damage the wireline telecommunication system, forcing users to migrate to cellular resources. This sudden influx of traffic by private, commercial, civil, and Federal users results in wireless system overloads, a decrease in signal quality, and disruption of service in the affected area. Additional factors contribute to diminished channel capacity of a wireless network, such as co-channel interference and the operation of multiple, independent, non-interoperable systems servicing the same geographical area, often using the same frequency bands and infrastructure (base station sites and towers). National security/emergency preparedness (NS/EP) planners and network operators must understand these interference effects to operate effectively in an overloaded environment.

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

ITS has contributed to the understanding of inter-PCS interference by participating in the Telecommunications Industry Association (TIA) committee TR46.2 (Mobile & Personal Communications 1800 — Network Interfaces). As a member of TR46.2, ITS contributed to the development of the Telecommunications Systems Bulletin “Licensed Band PCS Interference” (TSB-84A). This bulletin is a first step in characterizing the interfering environment caused by large numbers of active users and competing technologies. Since the completion of TR46.2’s work, coverage of PCS interference concerns is being transferred to the T1 subcommittee T1P1.2 (Wireless/Mobile Services and Systems — GSM/3G Radio). ITS will continue to be involved in interference issues with this new group.

Work in detecting, identifying, and mitigating co-channel interference requires tools to characterize the interference experienced by PCS air-interface signals. PCS interference models are tools that can be used to predict levels of interference and identify sources of interference. Several standard propagation models are accepted by industry members (i.e., Okumura and COST-231/Walfish/Ikegami) but no interference models have been developed or accepted. ITS is developing a series of PCS interference models starting with a model based on the ANSI/TIA/EIA-95B standard, and leading to models covering proposed third generation (3G) systems. The model performs system-specific interference prediction to determine co-channel interference from both immediate and adjacent cells.

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



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

The conceptual model is a structural model based on the 95-B standard which produces a representation of an instantaneous 95-B air-interface signal. The signal can contain outputs of multiple base stations with variable numbers of channels for each base station and can assign relative power levels for each individual channel. Both forward and reverse link processes are included in the model.

The input for the model is a sequence of binary values. This sequence can be (but is not required to be) random. For forward link signals, the appropriate Walsh code and orthogonal I and Q short pn codes spread the input sequence. For reverse link signals, the model modulates the input sequence with Walsh codes and then spreads the sequence with long and short pn codes. The resulting I and Q data streams pass through a baseband filter and a quadrature phase-shift keyed (QPSK) or an offset quadrature phase-shift keyed (OQPSK) modulation scheme. The model calculates each channel signal contribution separately from all other channel signals and then adds the processed signal to the other signal contributions to form a composite output signal. The power level for a single channel is an arbitrary gain factor of the baseband filter which is set separately for each channel. All the Walsh and pn code definitions come from requirements in the 95-B standard. The output of the model consists of a vector of numerical values representing a sampled QPSK or OQPSK signal.

There is no error correction added to the input sequence; only spreading codes and modulation processes are used. This model does not check for recovery information contained in the input. Its only purpose is to determine how well the system can transmit the bits of the input binary sequence.

The output of the physical model (see figure above) is a sampled modulated signal which is the composite of the signals transmitted from all sources identified in a specified scenario. Software- and hardware-based simulations can use the sampled signal from the model to evaluate system designs. These simulations can characterize one-on-one, one-on-many, and many-on-one interference. As a result, potential solutions to congestion can be proposed to solve existing problems or to anticipate and avoid potential problems. ITS is currently working on the verification and validation of the first, ANSI 95-B, model. The validation process will include both software and hardware aspects of the model.

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Third Party Test Evaluation for Other Agencies

Outputs

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

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

In FY 2003 ITS provided assistance to the U.S. Coast Guard. The Coast Guard has undertaken a project to modernize and upgrade its current National Distress and Response System (NDRS). This project will enhance the Coast Guard's communication capabilities, provide a common operating environment, and provide Coast Guard personnel with tools to perform their missions. The NDRS is the maritime 911 system for the coastal U.S. and the communications infrastructure for all Coast Guard coastal missions. The new system was originally called the National Distress and Response System Modernization Project (NDRSMP) and is now titled Rescue 21. Rescue 21 will consist of many regions along the U.S. coast and waterways. Each region will have a Group Communications Center (GCC) that is networked to a Search and Rescue Station and several Remote Transceiver Sites. Rescue 21 is a hybrid communications system composed of wireless and wired components. A typical operational scenario of Rescue 21 is shown in the figure on the next page.

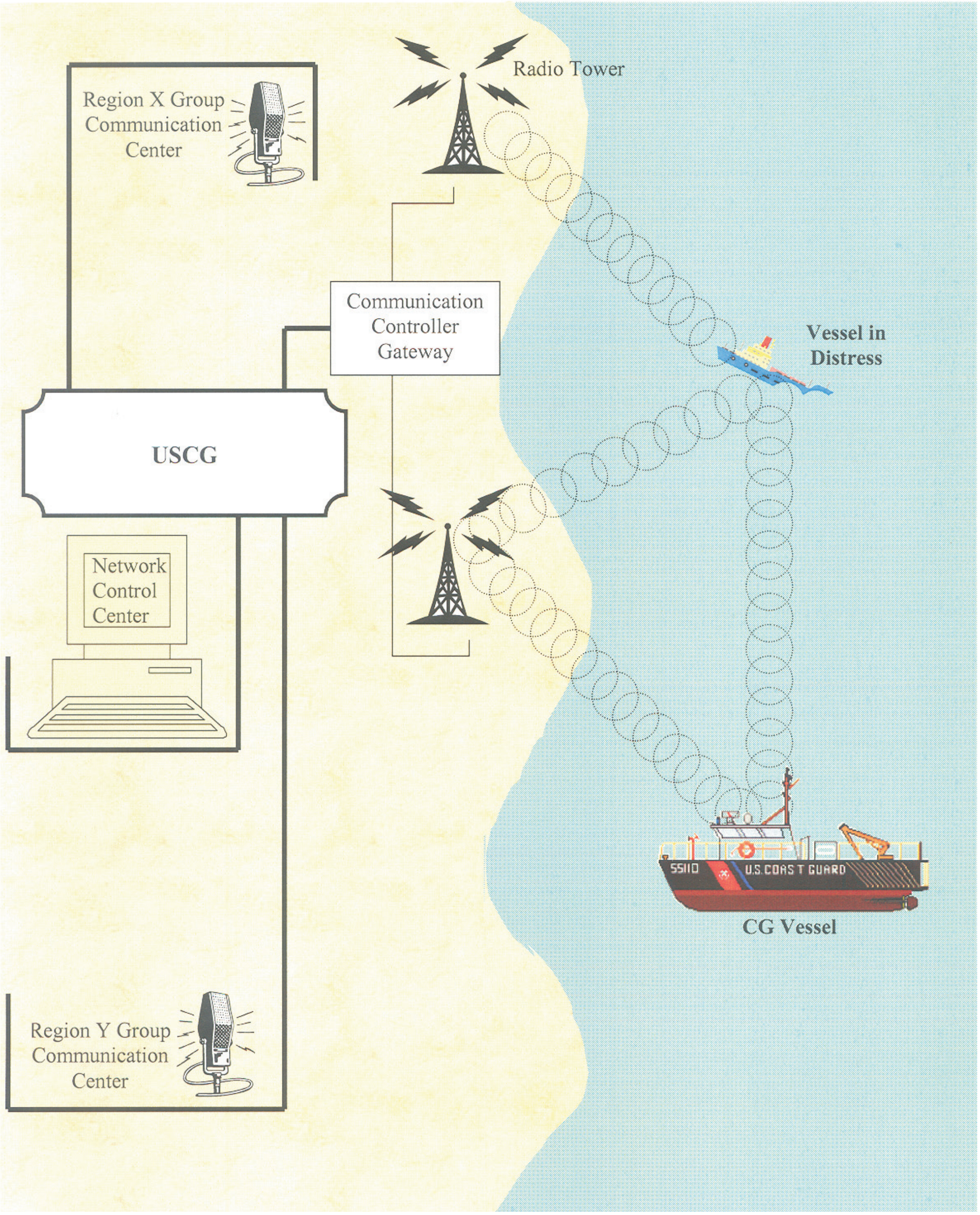
Rescue 21 is in the Developmental Testing and Evaluation (DT&E) Phase. DT&E includes two tests, a Formal Qualification Test (FQT) at the contractor's facility and a System Integration Test (SIT) in the field. ITS is providing technical assistance in reviewing the test plans and procedures as well as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

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

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

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

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



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

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Wireless Network Analysis and Forecasting

Outputs

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

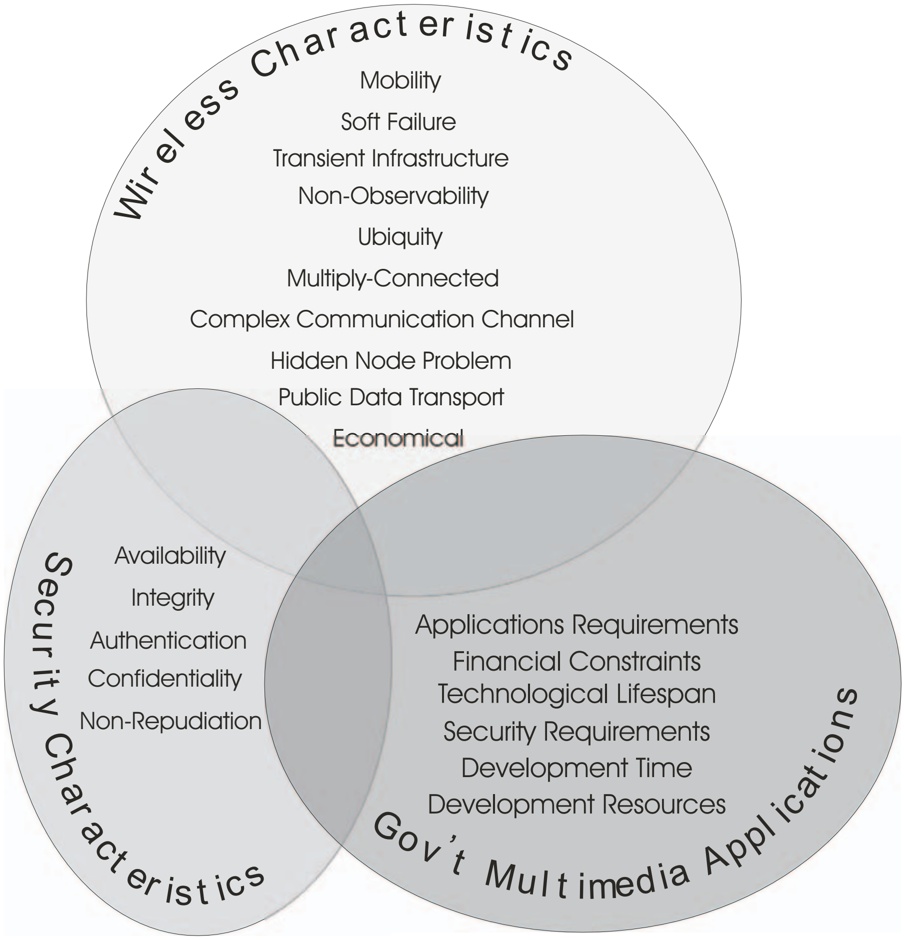
ITS produces analytical services that aid in the fielding of Federal communications products that rely on public wireless infrastructure. The studies that ITS has conducted are used to advise and inform Federal wireless users and designers. The work of the Institute can assist Federal wireless communications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

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

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

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

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



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

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

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

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

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Telecommunications Analysis Services

Outputs

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

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

Currently available are: on-line terrain data with 1-arc-second (30 m) for CONUS and 3-arc-second (90 m) resolution for much of the world and GLOBE (Global Land One-km Base Elevation) data for the entire world; the US Census data for 2000, 1997 update, and 1990; Federal Communications Commission (FCC) databases; and geographic information systems (GIS) databases (ARCINFO). For more information on available programs, see the Tools and Facilities section (p. 77-78) or call the contact listed below.

TA Services is currently assisting broadcast television providers with their transition to digital television (DTV) by providing a model for use in advanced television analysis (high-definition television, advanced television, and digital television). This model allows the user to create scenarios of desired and undesired station mixes. The model

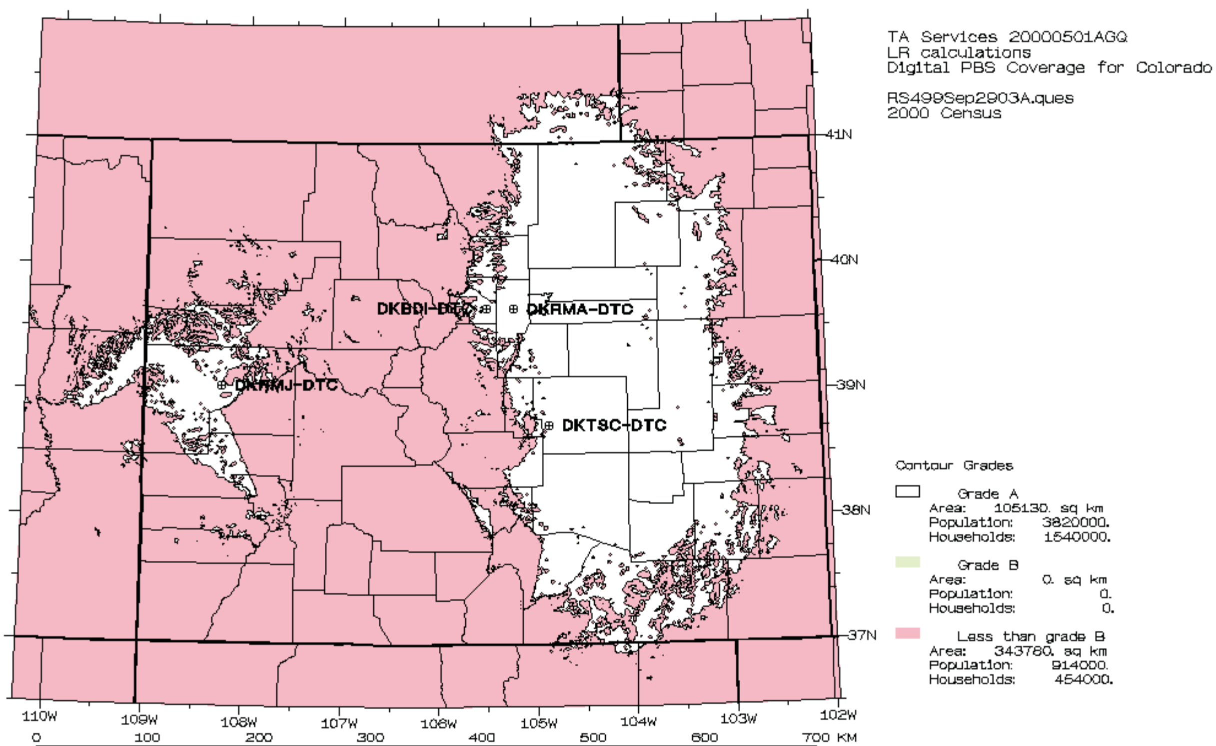

Figure 1. Digital PBS TV coverage for Colorado.

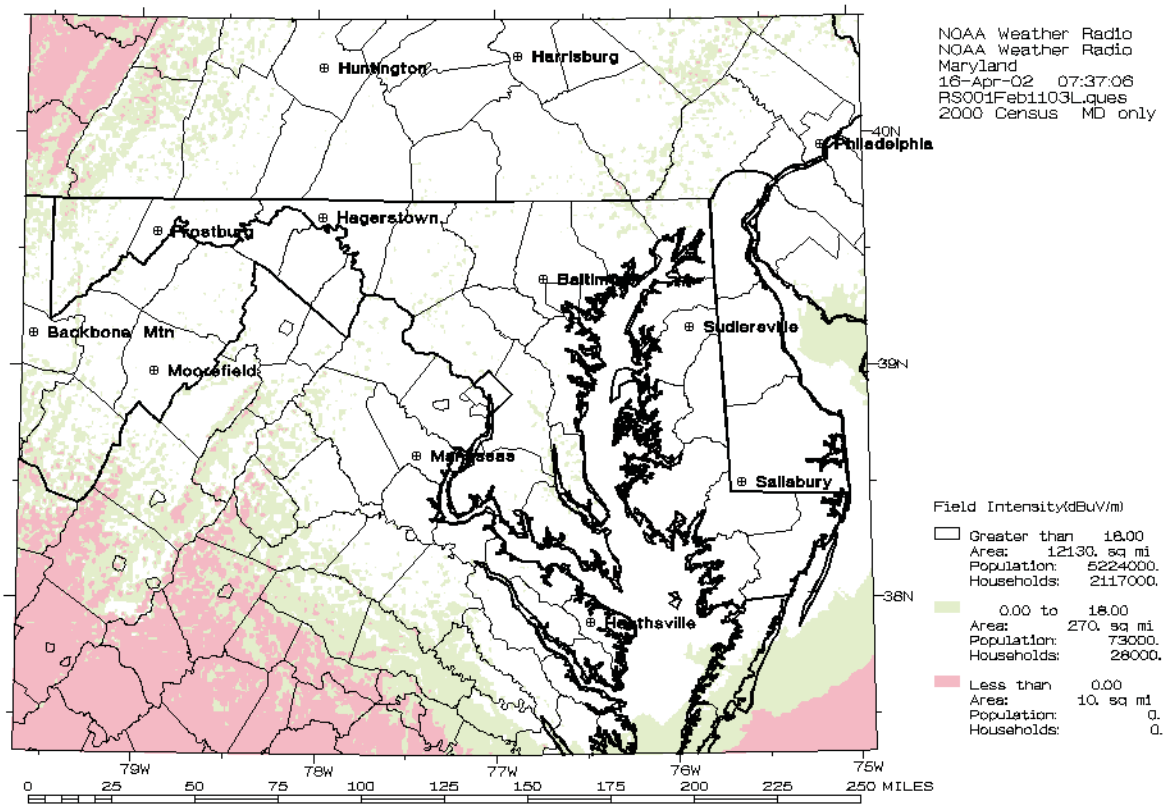

Figure 2. NWS station coverage for Maryland.

maintains a catalog of television stations and advanced television stations updated weekly from the FCC from which these scenarios are made. Results of analyses show those areas of new interference and the population and number of households within those areas. The model can also determine the amount of interference a selected station gives to other stations. This allows the engineer to make modifications to the station and then determine the effect those modifications have on the interference that station gives other surrounding stations. In addition to creating graphical plots, the program creates tabular output which shows the distance and bearing from the selected station to each potential interferer as well as a breakdown of the amount of interference each station generates. This year, using this same program, all of the Public Broadcasting Service's (PBS) digital TV stations (350) were converted to ArcView shape files and sent to PBS for use with their own GIS software. Figure 1 on the previous page shows the digital PBS TV coverage for Colorado.

TA Services is also assisting the National Weather Service (NWS) in locating additional sites to increase its coverage for weather radio reports and emergency warning broadcasts, such as those issued in September of this year for Hurricane Isabell on the east coast. Figure 2 above shows the calculated NWS coverage for Maryland. TA Services calculates that 98.6% of the Maryland population should be able to hear NWS weather radio broadcasts.

All models in TA Services and their outputs can be accessed via a network browser at http://flattop.its.bldrdoc.gov.

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Geographic Information System Applications

Outputs

- Propagation coverages for one or more transmitters draped over surfaces created by the program or imported by the user.
- Analysis of interference and overlap coverages of multiple transmitters.
- The ability to create and modify catalogs of imagery at various resolutions and city catalogs of building information.
- 2.5D or fly-through 3D visualization with interfaces to 3D visualization tools.

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

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

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

Figure 1. Analysis area of Waikiki Beach, Hawaii.

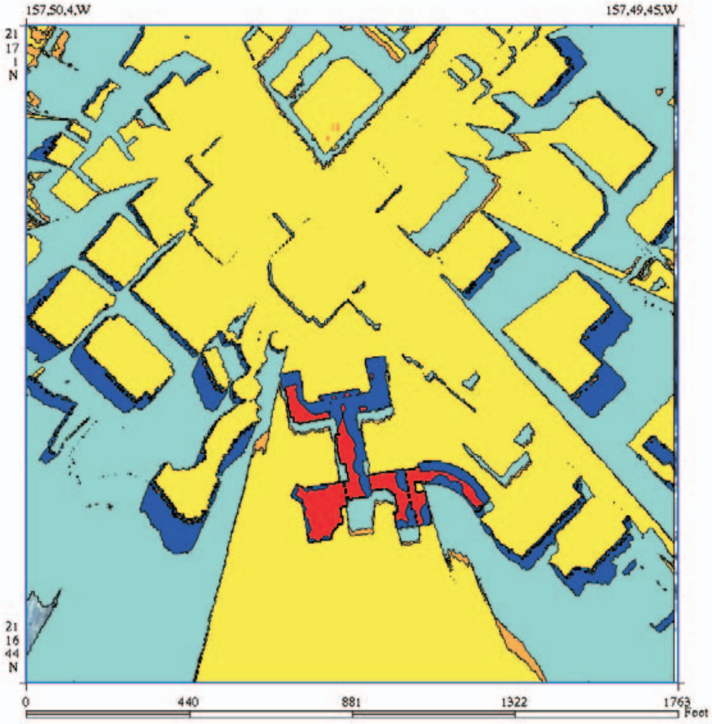

Figure 2. CSPT outdoor/indoor coverage prediction.

Then the user creates or imports transmitter, receiver, and antenna data. Lastly, the user selects the type of coverage and the propagation model to be used in the analysis. ITS is currently developing a coupled indoor/outdoor propagation model which will allow the user to predict signal strength penetrating a building or escaping from a building.

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

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

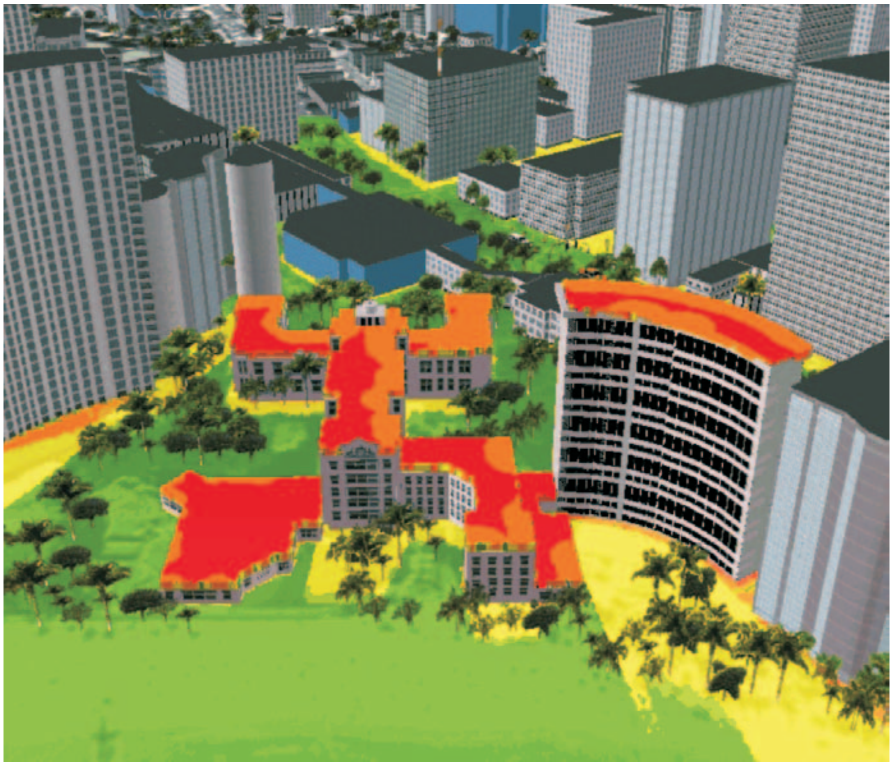

Figure 3. Same area of coverage shown in Figure 2, in 3D fly-through form.

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

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Broadband Wireless Standards

Outputs

- Preparation of technical standards and documents for the ITU-R that support the U.S. interest in broadband wireless systems.
- Development of new radio propagation algorithms or methods that improve spectrum usage of wireless systems.

Wireless communication has seen tremendous growth in recent years, in both the number of users and the types of new services, beyond simply voice communications. In particular, there has been an emphasis on Internet uses. These additional users and new services require greater bandwidths than before, which for wireless users means more radio spectrum. As more users require more spectrum, it is necessary to be able to predict signal coverage for various wireless services more accurately, so that everyone can share the available spectrum and peacefully co-exist without interference. The development of radio-wave propagation prediction models for accurate prediction of signal coverage supports broadband wireless standards for these broadband wireless systems.

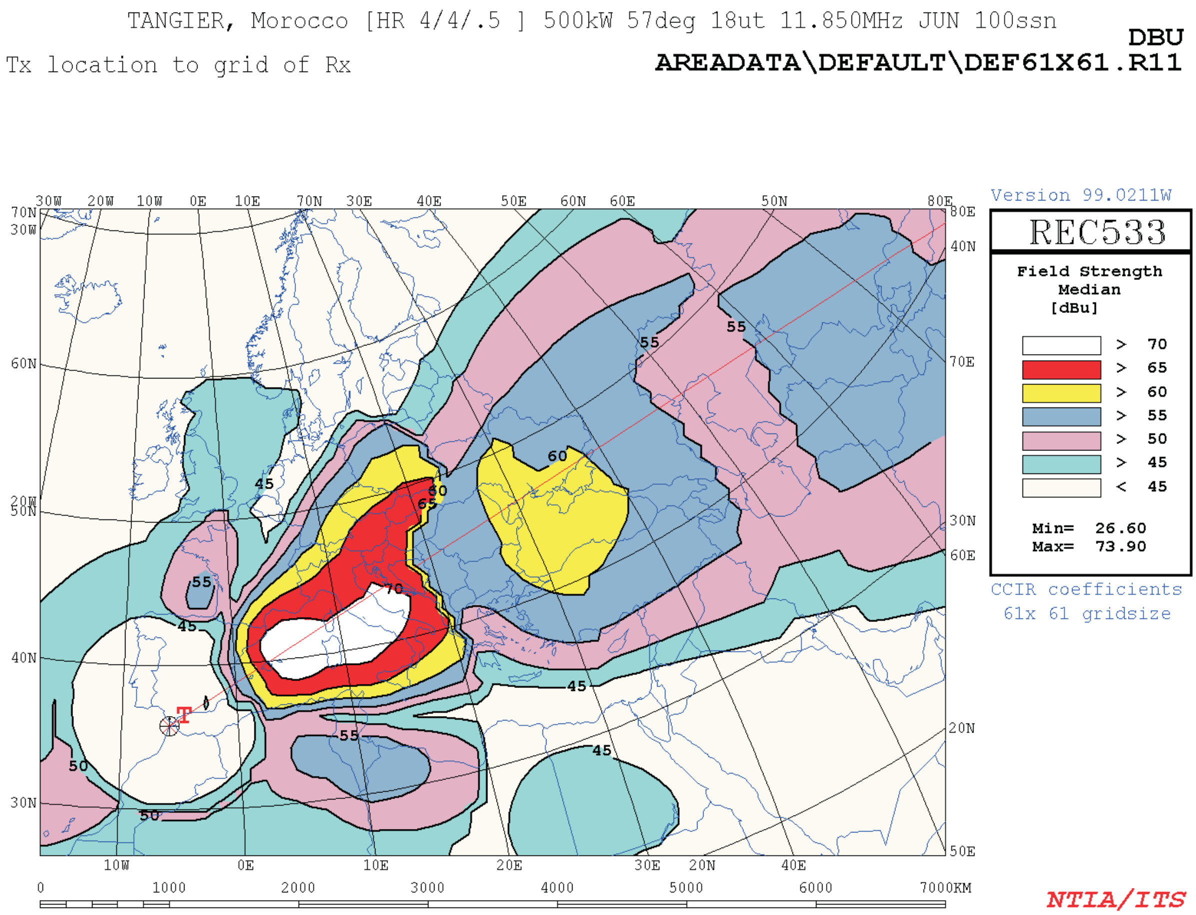
ITS and other research organizations have been developing and evaluating propagation models to predict wireless signal coverage more accurately. These propagation models are more responsive to the needs of cellular and private land mobile radio service providers, which make up the vast majority of wireless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

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

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

ITS participates in the international development of propagation prediction models that can be used by spectrum managers and system planners of land mobile, terrestrial broadcast, maritime mobile, and certain applicable fixed (e.g., point-to-multipoint) services. ITS supports this effort by participation in the International Telecommunication Union — Radiocommunication Sector (ITU-R) Study Group 3 (Radiowave Propagation). An ITS staff engineer is the Chair of the U.S. contingent of Study Group 3. Study Group 3 has recently developed and adopted such a model, ITU-R Recommendation P.1546, which blends features that the services had previously used independently of one another, thereby clarifying and unifying planning and coordination activities across the services.

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



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

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

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

ITS is also a member of ITU-R Study Group 3 Working Party 3L. Working Party 3L deals with ionospheric propagation above and below 2 MHz, in addition to trans-ionospheric propagation. In its membership of the ITU-R Study Group 3 Working Party 3L (Ionospheric Propagation), ITS is responsible for maintaining the High Frequency (HF) (3-30 MHz) propagation software developed by the ITU for international frequency coordination. The ITU website:

http://www.itu.int/ITU-R/software/study-groups/rsg3/databanks/ionosph/index.html

links to an ITS web site with the following reference: HF sky-wave propagation (Rec. P.533) (available from the ITS website)

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

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

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Propagation Model Development & Comparisons

Outputs

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

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

ITM & TIREM Intercomparison

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

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

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

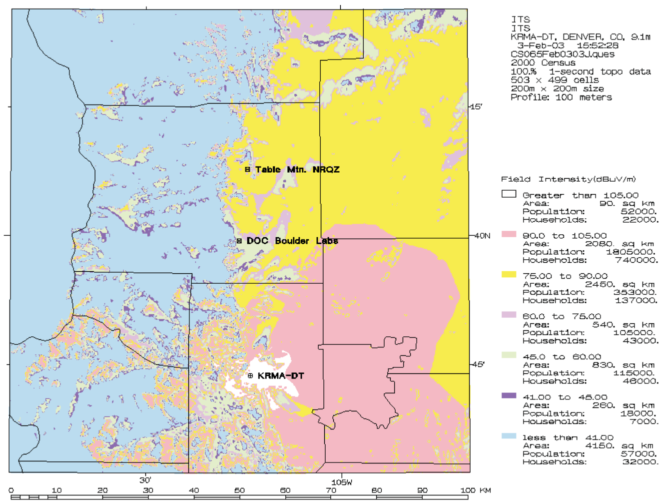
ITM & TIREM Harmonization

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

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

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

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



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

Effective Antenna Height Study

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

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

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

Recent Publication

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

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