Telecommunications Engineering, Analysis, and Modeling

The Telecommunications Engineering, Analysis, and Modeling Division conducts studies in 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 Telecommunications Analysis (TA) Services project which offers analytical tools via an on-line cooperative research and development agreement (CRADA) over the Internet. ITS can also customize these tools and analyses for larger projects and specialized applications, for example, the geographic information system (GIS) tools project funded by the Department of Defense.

Modeling is one of ITS's 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 international and national standards bodies as well.

Areas of Emphasis

ENGINEERING

PCS Applications The Institute participates in the Alliance for Telecommunications Industry Solutions (ATIS) subcommittee G3GRA (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.

U.S. Coast Guard Rescue 21 Technical Consulting The Institute assisted the U.S. Coast Guard in testing and evaluating its new communication capabilities by acting as a third-party technical consultant. ITS also modeled antennas for the vessel. The project was funded by the U.S. Coast Guard.

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.

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. This work is funded by the 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 Study Group 3, Working Parties 3J, 3K, 3L and 3M. 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. ITS is also starting to model a mobile-to-mobile, short-range (less than 2 km) scenario. This project is funded by NTIA.

PCS Applications

Outputs

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

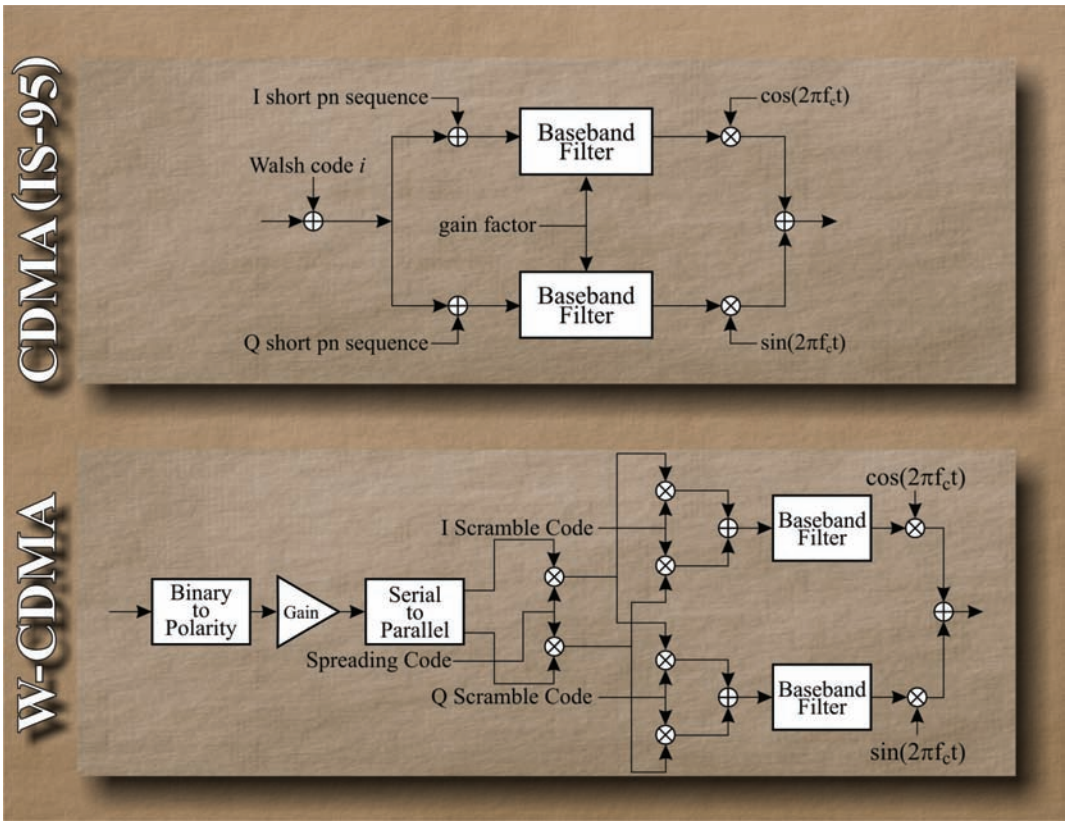
Recent natural disasters have demonstrated how important Personal Communications Services (PCS) have become in establishing emergency communications. These disasters damaged the terrestrial telecommunication system, forcing users to migrate to cellular resources. Emergency responders found themselves unable to establish inter-agency communication links, especially with responders from outside of the affected area and, as a last (or only) resort, relied on cellular systems to fulfill their missions. This sudden influx of traffic by private, commercial, civil, and Federal users resulted in wireless system overloads, a decrease in signal quality, and further disruption of service in the affected area. Beyond the physical damage caused by the events, additional factors contributed 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).

When the infrastructure is damaged or destroyed, one solution to re-establishing communications 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.

In normal, non-disaster situations, 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 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 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 PCS interference concerns has been transferred to the Alliance for Telecommunications Industry Solutions (ATIS) sub-committee WTSC/G3GRA (Wireless Technologies and Systems Committee/Radio Aspects of GSM/3G and Beyond). Work on the successor to TSB-84A is currently underway and ITS continues 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. A PCS interference model is a tool that can be used to predict levels 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 model has been developed or accepted. ITS is developing a PCS interference model capable of implementing any PCS technology, starting with the ANSI/TIA/EIA-95B standard, and progressing to



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

technologies proposed for third generation (3G) systems. The model covers system-specific interference modeling to determine 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. In addition to the 95B standard, the next-generation W-CDMA (Wideband CDMA) is currently being implemented. The figure shows the block diagrams of the forward data paths for both technologies.

The input for the model is a sequence of binary values. This sequence can be random, but has no requirement to be random. 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 the 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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U.S. Coast Guard Rescue 21 Technical Consulting

Outputs

- Written technical report to evaluate vessel communications capabilities.
- Radio frequency (RF) analysis.
- On-site vessel measurements.

Rescue 21 is a project undertaken by the U.S. Coast Guard (USCG) to modernize and upgrade its current National Distress and Response System (NDRS). This system will enhance the Coast Guard's communication capabilities, increase its response coverage area, provide a common operation environment, and provide USGC personnel with modernized tools to perform their missions. The NDRS is the maritime emergency response (911) system for the coastal U.S. and the communications infrastructure for all USCG coastal missions. Rescue 21 is a hybrid communications system composed of wireless and wired components. Rescue 21 will consist of many operating 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.

The USCG entered into an Inter-Agency agreement with ITS to evaluate the simultaneous communications capabilities of the Rescue 21 vessel subsystem. The focus of the investigation was to determine the physical possibility of achieving simultaneous communications (SC) — receiving a distant radio transmission on one channel while simultaneously transmitting on one or more nearby channels. In particular, a major concern of the USCG is the ability to monitor an emergency channel continuously while communicating on other working channels. The result of ITS's investigation was to determine if such a communication system was technically possible given the physical limitations of the 47-foot vessel (see Figure 1 below), and to produce a recommendation to either keep the existing Rescue 21 system (with possible modifications), or replace it with an alternative system.

The focus of the investigation was the following:

(1) Link budget and radio channel isolation specifications necessary to achieve line-of-sight (LoS) communications.

(2) Characterization of the current system, including sources of noise and interference.

(3) Possible methods for reducing interference in the system and increasing radio isolation to meet the specifications defined in (1).

Figure 1. 47-foot Coast Guard vessel (photograph by E.D. Nelson).

Figure 2. ITS staff taking measurements aboard the 47-foot Coast Guard vessel (photograph by C.J. Behm).

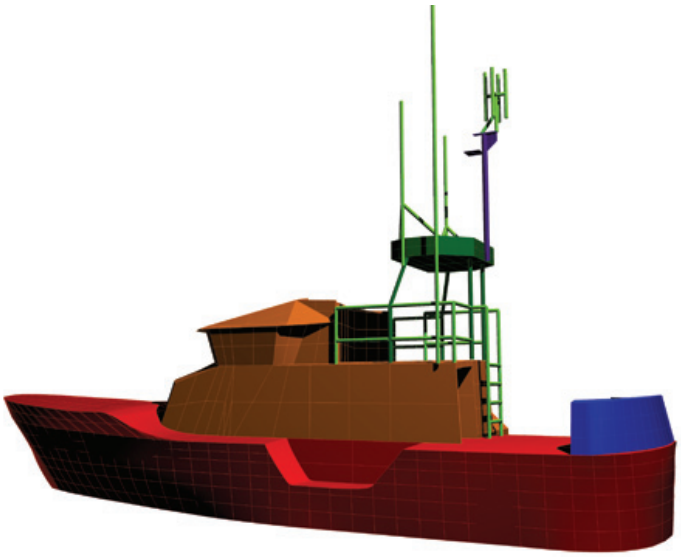

Figure 3. Model of the 47-foot vessel shown in Figure 1.

ITS's technical contributions were focused mainly in the following areas:

***In situ* measurements**

Multiple trips were made by ITS staff to the Atlantic City USCG Station to take measurements on the 47-foot vessel (see Figure 2). These measurements were used to characterize the system radio performance and the noise environment.

Propagation Modeling

In support of the RF coverage analysis, ITS provided the Coast Guard with antenna coverage predictions using the Irregular Terrain Model (ITM) and the Advanced Propagation Model (APM).

Antenna Modeling

A number of different antenna configurations were analyzed on the boat using the 47-foot vessel model in simulation software (see Figure 3).

Findings

(1) Subject to certain constraints, the Rescue 21 system was capable of providing adequate simultaneous communications on two channels between the shore and USCG vessel 47269 at 20 nautical miles.

(2) There are multiple noise sources within the shipboard communication environment that limit the system's simultaneous communications capabilities. If these interferers are eliminated, SC can be achieved.

(3) Simulations indicate that alternative antenna placements would provide increased isolation for the R21 radios.

(4) The current system design can be retained, since it was found to be adequate for the specific simultaneous communications scenario described above.

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Telecommunications Analysis Services

Outputs

- Internet access on a cost reimbursable basis to the latest ITS engineering models and databases for U.S. industry and Government agencies.
- 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.

The Telecommunications Analysis Services (TA Services) program 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 those with 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 1990, 1997 update, and 2000; Federal Communications Commission (FCC) databases; and geographic information systems (GIS) databases (ArcInfo). For more information on available programs, see page 64 of the Tools and Facilities section 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 such as that shown in Figure 1 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 those shown in Figure 2. This allows the user to determine both single transmitter performance as well as integrated system performance.

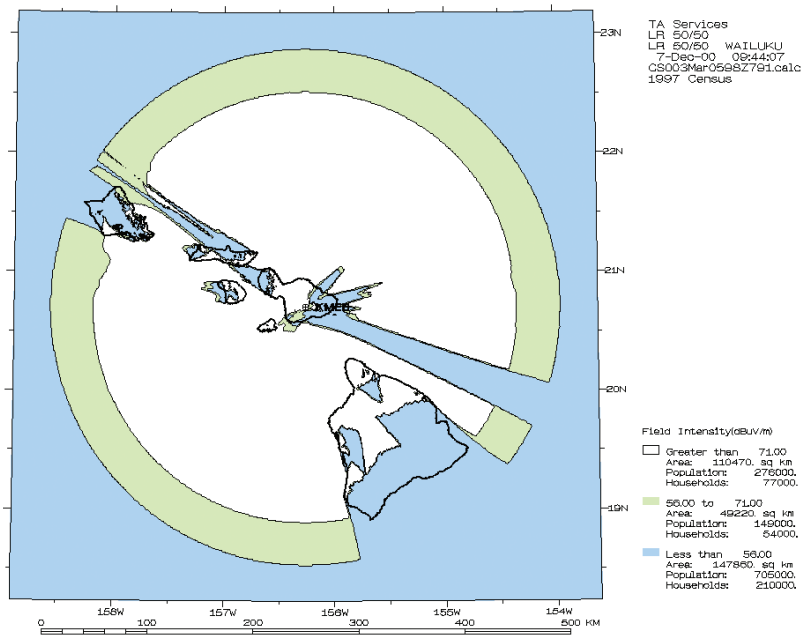
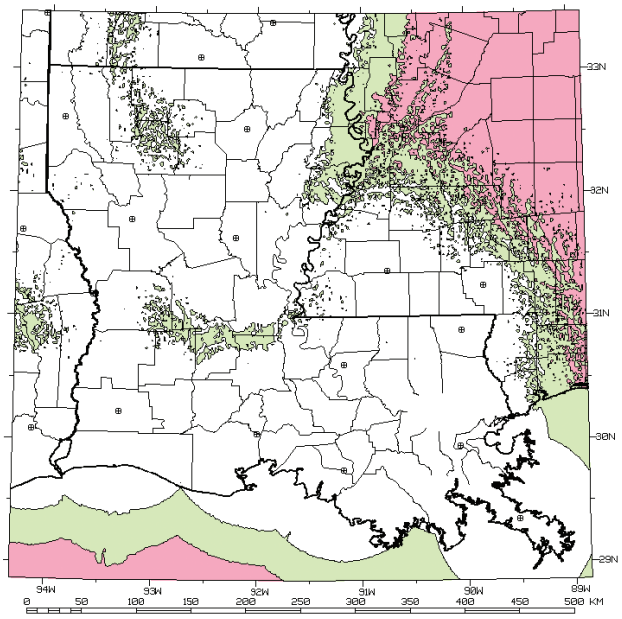


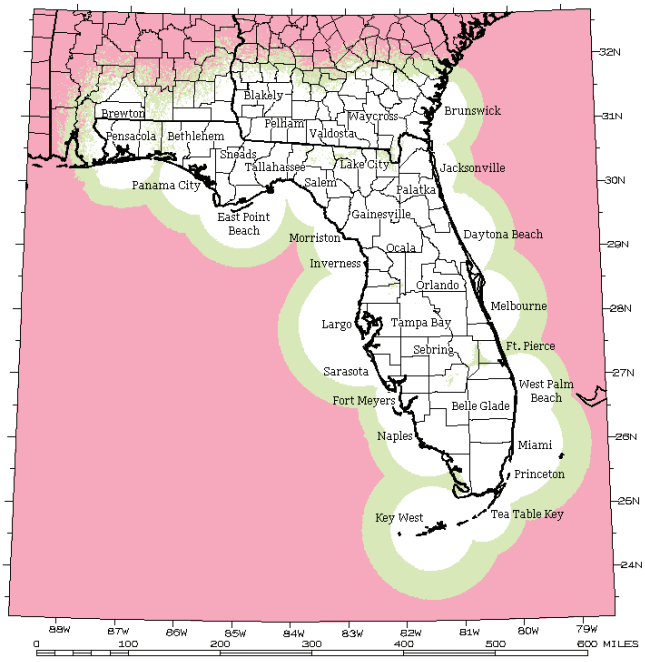
Figure 1. Sample output of the CSPM model of a transmitter located in Hawaii.

TA Services has assisted the broadcast television providers of the U.S. with their transition to digital television (DTV) by providing an application specific model for use in advanced television analysis (HDTV, advanced television, and DTV). This model allows the user to create scenarios of desired and undesired station mixes. The model maintains a catalog of television stations and advanced television stations

from the FCC from which these analyses are made. The results of these studies show those areas of new interference and the population and number of households within those areas so that designers can mitigate possible interference situations before they become a problem. The model can also determine the amount of interference a selected station gives to other stations. This allows the engineer to make modifications to the station and then determine the effect those modifications have on the given interference. 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 interferer as well as a breakdown of the amount of interference each station in the study contributes to the total interference.

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





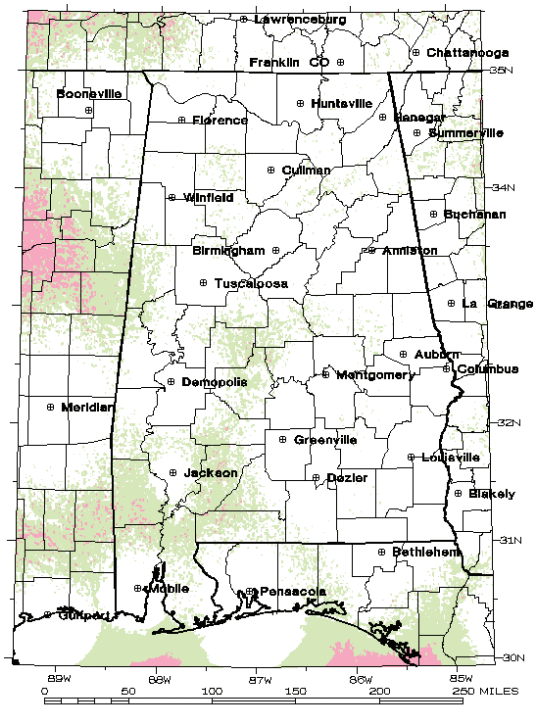


Figure 2. Composite coverage of National Weather Radio for some of the Gulf States (Louisiana, top; Alabama, above; Florida, left). White areas have good coverage, green areas have marginal coverage, and pink areas have signal below the minimum.

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Geographic Information System Applications

Outputs

- Propagation coverages (HF and VHF) for one or more transmitters draped over surfaces.
- Interference and overlap coverages (VHF).
- 2D and 3D visualization environments.
- Fly-through visualization capabilities.

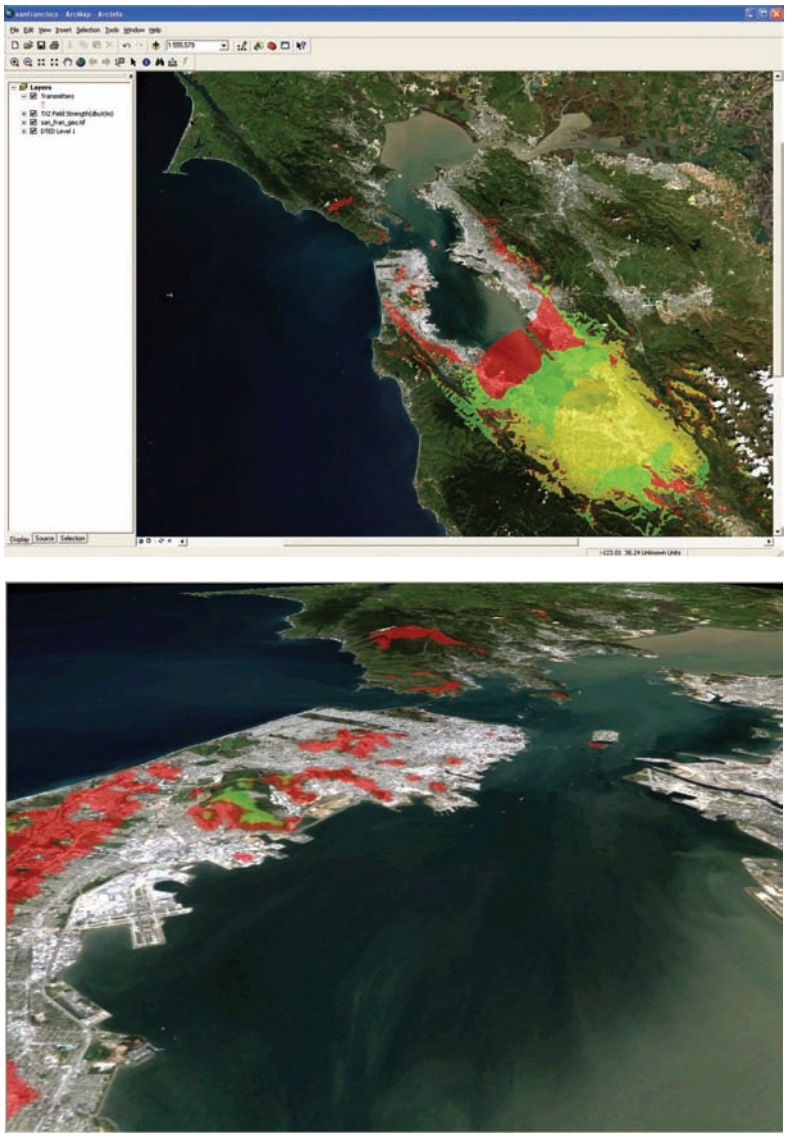

Figure 1. A CSPT-VHF study for San Francisco showing both 2D (top) and 3D (bottom) results.

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. The Institute 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.

One 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 San Francisco Bay, shown in both 2D and 3D. CSPT allows the user to transition into 3D and fly through the environment.

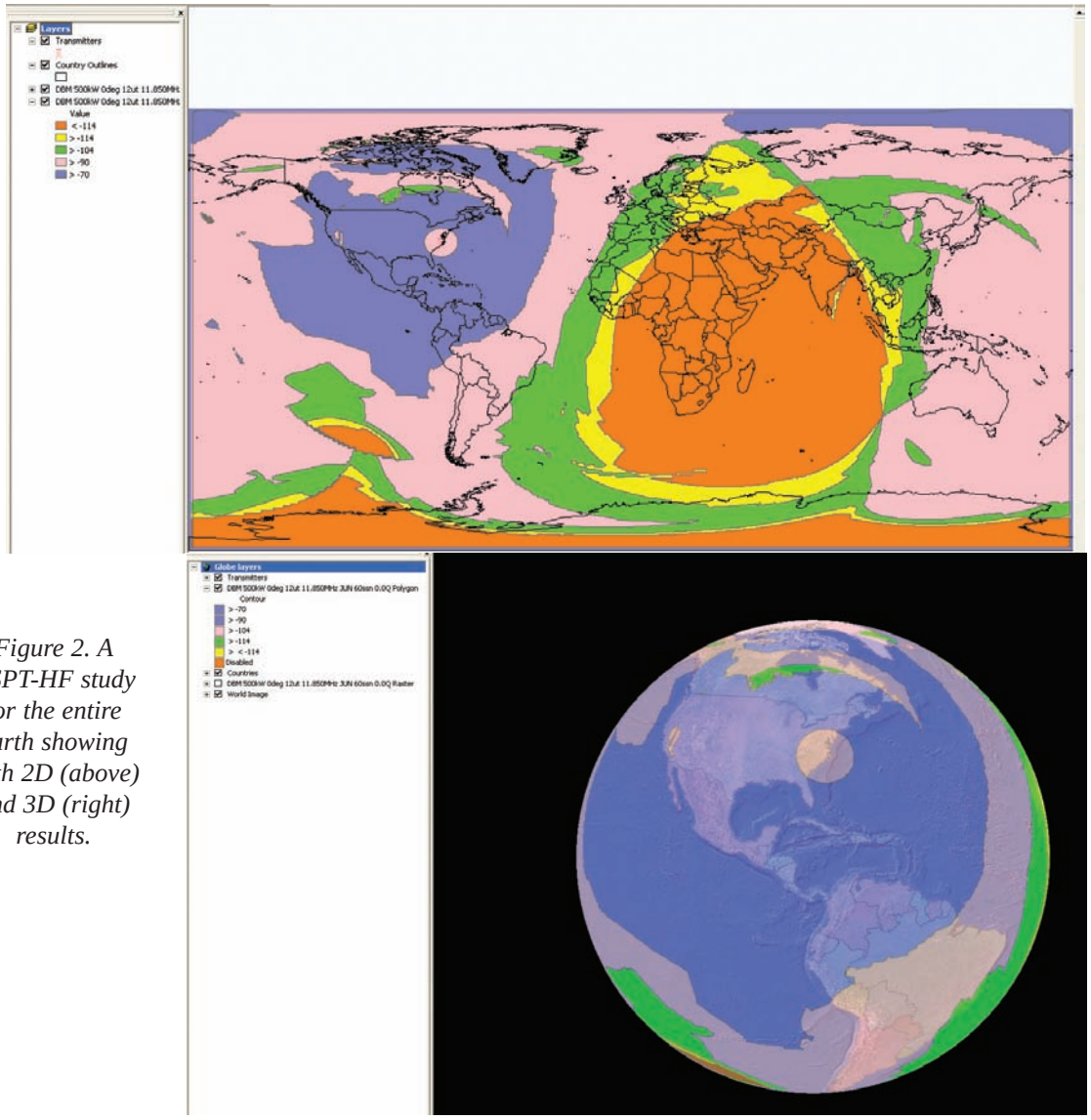

Figure 2. A CSPT-HF study for the entire earth showing both 2D (above) and 3D (right) results.

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. The GIS tool allows the user greater flexibility in creating scenarios for HF area coverage studies. These studies are not limited to nine scenarios as in the ICEAREA model. The output results of ICEPAC are imported into the GIS tool and can be displayed in 2D or 3D, as shown in Figure 2.

The general flow of the CSPT GIS tool is as follows. The user defines an area within which a study will be performed. This analysis area can be defined graphically by zooming into a map of the world or of the U.S. or by defining the latitude and longitude of the boundaries of the desired area. The user then imports desired GIS information such as political boundaries, roads, rivers, special imagery, or application-specific GIS data. 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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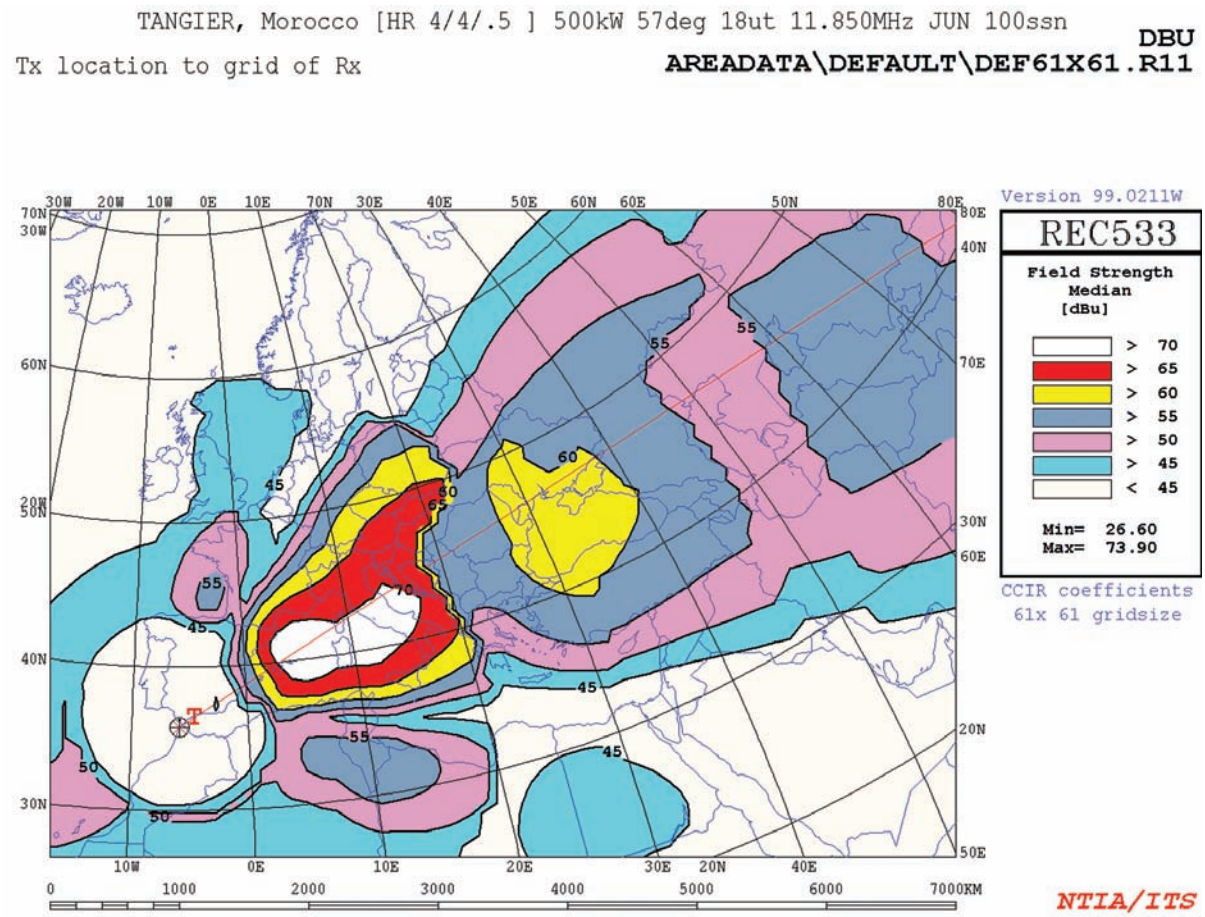
Broadband Wireless Standards

Outputs

- 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. In particular, there has been an emphasis on Internet and broadband data uses, over and above voice applications. These additional users and services require greater bandwidths than before, which for wireless users means more radio spectrum. As growing numbers of users require ever more spectrum, it is necessary to be able to predict signal coverage for various wireless services more accurately, so that inter-service spectrum sharing can occur without causing harmful interference to incumbents and new users/services. The development of radio-wave propagation prediction models for accurate prediction of signal coverage supports standards for these broadband wireless systems.

Historically, radio propagation model development tended to be very service specific, with models for the broadcast FM radio and television service or for the land mobile radio service, and little or no overlap in applicability between the models for different services. This service-specific approach was adequate for a regulatory philosophy that assigned



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

different, exclusive blocks of the radio spectrum to different services in a proprietary fashion. However, this lack of overlap between models can also create an impediment to the shared use of spectrum by different services or wireless applications, because, for example, a model that is used to predict intra-service system availability and interference might not apply flexibly and accurately to inter-service interference predictions. To overcome this problem, ITS and other research organizations have been developing and evaluating propagation models to predict wireless signal coverage more accurately and flexibly, both within and across services.

ITS participates in the international development of radio propagation prediction model standards 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, among others. ITS supports this effort by participation in the International Telecommunication Union's Radiocommunication Sector (ITU-R) Study Group 3 (Radiowave Propagation). The most recent meetings of the Working Parties (WP) of Study Group 3, held in Cleveland, Ohio, in late September and early October, 2005, were jointly sponsored by the National Aeronautics and Space Administration (NASA) and ITS. Four ITS engineers participated in these meetings as members of the official U.S. delegation.

Study Group 3 recently developed and adopted a radio propagation model which blends features that the different services had used independently, thereby clarifying and unifying planning and coordination activities across these services. This recommendation, Rec. ITU-R P.1546, is usually considered to be a site-general model, although for improved accuracy it specifies numerous adjustments and corrections to the basic method that are very nearly site-specific in their application. Numerous aspects of Rec. ITU-R P.1546 have been adopted by the Regional Radio Conference (RRC-04)[1] as the basis for planning and coordination studies within the Conference's planning area. To support the work of the Intersessional Planning Group (IPG) and to prepare for the second and final meetings of the Conference (RRC-06), Study Group 3, WP 3K (point-to-area propagation) and, in particular, Subgroup 3K-2, have undertaken a number of revisions to the Recommendation. For several years, an ITS engineer has served as chairman of Subgroup 3K-2.

As a much needed adjunct to this work, Subgroup 3K-1 of WP 3K is examining five proposed site-specific models for intra- and inter-service planning and coordination uses, when detailed terrain elevation data are available. Two of these models, the ITS Irregular Terrain Model (ITM) and a closely related hybrid model based on Recommendations ITU-R P.1546 and P.452, originated in contributions to WP 3K from the U.S. Administration which were authored by ITS. ITS has established a password protected worldwide website for participants in Subgroups 3K-1 and 3K-2 to exchange propagation measurement data and terrain profiles for use in testing and comparing these models. As part of this testing and comparison effort, ITS will contribute model source code and U.S. radio propagation measurement data.

In addition to the above areas, WP 3K deals with propagation aspects of short-path personal communications and wireless local area networks in the frequency range 300 MHz to 100 GHz in Subgroups 3K-3 and 3K-4, both of which are longstanding. At the most recent meetings of WP 3K, the Chairman of WP 3K established a new subgroup, Subgroup 3K-5, to address ultrawideband radio signal propagation. Based on a U.S. contribution authored by ITS, a draft new recommendation on ultrawideband propagation was extensively improved and revised.

ITS also participates in the work of Working Parties 3J (propagation fundamentals), 3M (point-to-point propagation, earth-space propagation and interference and coordination) and 3L (ionospheric propagation). ITS continues to be responsible for maintaining the HF (3-30 MHz) propagation software developed by the ITU-R for international frequency coordination. The ITU-R website, http://www.itu.int/ITU-R/software/study-groups/rsg3/databanks/ionosph/index.html links to an ITS website for HF propagation models for the authoritative source code for HF sky-wave propagation (Rec. P.533). This website also makes two ITS developed HF propagation models, ICEPAC and VOACAP, available for downloading. An example of the type of output that the Rec. P.533 software can produce is shown in the figure.

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[1] The RRC-04 is the first of two scheduled sessions of the international conference to establish agreements and standards for the coordination and planning of digital terrestrial broadcast services (radio and television) in parts of the ITU-R's Regions 1 and 3 of the world.

Propagation Model Development & Comparisons

Outputs

- Improvement of the effective height algorithm in the ITS Irregular Terrain Model (ITM).

The propagation model development effort continued the focus on improvements to the algorithm for determining the effective antenna heights within the ITS Irregular Terrain Model (ITM) in its point-to-point mode. The effective antenna heights determine a number of important intermediate quantities that are very influential in the prediction of the computed reference attenuation in the ITM, notably the smooth earth horizon distances and, in the case of line-of-sight paths, the radio horizon distances and horizon elevation angles. In the ITM, the sum of the smooth earth horizon distances determines the point at which the line-of-sight range attenuation curve is matched to the diffraction range attenuation curve. The radio horizon distances and elevation angles are used, among other things, to determine the values of the attenuation curve in the diffraction range. For any given transhorizon path, frequency of operation and polarization, higher effective heights will tend to yield less predicted attenuation than lower effective heights. For "short" line-of-sight paths and moderately flat terrain, however, there is the possibility of constructive and destructive interference between the direct ray and the ray reflected from the ground as the dominant propagation mechanism, so reduction in attenuation is not necessarily strictly monotonic with increasing effective heights.

For transhorizon paths the direct ray between the terminals' structural heights does not clear the intervening terrain, so the radio horizon distances and horizon elevation angles are determined from the highest visible (as seen from each terminal's structural height in the direction of the geodesic between the terminals) terrain point (for single horizon paths) or points (for double horizon paths) on the terrain profile between the terminals. For line-of-sight paths the direct ray between the terminals' structural heights clears the intervening terrain, so these quantities are undefined. To circumvent this difficulty, the ITM algorithm falls back to the method used in its area prediction mode, that is, the radio horizon distances and elevation angles are set empirically, using the observed medians of these quantities. The observed median radio horizon distances are monotonically increasing functions of the effective heights, and the observed median horizon elevation angles are monotonically decreasing functions of the radio horizon distances.

In the area prediction mode of the ITM, the path distance is a parameter. In contrast, in the point-to-point mode of the ITM, the path distance is a given for the path in question. Therefore, to complete the definition of the radio horizon distances and elevation angles for line-of-sight paths in the point-to-point mode, the sum of the radio horizon distances is compared to the path distance. If this sum is less than the path distance, which implies that the path is transhorizon, as opposed to line-of-sight, then the effective heights are increased by a factor designed to increase the sum to be just greater than or equal to the path distance. That is, it is assumed that the original estimates of the effective heights were too low for the inferred radio horizon distances to be consistent with the line-of-sight category and that, in consequence, these effective heights should be increased. In this instance, the radio horizon distances and elevation angles are also recomputed, based on the increased effective heights.

Figures 1 and 2 illustrate the differences in the ITM's predictions between two methods of estimating the effective antenna heights. Figure 1 shows predicted field strengths (dB µV/m) using the current ITM point-to-point mode algorithm for estimating the effective antenna heights around a notional transmitter site near Denver, Colorado. Figure 2 shows the same predicted field strength levels as Figure 1 for the same site, but with the effective antenna heights fixed at the structural heights, regardless of the comparison between the sum of the inferred radio horizon distances and the path distance. A comparison of the two figures reveals that fixing the effective heights at the structural heights yields a more conservative prediction. This result is not too surprising, since the current ITM algorithm for estimating the effective antenna heights always yields estimates that are greater than or equal to the structural heights.

During the previous year's effort, it was evident that considerable accuracy improvement over the current algorithm could be obtained for transhorizon paths, if one were to locate and fit the terrain in the vicinity of the point(s) of minimum Fresnel clearance on the terminal's immediate foreground (i.e., the terrain between the terminal in question and its radio horizon) and extrapolate that fit to the terminal's location. Unfortunately, this approach was not nearly so fruitful when applied to the full terrain profile on line-of-sight paths. One possible reason for this is the close coupling between the effective heights and the radio horizon distances and elevation angles for line-of-sight paths.

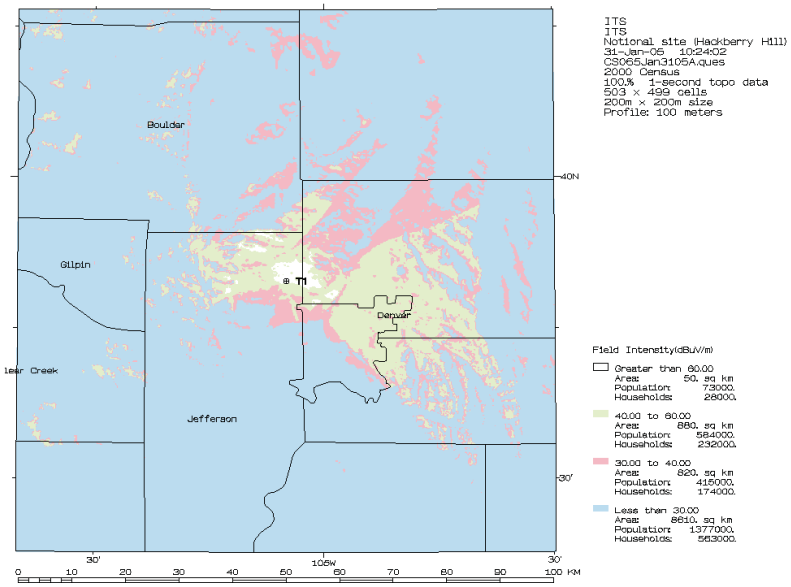

Figure 1. Communication System Performance Model (CSPM) plot showing predicted radio coverage using ITM with the existing effective height algorithm.

In order to overcome this coupling for line-of-sight paths, some method of determining the radio horizon distances and elevation angles on these paths is required. If one uses the same definition for these quantities that is applied to transhorizon paths, but extends the terrain which is considered to the geodesic beyond the terminals, then it is clear that these always exist. Furthermore, the sum of these radio horizon distances will always be greater than or equal to the path distance. This modification to the line-of-sight algorithm has been implemented and some initial testing/comparison to measured propagation data has been carried out. The results are encouraging, but it is expected that some additional refinements to the effective height algorithm will yield further predictive accuracy improvements.

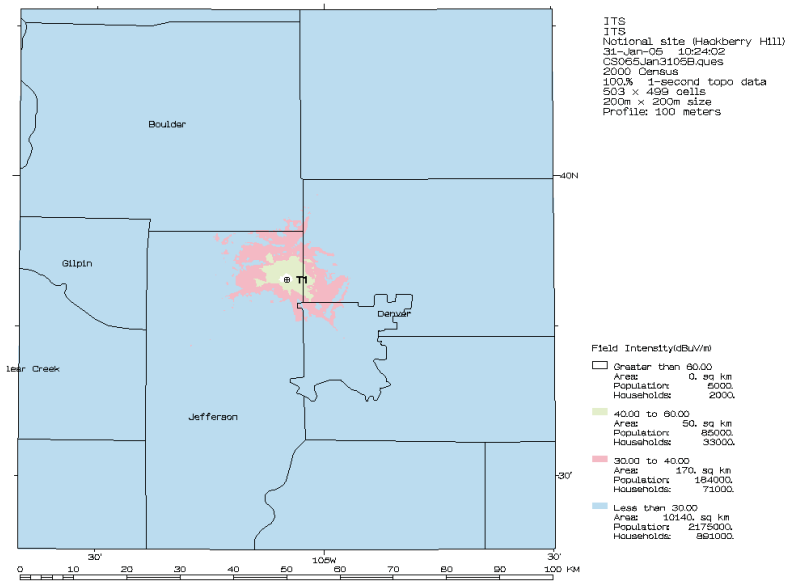

Figure 2. CSPM plot showing predicted radio coverage using ITM with effective heights set to the structured height above ground.

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