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17. Mobile, Terrestrial, and Satellite Propagation Modeling

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1. Introduction

During the reporting period, great efforts have been made in the improvement of coverage and interference-prediction methods for terrestrial and satellite mobile applications. This has coincided in time with the maturity of many second-generation cellular networks requiring very precise prediction models. Also, other wireless systems have proliferated or been initiated in this period: digital cordless, wireless local loop, wireless LANs, radio-PABX, LEO-satellite systems, etc. More accurate prediction tools are also needed for the planning of third-generation mobile systems for personal communications that will soon arrive on the scene.

As for terrestrial-propagation modeling, ray-tracing-based, site-specific tools have been developed by numerous companies and research institutions to supply the accurate predictions needed. Besides this trend, based on different deterministic modeling approaches, empirical models have continued to be produced for a great number of situations. Also, intermediate approaches, based on simplified, easy-to-use formulations derived from fully deterministic models, have appeared. On the other hand, the advent of personal satellite communication systems with a large number of LEO satellites facilitated the establishment of new types of LMSS (land mobile satellite service) propagation models, with a function for assessing satellite-diversity improvement. Moreover, studies on the frontier region, bridging wave propagation, antennas, and systems, are becoming more and more important.

In this paper, we focus on the following three basic areas, with special emphasis on recent advances: (1) Propagation modeling related to terrestrial mobile channels, (2) Propagation modeling related to mobile-satellite channels, and (3) modeling interfacing "wave propagation" and "systems."

2. Terrestrial mobile propagation modeling

2.1 Overview

In this section, a review of advances in mobile channel characterization/ modeling/prediction is presented. The basic types of propagation paths being studied are macrocells, both urban and non-urban; microcells in urban and highway environments; indoor picocells; and indoor coverage from outdoor base stations. Specific empirical models for these types of paths are available. More theoretical models are valid for any of these situations, although different simplifications have to be introduced to relieve the computational effort required.

The modeling of propagation effects in the last few years has also demanded more detailed predictions. Large prediction areas or pixels of $100 \times 100\text{m}^2$ (or even larger) were sufficient for first-generation mobile or non-mature second-generation systems. However, as the demand for these services increases, the cell sizes have to be reduced. More spatially-detailed information is needed for the assessment of coverage and interference. Nowadays, prediction areas/pixels of a few square meters–for example, $5 \times 5\ \text{m}^2$ (or even smaller) are required by system planners. The degree of detail needed to characterize the propagation environments is supplied by terrain, land-usage/morphography, and building databases with increasing resolutions.

The basic propagation mechanisms to be considered for the modeling of propagation effects are reflection, scattering, diffraction, and penetration/absorption. Scattering occurs when the environmental feature is small, or of a size similar to the wavelength. Scattering causes the energy from the transmitter to be re-radiated in many different directions in space. Also, scattering occurs when a large surface (terrain or building face) is rough in comparison with the wavelength. In this case, part of the energy is scattered in many other directions, instead of being reflected in the specular direction. The attenuation of the transmitted signal, such as through walls and trees, also has to be accounted for in terms of absorption/penetration losses.

Here, three basic model categories will be addressed: "empirical/statistical models," which are fast and versatile but not very accurate; "rigorous models," including integral- and differential-equation models, which are slow but accurate; and "approximate models," including ray optical plus UTD and PO, which are half-way between the first two types. These methods will be addressed in this chapter, with special emphasis on recent advances. Work is being done to reduce the computational complexity of these methodologies to make their use feasible in radio planning applications

The basic trend in the development of prediction tools has been the development of site-specific computerized tools, incorporating building information in different forms (vector or raster). Basically, ray-tracing-oriented tools–using more

or less comprehensive propagation models, such as UTD, and empirical corrections–have been developed. Simplifications to the full three-dimensional approach have been proposed, in which only the two-dimensional vertical or two-dimensional horizontal planes were considered. The basic demand from these tools has been an increased path-loss-prediction accuracy. However, new demands have also been placed on tool developers for more detailed predictions of polarization, wide-band, and directional effects. However, deterministic ray-tracing-based models cannot cope with the presence of small features in the surroundings, such as furniture, trees, traffic signs, cars, etc. This calls for the combined use of deterministic and statistical studies. Smaller scatterers (not available on building databases: lamp-posts, traffic lights, trees, fences, metallic signs, vehicles, etc.) can either be disregarded, or treated in a statistical way (macro-description versus micro-description)

2.2 Measurements

Some issues of great interest (for example, the effects of the human body on the gain of hand-held terminals) are still in the early stages of modeling. In such cases, sufficient experimental data is required to supply orders of magnitude for these effects. This is why the availability of measurements is of great importance for other than just model-validation purposes. A great effort is also being made by different operators and research institutions to improve their channel-sounding facilities at the frequency bands of interest: 2 GHz, 5GHz, 20 GHz, etc. Today it is not sufficient to increase just the capacity of channel sounders to resolve between closely spaced echoes in the delay axis. It is also required that such sounders provide the capability to identify the directions or angles of arrival (DoA/AoA) of the direct signal and multipath contributions, for smart-antenna and diversity studies. Similarly, channel sounders are required to provide polarimetric information, needed for the study and evaluation of polarization-diversity schemes.

2.3 Empirical/statistical models

Hata-like models for large cells, both in built-up and non-built-up areas, have continued to be widely used in the reporting period. These types of models are suitable for standard cells, in which the base station is elevated with respect to the surrounding environment. Also, the spatial detail in their predictions is very poor (circular coverage plots). Improvements can be achieved by combining these models with multi-edge diffraction models, to account for terrain-irregularity effects. Ad hoc empirical models have been developed, in order to cope with new scenarios that have become widespread, like urban microcells, indoor picocells, and indoor coverage from outdoor base stations. These models provide attenuation values as a function of the number of traversed internal/external walls and floors, etc. Examples of this approach can be found in [*Fischer et al., 1998*].

On the other hand, statistical modeling is a very convenient approach to the generation of synthetic channels for transmission-link simulation purposes, and for coverage and interference studies. Statistical models can be successfully used in the modeling of wideband transmissions over mobile channels, as well as to analyze space-diversity multiple-access (SDMA) and diversity schemes. Polarimetric information can also be introduced into these models. Statistical models also offer the advantage of short simulation times, while reflecting the time-variant behavior of the channel. They easily interface with transmission-link simulation tools for the assessment of modulation, coding, and medium-access schemes. A statistical model, describing a methodology for the generation of scattering functions for computer simulations, is available in [*Wang et al., 1997*].

Although very frequently used in the modeling of the land mobile satellite channels, not many Markov chain models have been reported in the available literature. An example of the use of a first-order Markov model to describe measurements of carrier-to-interference series was reported by *Babich and Lombardi* [*1997*]. Another methodology in which interest is growing is the modeling of propagation effects by means of neural networks. An example of the applicability of this approach can be found in [*Wolfle and Landstorfer, 1997*].

2.4 Approximate models

Under this category, we consider those models based on high-frequency approximations, such as GO (Geometrical Optics), PO (Physical Optics), UTD (Uniform Theory of Diffraction), etc. Interest in an accurate evaluation of multiple diffraction effects due to buildings, based on the classical Vogler formulation, has continued. The initial work–carried out at the Polytechnic University of Brooklyn, New York, by *Walfish and Bertoni* [*1988*], describing urban propagation losses as a sum of three terms: free-space losses, rooftop-to-street losses, and multiple diffraction past rows of buildings–was successively refined [*Xia and Bertoni, 1992*]. This last analytical model is difficult to apply directly, since it involves multiple-dimension integration to calculate the signal attenuation due to multiple diffraction past rows of buildings. This model has been recently expressed in a simplified form by *Xia* [*1997*], so that it can be effectively used within computerized propagation prediction tools for coverage and interference calculations, for base-station antennas above, below, and at approximately the same height as the average rooftop. On the other hand, the Euro-COST 231 group has recommended a combination of the original Walfish-Bertoni model and the *Ikegami et al.* [*1994*] model for urban-area propagation prediction.

Most propagation models for urban areas consider a flat terrain. However, in many real instances this is not the case. In [*Piazzi and Bertoni, 1998*], a study was presented in which buildings over a cylindrical terrain are modeled as a series of absorbing half screens, which are assumed to lie in a row, equally spaced along parallel streets, with the streets running perpendicular to the terrain slope. Numerical

results were obtained by using successive repetition of the Kirchhoff-Huygens approximation. Later, the methodology was further simplified for easy use with cellular planning tools.

UTD is a widely used technique, employed in site-specific tools using ray-tracing. The use of UTD techniques presents problems for edges that are in the transition region of preceding edges in multiple-edge paths. By considering slope-diffraction contributions, the problem can be solved as shown in [*Andersen, 1997*]. Work was also carried out to provide new diffraction coefficients for important canonical forms, from the point of view of mobile propagation modeling: specifically, solid and hollow dielectric wedges, representing rooftops [*Demetrescu et al., 1998*]. In this paper, it was stated that the widely accepted Luebbers heuristic solution for incorporating the electromagnetic constants of dielectric rooftops showed a difference of 10 dB from the measurement in the shadow regions.

A growing interest has been observed in the modeling of smaller objects in the environment near the mobile station. In this respect, some attempts have been reported in which objects such as lampposts, cars, and traffic signs have been modeled, using metallic cylinders and finite metallic plates, etc. [*Perez-Fontan et al., 1995*]. This brings up the question of how to introduce those small objects (also furniture, in indoor environments) not available in building databases as site-specific modeling tools. The most dominant approach seems to attempt a hybrid physical-statistical model, in which ray-tracing models are used that take into account the main features in the environment (building blocks), and in which the presence of smaller objects is introduced statistically.

A great effort has also been placed into reducing the computational load needed to compute coverage or other parameters, for large urban areas as well as indoor environments. Two main approaches are common in ray-tracing implementations: ray launching or shooting, and point-to-point ray-tracing. Ray-launching techniques require the definition of a spherical "collection area" of some three to five meters in diameter, since it is highly improbable that any launched ray will hit the actual receiver position. Actual point-to-point ray-tracing–based on imaging techniques and the implementation of Snell's law for reflection, and the Keller law for diffracted rays plus blockage algorithms–requires the performance of receiver-independent preprocessing tasks, prior to any actual ray-tracing, in order to reduce the search field [*Aguado et al., 1997*; *Dotling et al., 1997*; *Manabe et al., 1996*; *Fujii and Imai, 1996*]. Ray-tracing tools also require an appropriate description of other propagation mechanisms, such as penetration though walls. In [*De Coster et al., 1997*], the generalized transmission coefficient of dielectric walls, based on an infinite number of successive reflections, was used. Additional data for building penetration can be found, for example, in [*Torres et al., 1998*].

An important factor that has attracted some work is the issue of paths through vegetated areas. Several approaches have been followed to assess losses due to a mass of vegetation, or more specifically, trees of different types, between the transmitter and the receiver. It is important that ray-tracing-based tools also account for these effects, either in a theoretical way, or alternatively, in a more-empirical way. In [*Kurner et al.*, *1997*] the lateral-wave methodology proposed by Tamir was employed to describe losses due to wooded areas. This model is valid for wooded areas resembling a slab, with different dielectric properties from those of the ground. Sometimes the model geometry is not found in real conditions. Other applicable models are based on empirical observations, producing exponential laws. Still, diffraction models are also considered for describing path losses over wooded areas, if these losses are smaller than those due to absorption through vegetation. Similarly, workers are constantly trying to incorporate other contributions off the great-circle path (vertical two-dimensional plane) into three-dimensional ray-tracing models. Diffuse scattering from terrain is one such contribution attracting the attention of model developers. In [*Tameh et al.*, *1997*], terrain scattering is modeled by means of its bi-static scattering radar cross section. Several approaches are reported possible: Kirchhoff, small perturbation, and a Lambert model. The latter approach was pursued due to its simplicity.

2.5 Theoretical models

The parabolic-equation (PE) method has usually been employed in two-dimensional problems. However, three-dimensional studies have also been attempted with this method. A three-dimensional PE method was used by *Zaporozhets* [*1997*] for the study of diffraction and scattering from buildings, including detailed features like doors, windows, wall roughness, etc. The PE method was found to be most effective for small-scale problems, like scattering from a single building or a group of buildings. Later, the detailed information on building scattering obtained with this PE method could be used within faster ray-tracing based models. Two types of rough surfaces were considered: small-scale roughness, which can be described as a set of random points, and rough brick walls, which can be described by a set of plates shifted according to some random distribution. The small-scale roughness was found to produce a reduction in the reflection-coefficient value, while rough brick walls presented a different scattered-field structure, with large ripples in the specular region. These effects, observed experimentally, are adequately described using the PE method.

Similarly, another three-dimensional PE approach was presented by *Zelley et al.* [*1997*] for irregular terrain, in order to take into account terrain gradients traversing the great-circle path, and obstacles to the side of the great-circle path, such as hills, or propagation around the sides of obstacles. This method quite effectively replaces the typically used knife-edge approach, while incorporating the surface impedance of the terrain. In some environments, it was found that this three-dimensional PE method provided a better agreement with experimental results than that obtained using the two-dimensional PE method.

An electric-field integral-equation (EFIE) was proposed by *Brennan and Cullen* [*1997*] to analyze the propagation of UHF waves over corrugated two-dimensional perfectly electrically conducting surfaces. Different alternatives to speeding up the computation were proposed. Assuming a two-dimensional, perfectly conducting surface (grazing incidence), locally smooth terrain, time-harmonic fields, and a TM*z* line source, efficient numerical schemes were described. The computation times needed are dramatically reduced. The Fast Far Field Approximation (FAFFA) avoids the computation of a large number of discretized integrals over the unknown surface-current-density multiplied by mutual-impedance terms. It conceptually divides the scatterers into large groups of points that interact if they are close to each other, but do not interact if they are far away. The information about incident and scattered waves from one group is transferred to a group of receiving points. The importance of judiciously choosing the size of the groups is stressed. The Natural Basis Solution (NBS) uses complex-valued oscillatory basis functions, defined over large domains. Enforcing the boundary conditions at the domain centers results in matrix equations of much lower order than the original equations. The fields for two terrain profiles were calculated. For a gently undulating terrain profile, both methods gave good results; however, for a hilly profile, the NBS failed to yield good results. The Tabulated Interaction Method–where the far-field behavior of a linear surface segment is tabulated for different incident and scattered plane waves–is a computationally even more efficient extension of FAFFA.

In [*Constantinou and Ong*, *1998*] a three-dimensional study of urban-area propagation was carried out, using the asymptotic path-integral technique. This technique was applied successfully to the study of diffraction from three-dimensional idealized obstacles, and its accuracy was verified experimentally. The Method of Moments was used by *De Backer et al.* [*1996*] to solve a set of integral equations describing propagation conditions in indoor environments. Overall agreement between MoM and GO results was fairly good, particularly if a spatial filter was used to eliminate fading effects. The ray-tracing approach, however, was found to predict important propagation paths erroneously, or not at all. Another rigorous technique being employed for propagation modeling is the Finite-Difference/Time-Domain (FDTD). In [*Remley et al.*, *1998*], a comparative study with a ray-tracing model was presented.

3. Land mobile satellite propagation modeling

Since propagation modeling for maritime mobile satellite service (MMSS) and aeronautical mobile satellite service (AMSS) had been performed mainly during the period of the 1980s, recent study activities, on propagation modeling solely for land mobile satellite service (LMSS), are introduced in this section. After discussing propagation impairment factors, such as path blockage and tree shadowing, model development on LMSS propagation channels is highlighted. Moreover, a propagation-degradation countermeasure, adopting multi-satellite diversity, is discussed. By the way, propagation issues raised here seem to be common with those of high-altitude-platform stations (HAPS), which might be a potential wireless-network infrastructure in the 21st century.

3.1 Propagation-impairment factors

There are two major communication environments for LMSS. One is a vehicular environment (LMSS-V), in which a person communicates with a mobile terminal while moving at a high speed in a relatively wide area. The other is a personal-use environment (LMSS-P), in which a handheld terminal moves very slowly in a relatively narrow area. Propagation-impairment factors in LMSS-V include heavy signal shadowing by mountains, buildings and tunnels; small signal shadowing by roadside trees and small obstacles, such as utility poles; and multipath fading due to scattering from buildings and the ground. Although most propagation-impairment factors are common in LMSS-P, radiowave absorption by the human head and reception of satellite signals inside a building are additional factors to be considered.

Since LMSSs are usually low-margin systems, satellite visibility is the most dominate factor in determining link quality or service availability. Satellite visibility measurements were carried out in various ways, some of which were reviewed in *Karasawa et al.* [*1997b*]. Photogrammetry, using a number of pictures taken from a fish-eye camera, was adopted by *Akturan, and Vogel* [*1995*]. These data showed that satellite visibility is of the order of 30%, 50%, and 65% for elevation angles of 20, 30, and 40 degrees, respectively, in urban areas. A method predicting satellite visibility, based on a computer simulation assuming that the height of buildings along a road-side area follows the Rayleigh distribution, was also given by *Saunders and Evans* [*1997*]. Statistical analysis for satellite visibility in suburban areas is still insufficient because of the wide variety of environments.

The effect of shadowing by trees is also an important factor to be considered, particularly at higher frequencies, such as Ku and Ka bands. Although this problem has been studied at the early stage of LMSS development, more systematic measurements at L- and S-band frequencies were carried out by *Vogel et al.* [*1995*]. The measurements were made through three different trees, a pecan, a cottonwood, and a Loblolly pine still in leaf. All trees had heights in the range from 9 to 12 m. The results showed a mean attenuation from 5 dB to 10 dB, with a standard deviation of 3 to 6 dB. There seems to be no significant dependence on frequencies in the L and S bands. Based on results available so far, it seems reasonable to assume that the probability density function (PDF) of signal-level degradation due to tree shadowing follows a log-normal distribution, with appropriate mean and standard deviation values at frequencies ranging from 1 to 3 GHz.

At frequencies above 10 GHz, the trees act like obstacles that fully block the satellite signal. Based on measurements using the ACTS (19.9 GHz) and Italsat (18.7 GHz) satellites, attenuation ranging from 17 dB to 26 dB was reported [*Rice et al., 1996*; *D'Amato et al., 1997*]. Reliable operation can only be achieved in clear line-of-sight conditions in the higher frequency bands.

3.2 Channel characterization and modeling

Studies on propagation-channel modeling with application to LEO satellite systems have been conducted in this period. These studies have mainly been focused on the lower frequency bands, such as L band (1-2 GHz) and S band (2-4 GHz). The basic concept for the LMSS propagation channel, however, might be common to all frequency bands.

A typical but conceptual propagation environment for LMSS is characterized by a combination of three states, appearing one after another, based on a Markov process [*Karasawa et al., 1995*]. The three states, named "states A, B and C," represent the line-of-sight (LOS) condition, slight shadowing by trees and/or small obstacles such as utility poles, and full shadowing by large obstacles such as buildings, respectively. Each state consists of the direct-wave component, with or without shadowing, and multipath wave components. The same categorization was adopted by *Akturan and Vogel* [*1995*]. The three-state model was developed based on pioneering models for LMSS propagation channels represented by *Loo* [*1985*], *Lutz et al.* [*1991*], *Barts and Stutzman* [*1992*], and so on. Probability density functions (PDF) for each state, f_A, f_B, and f_C, can be represented by the Nakagami-Rice distribution for state A, Loo's for state B, and Rayleigh's for state C, with state-occurrence probability parameters of p_A, p_B, and p_C (where $p_A + p_B + p_C = 1$). Accordingly, the overall PDF is given by $p_A f_A + p_B f_B + p_C f_C$. There are eight parameters in the model. *Akturan and Vogel* [*1997*] proposed to adopt Loo's distribution for f_C, in place of the Rayleigh distribution, for urban environments. The three-state model has proven to be a good representation of LMSS environments such as urban and suburban environments at L-band frequencies. The parameter values in the model can be obtained from the above discussions in Section 3.1, and a set of suggested values are given in [*Karasawa et al. 1997b*]. The three-state model also has the capability of expressing dynamic behavior in terms of state-transition characteristics, adopting the Markov Process.

Although only limited LMSS propagation data at higher frequency bands are available at the present time, the model can be expected to have a similar structure for higher-frequency bands, up to Ka band. More information about the parameters' values might be necessary for a wide range of predictions in frequency, elevation angle, and operating environment. Measurement and modeling for Ka-band frequencies seem to be a challenging study item in the next triennial period.

3.3 Propagation countermeasures by means of satellite diversity

In order to drastically improve the signal quality and service availability, a satellite-diversity scheme is promising, if at least two satellite zones overlap. In satellite diversity, the best satellite (i.e., a satellite in a line-of-sight condition, if available) is always selected, even in a propagation environment that is varying with time due to moving mobile terminals or satellites.

The three-state model given above has a capability for assessing satellite-diversity effects in the case of multi-visibility satellite constellations (i.e., switching to the least impaired path based on the state-by-state selection scheme) [*Karasawa et al.*, *1997b*]. Based on the calculation, drastic improvement by means of diversity can be demonstrated, particularly in a suburban environment. Using an elevation-angle-dependent two-state (good/bad) channel model, satellite-diversity effects in highway and city environments were also demonstrated by *Bischl et al.* [*1996*]. The most effective diversity scheme, but one which must overcome more difficulties, is optimal instantaneous switching or combining of simultaneous signals from two or more satellites. Such an analysis was done by *Akturan and Vogel* [*1997*], based on a joint probability of signal-level distribution. Dynamic behavior of time-varying received signals in the case of a LEO satellite system, after utilizing satellite diversity, can also be analyzed, assuming that the state transition of each satellite path depends on elevation angle, complying with the Markov process.

4. Interfacing propagation and system studies

Wide-band propagation models are needed to provide relevant information for system definition. The evaluation of suitable modulation, coding, and multiple-access schemes can only be carried out if adequate information about the propagation channel is available. Multipath-fading properties–such as time variability, Doppler spreading, delay spreading of the channel, depolarization, and angular spreading of incident waves–can be represented in terms of time varying tap-delay lines for transmission-link studies.

The search for increased-capacity mobile networks requires models capable of reproducing the spatial characteristics of the multipath-propagation channel. Several schemes can be applied to increase the capacity of mobile networks. A technique receiving much attention nowadays is the use of smart antennas, following either the SFIR strategy (spatial filtering for interference reduction) or the SDMA strategy (space-division multiple-access) [*Paulraj and Papadious*, *1997*]. Directional models are capable of supplying the required information–that is, the directions of arrival (DoA) of multipath echoes–to analyze the gains supplied by smart-antenna systems. Directional models for new wireless systems should include the following features: direction and polarization information, non-stationary scenarios, dynamic evolution of paths for performance evaluation of RAKE receivers, slow and fast fading, and different complexity levels with compatibility. Also, for network simulations, a distance-related path loss, a slow-fading and mobility model might be necessary [*Skler*, *1997*]. For evaluation of two-dimensional RAKE in DS/CDMA systems, a snapshot model, which generates an instantaneous propagation environment realizing a given statistical condition in terms of delay profile and angular profile, was presented [*Inoue and Karasawa*, *1998*].

Another important application of directional, wide-band models is in vehicle location. Adaptive self planning of radio networks and the location of traffic hotspots requires combined information on channel time spreading and angle spreading, which can only be furnished by adequate, reliable models. An overview of spatial channel models is given in [*Ertel et al.*, *1998*].

To design reliable mobile-radio systems, it is vital to have a good understanding of the impact of wave-propagation characteristics on digital-transmission quality in a wide variety of mobile-radio environments. In particular, in wideband digital-communication systems, the occurrence of irreducible bit errors, due to inter-symbol interference (ISI), or burst errors, due to clock cycle slip, is intimately connected with frequency-selective fading. Studies in this area bridge "wave propagation" with "systems," and they are gaining more and more in importance. For this purpose, a very simple channel model–the "equivalent transmission-path model" (ETP model), for calculating the irreducible bit error rate (BER) and the occurrence rate of clock cycle slip under the frequency-selective Nakagami-Rice fading environment–was introduced by *Karasawa et al.* [*1996*, *1997a*]. Since Rayleigh fading is a special type of Nakagami-Rice fading wherein the direct wave component becomes negligible, the Nakagami-Rice fading model widely covers the multipath fading environment that appears in mobile-radio systems. In the environment, it has been identified, through computer simulations and theoretical analysis, that three fading parameters are really key parameters governing digital-transmission characteristics (i.e., BER due to ISI and occurrence of clock cycle slip). Without changing the key parameter values, a simple two-wave model (the ETP model) was obtained. As for prediction of BER due to ISI, the BER can be expressed as a function of the key parameters in a simple equation, based on the ETP model. Moreover, the occurrence of clock cycle slip is expressed in a similar way. These formulae are characterized by the clear separation of propagation factors and system factors. The ETP model can therefore play an effective role in bridging "wave propagation" and "systems."

Degradation categories, due to signal time spreading viewed in the time-delay domain and the frequency domain, are summarized in [*Skler*, *1997*]. Countermeasure schemes, combating ISI and CCI (co-channel interference) by means of space-time signal processing with adaptive array configurations, are given in [*Paulraj and Papadious*, *1997*].

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