A GENERIC CHANNEL SIMULATOR FOR WIRELESS CHANNELS

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ABSTRACT

This paper reviews the wireless channels simulated by the Generic Channel Simulator (GCS), a software package developed for the DOD[1]. The wireless channels considered are: Cellular/PCS, VHF/UHF Mobile-Mobile and Mobile-Base Station, VHF/UHF Air-Air and Air-Ground, Land Mobile Satellite, Indoor Channels, and HF Ionospheric. Simulations include distortion (multipath) and additive disturbances. Input parameters and environments for default scenarios are discussed. The background and current status of the GCS are reviewed. This software will be made available via the Internet.

INTRODUCTION

In order to evaluate various modem and error control concepts, to obtain a comparative evaluation of modems under identical conditions, and to write meaningful specifications for link performance, it is necessary to have available useful stochastic/ mathematical models of the propagation channel and the additive disturbances. Precise models are neither necessary nor likely attainable due to the non-stationary behavior of the real channel. It is sufficient for the models to allow modems to be exercised over the range of conditions both observed in practice and inferable from physical considerations.

The GCS is an outgrowth of Wideband HF (WBHF) Ionospheric modeling and simulation work carried out under Contract DAAB07-93-C-N651. [1] documents the basis for the HF channel models developed. The tapped delay line and associated statistical models employed were of a generic nature and it was found that much of the software could be employed directly or modified to model other radio channels, particularly the mobile cellular and non-cellular channels in the higher frequency bands.

Thus under Contract DAAB07-94-C-H601 modifications and additions were made to allow the simulation of macrocell and microcell channels[2]. A subset of the software was used to simulate the models adopted by the JTC[2] as a commercial standard for testing of PCS/Cellular modems. However the GCS includes a more realistic simulation of PCS/Cellular channels than the JTC simulation using the Mixed Discrete/Scatter Model described below. In addition, the most recent model development for the GCS [3], has made the channel simulations more versatile and has increased the types of channels simulated. Current with the work carried out in [3], software development and modifications of the GCS have been carried out by MIT Lincoln Laboratory under a separate contract [4]. Prior software development was carried out by the Mitre Corp[2][5][3].

There are three broad classes of channel phenomena of interest: path loss, distortion produced by the propagation channel, and additive disturbances. It is intended that the GCS represent each of these phenomena for each channel. Thus the work carried out in the original contract (DAAB07-93-C-N651) provided simulations for HF narrowband interference and atmospheric noise in a 1 MHz band in addition to propagation channel simulation. Path loss formulae were not programmed for the HF channel as programs are generally available.

Extensive treatment of path loss is provided for the VHF/UHF to PCS/Cellular bands, including propagation loss models for urban environments. However the only additive disturbance simulated in this band, other than white Gaussian noise, is automobile ignition noise.

At the present time the GCS simulates the following channels: Cellular/PCS (Macrocell and Microcell), VHF/UHF Mobile-Mobile and Mobile-Base Station, VHF/UHF Air-Air and Air-Ground, Land Mobile Satellite, Indoor Channels, and HF Ionospheric. The GCS should provide a useful tool in the comparative evaluation of communication and detection techniques over both military

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[1] Mitre Corp Contracts DAAB07-93-C-N651 and DAAB07-94-C-H601 and BELLO, Inc. Contract MDA904-95-C-2078.

[2] The JTC was a cooperative effort between committee T1 (actually technical subcommittee T1P1) sponsored by the Alliance for Telecommunication Industry Solutions (ATIS) and the Telecommunication Industry Association (TR46).

[3] Some software utilized in a real time WBHF channel simulator [8] was incorporated in the GCS.

and non-military wireless channels. The JTC portion of the GCS has been used recently for PCS performance prediction[6][7].

GENERIC CHANNEL MODELS EMPLOYED

The models used are primarily for representation of short-term wireless channel fluctuations. Options for use of log-normal distributed fluctuations to represent long term variations are included only for the WBHF and Land Mobile Satellite channels at the present time.

Aside from the Quiet WBHF channel, three generic models are used , individually or in combination, to simulate the wireless channels: 1) the *Complex Gaussian Factorable WSSUS Model;* 2) the *Discrete Non-Fading Paths Model;* and 3) the *Discrete Complex Gaussian Factorable WSSUS Model*.

The WSSUS Model, defined in [9], has a phenomenological interpretation as a continuum of wide-sense stationary fluctuating elemental scatterers, with a power density in delay and Doppler, $S(\xi,\nu)$, called the Scattering Function[4]. Using results in [9], a WSSUS channel can be realized as a uniformly tapped delay line with generally correlated complex Gaussian time variant tap gains and tap spacing <1/W, where W is the channel bandwidth.

Model 1) above uses a special case of the WSSUS model in which the fluctuations are Complex Gaussian and the Doppler Power Spectrum, $P(\nu)$[5], is the same for all delays. The scattering function then factors into the product $P(\nu)Q(\xi)$ where $Q(\xi)$[6] is the Delay Power Spectrum. Thus the model is completely specified statistically once $P(\nu)$ and $Q(\xi)$ are designated. The scatter portion of the Mixed Model simulated by the GCS is assumed to be composed of N scatter paths, each represented by a Gaussian Factorable WSSUS model. Thus the Scattering Function for the scatter portion of the Mixed model can be expressed as

$$S(\xi,\nu)=\sum_{n=1}^{N} p_n P_n(\nu-\nu_n)Q_n(\xi-\xi_n)$$

where (ν_n,ξ_n) are the mean Doppler shift and path delay of the n'th scatter path and p_n is the mean absolute magnitude squared of the n'th scatter path transfer function.

Model 2) is used to represent isolated reflections. Such a model consists of a set of random phased and Doppler shifted paths with fixed amplitudes and path delays.

While Model 1) is used to represent the Disturbed WBHF channel and a modified Model 2) to represent the Quiet WBHF channel[7], a combination of Model 1) and Model 2), called the Mixed Discrete/Scatter Model, or the Mixed Model, for short, is used to represent all the other wireless channels in the GCS, as discussed in more detail below.

Model 3), used to implement the JTC standards for PCS Outdoor and Indoor Channels, consists of a finite set of independently fluctuating paths with statistically stationary complex Gaussian statistics and the same $P(\nu)$ for the fading of each path. Given $P(\nu)$, the channel is completely determined statistically by specifying the delays and strengths of the paths. The JTC standards involve a specification of these path delays and strengths for different environments[10].

PCS/CELLULAR AND INDOOR CHANNELS

A review [3] of the measured multipath characteristics for Macrocell and Microcell Outdoor channels and Indoor channels reveals a common pattern: the impulse responses consist of a mixture of groups of large numbers of unresolved paths plus a few discrete resolved paths due to large reflecting objects. A direct line-of-sight (LOS) path of significant strength may also be present. The Mixed Model is used to represent these channels, wherein each group of unresolved paths, called a *scatter path*, is represented by a complex Gaussian WSSUS Model (usually two scatter paths are sufficient) and the set of resolved paths is represented by the Discrete Non-Fading Paths Model.

The user must select the following parameters for the Mixed Model: carrier frequency; channel sampling rate; the number, relative strengths, and bulk delays of both the scatter paths and the discrete paths; the Doppler Power Spectrum and Delay Power Spectrum for each scatter path; and the Doppler shift of each discrete path. While the Delay Power Spectrum can be selected arbitrarily, an exponential shaped spectrum is available pre-programmed because so much experimental data supports this shape for built-up areas.

The user has three choices for Doppler Power Spectrum: uniform over the band $(-V/\lambda<\nu<V/\lambda)$, where V is the velocity of the moving terminal and λ is the wavelength at

[4] $S(\xi,\nu)d\xi d\nu$ is proportional to the received power due to scatterers having delays in the interval $(\xi,\xi+d\xi)$ and Doppler shifts in the interval $(\nu,\nu+d\nu)$.

[5] $P(\nu)d\nu$ is the received power due to scatterers providing Doppler shifts in the interval $(\nu,\nu+d\nu)$.

[6] $Q(\xi)d\xi$ is the received power due to scatterers providing delays in the interval $(\xi,\xi+d\xi)$.

[7] This model is modified to include linear group delay distortion for each path in the case of the Quiet WBHF channel.

the carrier frequency; a Jakes/Clarke spectrum [11] [12], and the power spectrum shape that would be generated by passing white noise through a 32'nd order IIR filter. In the latter case the user specifies the filter coefficients. These coefficients would be generated by a suitable filter synthesis program which approximates a desired magnitude squared transfer function.

Due to the many selections required to specify the Mixed Channel, a number of Default Scenarios have been provided to the user, utilizing parameter values based upon an extensive review of published measurements [3]. For the Macrocell Outdoor Channel three environments may be selected: Urban High Rise, Urban Suburban Low Rise, and Residential. Due to the paucity of published data, no environmental distinction is made for the Microcell Outdoor Channel Default Scenarios. For the Indoor Channel four environments may be selected: Small Office, Large Office, Commercial, and Indoor-Outdoor.

As mentioned previously, wireless channels generally contain a mixture of unresolved multipath components, a possible direct path, and a possible set of discrete paths. Only the collection of unresolved paths should be modeled as a WSSUS channel. However for virtually all papers modeling mobile channels, no attempt is made to extract the direct path and strong reflected components before carrying out computations on estimated Delay Power Spectra. Data bases do exist from which parameters of the mixed model can be extracted. These data bases should be processed to extract parameters for the Mixed Model. When this is done it will be possible to update the Default Scenarios currently used in the GCS.

VHF/UHF MOBILE-MOBILE AND MOBILE-BASE STATION CHANNELS

The physical aspects of the VHF/UHF Mobile channels are similar to those of the cellular/PCS channels so the Mixed Model is suitable also. Both of these channels partition into two classes: those in which one of the terminals is at the ground mobile level and the other is elevated above the roof line and those in which both terminals are at the ground mobile level. From a channel modeling viewpoint, the lower operating frequency band and the mobility of both ground terminals distinguish the VHF/UHF Mobile channels from the cellular/PCS channels.

Unfortunately there exists no published data on measurement campaigns dedicated to estimating the multipath characteristics of the VHF/UHF Mobile channel as there were for the Cellular/PCS channels. We have assumed that the multipath spreads and structures observed for the latter channels may be used for the VHF/UHF channels, with an adjustment of Doppler spread and shifts appropriate to the lower frequency band. In addition, in the case of Mobile-Mobile channels, the choice of Doppler Power Spectra include a theoretically derived change in shape of the spectrum due to both terminals being mobile[3].

The predominant source of noise at VHF/UHF is automobile ignition noise. However, it is noted in [3] that mean ignition noise power appears to have dropped to levels comparable with thermal noise at PCS frequencies due to efforts of automobile manufacturers to reduce ignition noise levels. The ignition noise model discussed in [3] and implemented by the GCS is a random impulse train with Poisson arrival statistics. Impulse areas are statistically independent with uniformly distributed phases and amplitudes following a Weibull distribution. The required parameters to specify this model are the average number of impulses/sec, the ignition noise power density relative to thermal noise in the frequency band of interest, and the exponent parameter of the Weibull distribution. Available measurements are used in [3] to recommend ranges of parameters for the ignition noise model. Default Scenarios programmed in the GCS use these recommendations.

VHF/UHF AIR-AIR AND AIR-GROUND CHANNELS

From an appeal to physical considerations it may be deduced that the VHF/UHF Air-Air and Air-Ground Channels can be represented by a Mixed Model. Specifically, over water there are two possible discrete paths: a direct LOS path from the transmitting to receiving platform, and a possible “specular” reflection path from the surface. In addition there is a scatter path due to scatter from surface irregularities. Over land it is possible to have tilted, relatively flat surfaces, that can produce more than one specular reflection in addition to the scatter path.

Obtaining measurements of parameters for these mixed models has proven very difficult. For this reason a theoretical channel model was developed [3], modifying an Air-Satellite channel model developed in [13]. While this model is used to compute the Doppler and Delay Power Spectra for the scatter channel, the user is given the choice of directly specifying the relative strengths of all paths or using the theory to calculate the relative strengths. This additional flexibility was provided because the theory is more applicable to overwater than to overland channels. The user may also specify additional discrete paths, with associated delays and Doppler shifts to accommodate overland reflections from properly oriented ground facets.

The parameters for the theoretical channel model are: carrier frequency; altitudes and ground separation of two aircraft ; rms surface height and slope; dielectric constant and conductivity of surface; polarization; product of antenna gains in direction of specular point normalized to the product of gains in the LOS direction; and components of velocity vectors for the two aircraft. Based upon the limited experimental data available, Default Scenarios were formulated for Overwater and Overland environments. Further sub-environments may be selected, such as roughness of surface (Smooth, Medium, or Rough) and geometry/velocity configuration (Near, Medium, and Far), etc.

In the case of Air-Ground Channel and related Overwater and Overland Default Scenarios it was decided to include a flat fading model only, under the assumption that for most channel allocations and applications the multipath would be sufficiently small to produce little selective fading. However, since the Air-Ground Channel is a special case of the Air-Air channel this restriction can be circumvented.

LAND MOBILE SATELLITE CHANNEL

The Land Mobile Satellite (LMS) Channel has similarities to the Air-Ground Channel. In fact field experiments using helicopter-ground transmissions have been used to gather propagation data useful for LMS Channel modeling. The major application of the LMS channel is for cellular type communication to ground terminals in non-urban areas. This usually results in sufficiently small multipath spread that a flat fading model is suitable for applications, increasing the similarity to the Air-Ground Model. However, there are more experimental data for the LMS channel focused on the dynamics of the changing environment due to a moving terminal.

Thus, in modeling the LMS channel three propagation categories or states are used: Clear or Open, Shadowed, and Blocked. The relative importance of these categories depends upon the environment. The Clear State corresponds to open areas with a clear line-of-sight and a minimal amount of multipath and scatter. This state will occur frequently in rural environments.

On the other hand the Blocked State occurs when the line-of-sight between the satellite and mobile is blocked by impenetrable objects and reception occurs via diffraction and reflections. Such a channel state is typical of terrestrial land-mobile cellular channels in urban environments when no direct path or large resolvable reflected paths exist.

The Shadowed State is exemplified by a line-of-sight path through vegetation, for example transmission to a mobile traveling along a tree-lined street. In this case an attenuated, time variant, line-of-sight signal and a scatter multipath signal exist. The line-of-sight signal fluctuates slowly compared to the multipath signal and has been modeled by lognormal statistics.

The simulator provides models for the individual states. These models are essentially special cases of models already used elsewhere in the GCS except that lognormal statistics are introduced to model certain slow variations in the power of the direct path signal and/or the multipath signal.

Since the ground terminal is mobile, the individual propagation states persist only for a finite time and there are random transitions from one state to another due to the changing propagation path. Markov Chain models have been used to represent the flat fading LMS channel as a stochastic process involving two or more states. Experimental data reported in the literature has been used to provide Default Scenarios. The details of the model are presented in [3].

THE WIDEBAND HF CHANNEL

The Wideband HF Channel simulation uses three sets of parameters: *propagation* channel parameters, *atmospheric noise* parameters, and *narrowband interference* parameters. We consider these sets of parameters in order.

The propagation channel parameters consist of three groups: *quiet path* parameters, *disturbed path* parameters, and *slow fading* parameters. For the quiet ionospheric condition, it is necessary to select the *number* of quiet paths, the *amplitude* of each path in dB relative the largest path, the *Doppler shift* of each path in Hz, the *bulk delay* of each path in milliseconds, and the (linear group) *delay distortion* of each path in microsec/MHz. Numerical values for Default Scenarios are taken from [1] and [14].

A propagation path traversing the disturbed ionosphere may be modeled as a WSSUS channel[1]. Theoretical Doppler and Delay Power Spectral shapes presented in [1] are used in the channel simulations. Three disturbed path parameters: *Doppler shift*, *rms Doppler Spread*, and *rms Delay Spread* are needed by the GCS to completely specify the channel.

The long term or slow fading can be modeled as a stochastic process by exponentiating a Gaussian process with an exponential autocorrelation function [1]. To completely specify this process requires only the rms value of the Gaussian process and the time constant of the exponential autocorrelation function.

Atmospheric burst noise perceived at any point in space is due to the superposition of received signals from lightning flashes arriving from storms around the world. Most of the noise is received as over-the-horizon flashes rather than line-of-sight flashes. Flashes are arrive randomly in time and each flash is assumed to consist of a random number of strokes with random interarrival times based upon empirical distributions. The analysis presented in [1] reduces the specification of the wideband atmospheric noise model to only two free parameters, the rate of occurrence of lightning flashes worldwide in flashes/second and the CCIR parameter V_d (the ratio of the rms to mean value of the atmospheric noise, expressed in dB).

Any attempt to process received signals with wide bandwidths, e.g., 1 MHz, at HF frequencies, must confront the large number of strong narrowband interferers present. Strictly speaking, the following information is needed to model narrowband interference: the distribution function for strength of interferers, the arrival time statistics for interferers, the statistics for frequency location of interferers, the statistics for bandwidths of transmitted interferers, and the fading statistics for interferers. Unfortunately the published measurements actually taken provide information far short of this ambitious list. Nonetheless, it is necessary to model these items. This has been done in [1] by using available measurements, heuristic reasoning, and sometimes arbitrary assumptions.

The resulting parameters needed to specify the model are: the ratio of interference power to noise power in a 1 MHz band, the maximum RMS Doppler spread superimposed on interferer by the propagation path, the maximum interferer bandwidth, Truncated Pareto distribution parameters used to model the distribution function of the interference, average number of coexisting interferers, and average lifetimes of interferers. Default Scenarios for the WBHF simulation used in the GCS are presented in [3].

SOFTWARE

For each channel separate programs are provided which simulate distortion and additive disturbances (e.g., interference). Channel models and additive disturbance programs are normalized so any desired SNR can be achieved by adjustment of scale factors after simulator output files have been generated. Modifying the Default Scenarios is straightforward, so software can be upgraded when additional experimental data is available. The software has been programmed in ANSI C and developed in a UNIX environment on a SUN workstation. Both Motif Windows and command-line scripts can be used for entry of parameters. This software together with some supporting documentation will be made available via the Internet.

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