Implementation of a Real-Time Satellite Channel Simulator

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Abstract

This paper is focused upon implementation aspects of a real-time simulator applicable to narrowband land mobile satellite channels. The satellite channel is mainly affected by shadowing. If a direct signal component exists (line of sight (LOS) conditions), the channel is in a so-called *good/clear* state and the probability density function (pdf) of the signal amplitude is Rician distributed. The shadowed state (*bad/blocked* state) is modeled by a Rayleigh distribution of the signal amplitude whereat, with respect to the relative slow shadowing process, the mean power of the Rayleigh fading component is lognormal distributed. The transitions between blocked and LOS periods modeled by a two state Markov chain. In order to regard the multipath propagation, the core software procedure of the simulator is a Rayleigh fading generator incorporating a flexible (user definable) spectrum shaping to take into account Doppler effects due to mobility of the user and movements of the satellite. The real-time channel simulator is a useful tool to demonstrate the influence of the channel on mobile communication in laboratory or teaching purposes. In response to experimenters concerns, arbitrary RF-modules can be connected to the I/Q connectors of the simulator. The baseband channel simulator software runs on a high-performance TMS320C6701 DSP platform

1 Introduction

In the last years, non-geostationary satellite systems like LEO (Low Earth Orbit) systems became more and more important. Especially in areas with small population or low infrastructure, satellite communication is superior to terrestrial mobile communication. Satellite systems can also be used complementary to existing communication networks in order to increase the availability of service. The main difference between satellite and terrestrial systems is of course the transmission channel. In order to plan future or improve existing systems, it is indispensable to simulate the physical behavior of the propagation paths.

Shadowing is the major problem of mobile satellite communication. Due to low elevation angles of LEO systems, obstacles like buildings or trees prevent from a permanent line-of-sight (LOS) connection between the mobile user and the satellite. Also, in contrast to geostationary satellite systems, multipath propagation is not negligible.

This paper is organized as follows. In chapter 2 a channel model for a land mobile satellite (LMS) channel is presented. Based on this theoretical background, implementation aspects are described in chapter 3. Finally we summarize the paper in the end.

2 Channel Model

The following channel model, which is known as the Lutz model [1], was derived by the DLR (German Aerospace Research Establishment) from measurement campaigns. In figure 1 it is shown that the signal $s(t)$ is affected by a fading component $h(t)$ and a noise component $n(t)$. The noise is assumed to be white and Gaussian distributed (AWGN). The fading is primarily determined by shadowing. In order to take into account this fact, a two state model is adopted. We distinguish between a good state, which

means LOS transmission between satellite and user terminal and a bad state with no line of sight (NLOS) connection. The switching between these two states is generated by a two state Markov process. This process is controlled by the durations D_b and D_g, which indicate a "bad" state and a "good" state, respectively. The time share of shadowing (probability for the bad state) , A, is given by

$$A = \frac{D_b}{D_g + D_b}. \qquad (1)$$

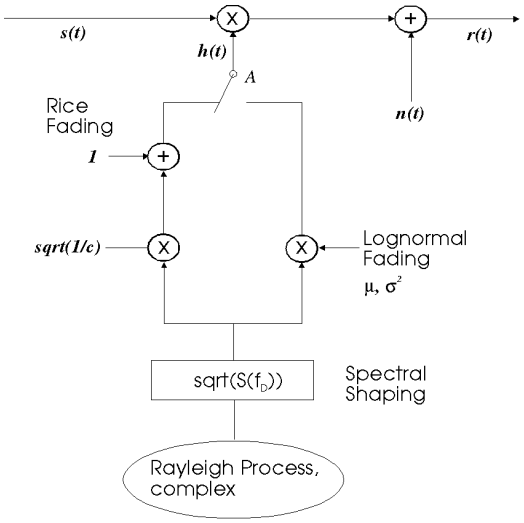

Fig. 1 Lutz model of a LMS channel.

2.1 Good state

The good or clear state consists of multipath fading with a superimposed direct signal component. The received power S follows the Rician probability density function

$$p_{Rice}(S) = c \cdot \exp(-c(S+1)) \cdot I_0\left(2c\sqrt{S}\right) \qquad (2)$$

where I_0 is the modified Bessel function of order zero and c is the Rice factor.

$$c = \frac{power_of_the_direct_component}{average_multipath_received_power} \qquad (3)$$

2.2 Bad state

In the shadowed case, NLOS is assumed and only multipath fading exists. The state is modeled by the Rayleigh lognormal distribution. This means that the momentary received power S is Rayleigh distributed

$$p_{Rayl}(S \mid S_0) = \frac{1}{S_0} \exp\left(\frac{-S}{S_0}\right). \qquad (4)$$

Here, S_0 is the mean multipath power following the lognormal distribution

$$p_{\ln}(S_0) = \frac{10}{\sqrt{2p}\,s \ln 10} \cdot \frac{1}{S_0} \cdot \exp\left(-\frac{(10\log S_0 - m)^2}{2s^2}\right) \qquad (5)$$

where μ is the mean power level decrease and σ is the standard deviation.

Another important affect on the LMS channel is the Doppler fading. Due to the motion of the satellite, there is a large Doppler shift (several 10kHz depending on the orbital height). In addition, the motion of the mobile user causes a Doppler spread. The Doppler shift and the Doppler spread are considered by the spectral shaping of the complex Rayleigh process.
The classical Jakes/Clarke power density spectrum assumed for the bad state is characterized by

$$S_D(f_D) = \frac{2s_m^2}{p \cdot f_{D,\max} \cdot \sqrt{1-\left(\frac{f_D - f_{D,Sat}}{f_{D,\max}}\right)^2}} \qquad (6)$$

,

where $2s^2_m$ is the mean power and $f_{D,max}$ is the maximum Doppler frequency (Doppler spread) derived from the speed of the mobile terminal v_M and the frequency f_0

$$f_{D,\max} = \frac{v_M \cdot f_0}{c_0} \cdot \sin(\Theta). \qquad (7)$$

Here, c_0 is the speed of light and Θ is the elevation angle to the satellite. The Doppler shift caused by the satellite movement $f_{D,sat}$ depends on the speed of the satellite relative to the earth surface

$$f_{D,sat} = \frac{v_{sat} \cdot f_0}{c_0}. \qquad (8)$$

The good state is characterized by the Rice power density spectrum. It is built by the Jakes power density spectrum with an additional spectral line for the direct path

$$S_D(f_D) = \frac{2\sigma_m^2}{\pi \cdot f_{D,\max} \cdot \sqrt{1-\left(\frac{f_D - f_{D,Sat}}{f_{D,\max}}\right)^2}} + \delta(f_D - f_{D,Sat}) \quad (9)$$

3 Practical Implementation

As mentioned before can be two types of time selective fading distinguished. First, a fast (Rayleigh) fading due to mobile motion relative to the scatter sources and, second, slow (log-normal) fading caused by shadowing.

3.1 Rayleigh fading / multipath generator

In order to simulate the diffuse scattering a complex-Gaussian random process is applied to an appropriate digital filter (spectral shaping block). The filter is designed such that it matches to the shape of the desired spectrum and introduces some Doppler spread, but no Doppler shift. Since a unit-energy filter is used, the power of the multipath component is equal to the power of the complex white noise process. This flexible design allows us to approximate any symmetrical Doppler spectra as well as classical Jakes spectrum, which is based on the assumption of isotropic scattering from all directions. The poles of such filters are very close to the unit circle in the z-plane, stability problems may occur due to finite wordlength effects. We implemented an 8th order cascaded form filter (biquad sections) instead of a direct form filter in order to improve stability.

3.2 Interpolator

Generally, it is efficient to work with baseband components. Therefore, we exclude the Doppler shift (7) due to the satellite movement relative to the mobile, which enables us to reduce the sample rate of the Rayleigh fading generator drastically. The necessary sample rate conversion is done by linear interpolation. The resulting spurious spectral components caused by this imperfect method can be neglected [5]. The interpolation factor can be calculated as follows. Starting from the normalized Doppler spread

$$\Omega_{D,\max} = 2\pi \cdot \frac{f_{D,\max}}{f_s} \quad (10)$$

and the normalized cut-off frequency of the spectral shaping filter, which results from the filter design procedure

$$\Omega_{cut} = 2\pi \cdot \frac{f_{cut}}{f_s}, \quad (11)$$

were f_{cut} is the cut-off frequency and f_s is the sample rate. We can formulate the desired interpolation factor I as a quotient of

$$I = \left\lceil \frac{\Omega_{cut}}{\Omega_{D,\max}} \right\rceil, \quad (12)$$

where $\lceil\ \rceil$ is the fixed integer part.

From this point, one can see that the sample clock (oversampling factor) of the multipath generator directly depends on the chosen filter cut-off frequency.

3.3 The complex Gaussian noise source

Superposition of identical distributed random variables is commonly used in order to produce a Gaussian noise source. The main drawback of this method is that many (theoretical infinite) independent random numbers are required for a good approximation. Furthermore, the falling edge according to $\exp(-x^2)$ will be insufficient approximated for big values of x [8]. However, this is an important factor, in order to obtain accurate error probability simulation.
As a consequence, we use the Box-Muller method for generating random deviates with a normal distribution. In order to obviate trigonometric function calls, the algorithm is modified without loss in accuracy [6].

3.4 Doppler shift

As stated in the previous section, the Doppler shift introduced by the satellite motion relative to the mobile is excluded from the multipath generator. Figure 3 shows its separation into a satellite and a terrestrial process [7]. Doppler shift is also applied to the LOS component when the good state occurs. In order to reduce computing time consumption, the complex rotation factor (sin/cos) is provided by a lookup table.

3.5 Log-normal fading

The log-normal fading process represents the shadowing due to obstacles in the propagation path. It is necessary to specify a time series model for the log-normal process, merely the mean and standard derivation for the log-normal distribution function are published in [1]. Therefore, we employ the following simple model: when the bad state occurs, a value for the slow fading factor is chosen randomly from the appropriate log-normal distribution and held

constant over the whole duration as long as the state is maintained.

3.6 Markov chain model / state switching

The state switching takes into account that the mobil user motion can be translated in series of environmental changes.
As mentioned before, Lutz et al [1] have presented a "good/bad" two-state Markov chain model. The most important parameters of this model are the fraction of time A when the bad state occurs and the D_g/D_b average distance in meters traveled by the mobile user as long as the good/bad state occurs.
The Markov chain simulation starts by choosing the first state randomly with the probability A for the bad state and 1-A for the good state. In each state, the duration in meters (or seconds using an appropriate vehicle velocity) for which that state persists an exponentially distributed random variable with mean value equal to the average duration of that state (D_g or D_b as the case may be). When one state ends the other state is chosen an another independent exponentially distributed random variable is chosen with the appropriate average duration for that state. If the bad state is chosen, the slow (log-normal) fading factor will updated.
With this in mind, we can get the current state duration from an exponential distribution function

$$D(x) = -D_{g/b} \cdot \ln(x) \qquad (13)$$

where x is a random variable from an uniform distribution function. In order to avoid numerical problems, we replace the term x by 1-x since our uniform random number generator delivers variables in the interval [0,1[.

Figure 3 depicts the whole simulator structure. The satellite-to-ground propagation path delay is represented by τ_{SG} , whereas attenuation factor A_{SG} includes all propagation path losses for the satellite to ground path (free space, atmospheric etc.)[7] . The white Gaussian random number generators are abbreviated with the term 'WGN'.

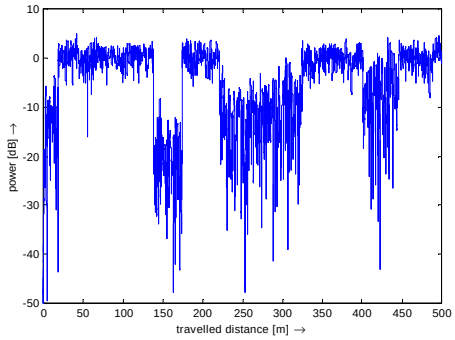

Fig. 2 Typical power versus distance plot.

4 Summary and Outlook

In this paper the implementation of a LMS channel model is presented. After the description of the theoretical background, implementation aspects are discussed. A real-time satellite channel simulator for the TMS320C6701 DSP is developed.

Currently, the simulator software runs on a dual TMS320C6701 PCI bus board. We plan to utilize the simulator as a standalone system with low-cost C6x-EVM boards.

In the near future, it is also planned to build up a whole LEO satellite communication system. In addition we want to evolve a wideband DSP channel simulator for modern wideband communication systems.

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Authors Profile

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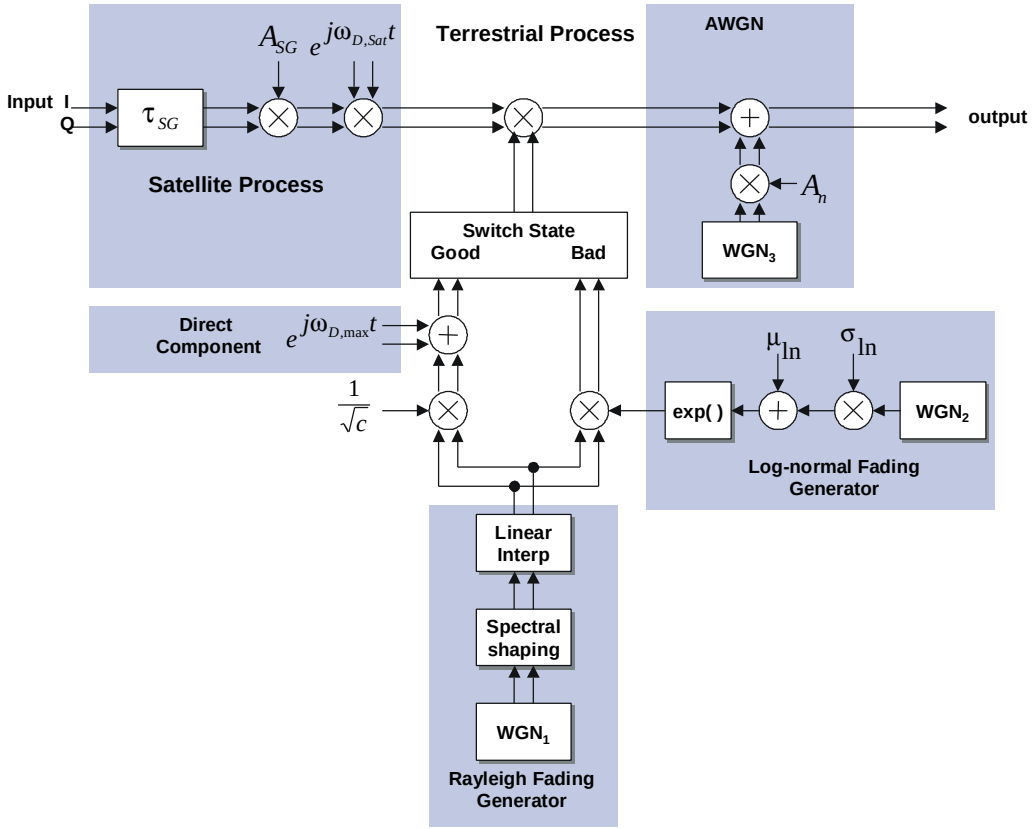

Fig. 3 Narrowband land mobile satellite channel simulator.