Modeling of Land Mobile Satellite Systems Using LCR and AFD

Sonika Singh[1], and R.C.Ramola[2]
[1]Depatment of Electronics & Communication Engineering,
Uttarakhand Technical University, Dehradun (U.K), India.

[2]Depatment of Electronics & Communication Engineering,
ICFAI University, Dehradun (U.K),India.

Abstract- In this paper a multi-state model is developed for land mobile satellite systems, based upon measurements in an urban environment at 1.8 GHz, using Nakagami distribution. Multi-state models can yield more accurate fading amplitude time series than can single state models. Here pdfs have been derived using the second order statistics of LCR and AFD data. This simulator is general, and can be configured to yield existing models and can be used in developing computer simulations of mobile satellite fading channel amplitude time series realizations .

Keywords: Land Mobile Satellite Systems, Fading channels, Rayleigh distribution,Rician distribution,Nakagami distribution ,LCR,AFD.

1. INTRODUCTION

The increasing demand for capacity(integrated voice and data services) and high required link availability over wide areas has led to the concept of utilizing non-geostationary satellite systems as a part of future universal telecommunications. Constellations of low-earth orbit (LEO), medium earth orbit (MEO), and highly elliptical orbit (HEO) satellites have been proposed to serve the needs for lower path losses and higher elevation angles. In addition, LEO and MEO systems often employ satellite diversity to improve performance. In this case, correlations between links to multiple satellites must be studied in order to assess performance. A detailed characterisation of the mobile satellite channel in all types of environments over the whole range of elevation angles and for all frequency bands allocated to mobile satellite services (MSS's) is of great importance to system engineers. Many experiments have been conducted in suburban, rural, open, wooded, and mountainous areas for elevation angles from 13^0 to 80^0 [1] at UHF, L and S bands. A number of researchers. e.g., Loo [4] and Lutz [5], have attempted to use empirical data to develop fading probability density functions (pdfs) for modeling mobile satellite channels. The Lutz model distinguishes between time intervals with high-received signal power ("good" or unshadowed channel state) and time intends with low power levels ("bad" or shadowed channel state). The good channel state corresponds to an unobstructed (unshadowed) signal path between the transmitter and the receiver, and the bad state corresponds to areas to where the direct (or "line-of-sight") signal is shadowed by obstacles. In the Lutz model a Markov model is used to approximate the characteristics of the switching process between the good and bad states.

The multi-state model of [2] provides analytical expressions for the probability density function (pdf) of received signal envelope in a mobile satellite channel, using average fade duration (AFD) and level crossing rate (LCR) data obtained from land mobile satellite system (LMSS) propagation experiment conducted at 1.8 GHz, at the Athens city center for high-elevation angle channels [3]. The transmitter platform used was a helicopter flying in predetermined paths to simulate high-elevation angle (60^0 , 70^0, and 80^0) communication. A land vehicle specially prepared to accommodate the receiver system was performing the channel recordings. Four narrow streets with large building blocks were selected as representatives, and the statistical analysis presented included cumulative distributions functions, level crossing rate (LCR), average duration of fades (AFD), and fade and unfade duration distributions. A composite pdf model based upon a Nakagami distribution was developed. This multi-state model divides the fading pdf into two "regimes" similar to the Lutz model, an unshadowed regime and a shadowed regime. The composite pdf is the sum of these two pdfs, weighted by their respective probabilities of occurrence. The differences between the model in [l] and those in [4] and [5] lies first in that in [2], the data for an urban environment is used and moreover, a different approach is employed, based upon measured data for level crossing rate (LCR) and average fade duration (AFD). In this simulation Nakagami-m model has been used for fading amplitude distribution in each of the states:

$$P_N(x,m,P)=\frac{2m^m}{\Gamma(m)P^m}\,x^{2m-1}\exp\left(-mx^2/P\right) \quad (1)$$

where *P,* the average power in the distribution is equal to $E(x^2)$, and the parameter *m* is the "shape" parameter. The parameter *m* is somewhat analogous to the Rician k-factor in Rician fading [6]. The Nakagami distribution has been used here as it is more general in nature and can accommodate both Rayleigh and Rician model as a special case. Also, it offers great flexibility and accuracy in matching both experimental data and various well-known theoretical distributions [6].

2. MODEL DEVELOPMENT

In this simulation firstly, a random fading time series is generated according to the analytical model derived in [2], using the technique given in [7].Thus time series represents the channel amplitude process within a single state. The statistics of the generated Nakagami time series have been extensively verified against theoretical statistics for the given parameters. The fading time series is used to represent the fading amplitude during periods the channel is in a single "state". To create the multi-state fading time series Markov model is used for the switching process, that switches between fading states (shadowed or unshadowed), with a given set of transition probabilities. These transition probabilities are also based upon the measurements to the largest extent possible. This two-state simplification of the wireless channel behavior is also known as a Gilbert-Elliot model [6], Nakagami distribution can model conditions varying from Rayleigh to Rician and beyond, although here we have Nakagami fading within each state, in addition to transitions bctwccn states. Putting together the single-state fading generators and the Markov switching generator yields a new multi-state time series that represents the fading channel envelope time series. The *pdf* for this model can be represented as

$$P_Z(x)=\sum \alpha_K P_N(x,m_K,P_K) \quad (2)$$

where the values of *m* and *P* for the shadowed state are denoted *mL* and *PL,* and subscript "2" is analogously employed for the unshadowed state. The constants α_1, and α_2 are normalized to agree with the measured cumulative fade probability (probability that the channel is in a given fade state), and also ensure the composite pdf has unit area. A block diagram of the fading simulator is given in Fig. 1

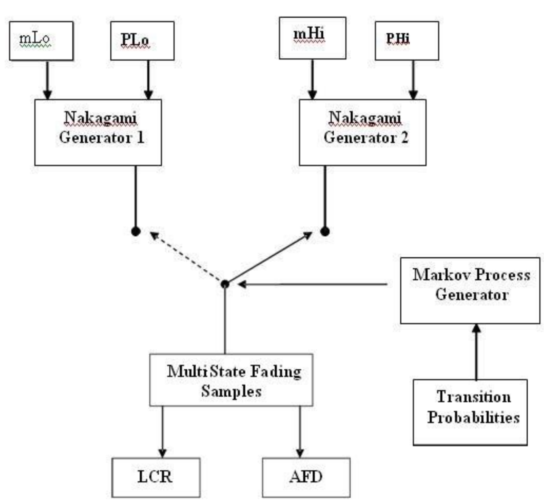

Fig. 1. Multi-state fading simulator model.

In Fig. 1 mLo and mHi represent the shape factor and PLo and PHi, the average power in the distribution respectively. For the first Nakagami generator (Nakagami 1 in Fig. 1) used to generate the fading samples corresponding to the bad or shadowed state, while mHi and PHi represent the "m" and "P" values corresponding to the good or unshadowed state. From eq.(2) it can be observed that the pdf of the model comprises the addition of two different Nakagami generated time series weighted by their respective probabilities of occurrence. The switching between the two Nakagami generators according to their "state probabilities" is accomplished using the Markov switching generator. A brief description of the steps used in the model development are as follows:

a). The first step is data gathering. The data used in the initial model development was gathered from experiments conducted as described in [3]. The Land Mobile Satellite System (LMSS) propagation experiment at 1.8 GHz was conducted in Athens, Greece for high elevation angle channels. A land vehicle specifically prepared to accommodate the receiver system performed the channel recordings. Four narrow streets with large building blocks were selected as representative and the statistical analysis presented included time series recordings. Cumulative distributions functions (cdf), level crossing rate (LCR), average duration of fades (AFD); fade and unfade duration distribution. For the model developed in [2],only the AFD and LCR data and a single point on the cdf, are required.

b). The second step is curve fitting. Models based on empirical data, that attempt to find pdf s must make some assumptions, partition the data and then apply some sort of curve fit. Here. LCR data is used obtained from the data by creating thresholds. In addition to the LCR data, the AFD is used, which is derived from the LCR and actual fading time series. These two functions

are directly related to the desired fading pdf via a first order differential equation. The generic expression for the average fade duration for a fade below a level of R dB (beneath the mean amplitude) is [6].

AFD(R)=cdf(R/LCR(R) (3)

where LCR(R) is the level crossing rate at level R and the distribution function cdf(R) is the integral of the pdf px(x), from 0 to R. The pdf px(x) is the probability density function of the time-varying fading envelope x(t), with R=20log(x). From (3), the explicit expression for the function, px(x) is then

px(x) = d/d(x)[LCR(x)AFD(x)
= L(x)A'(x)+A(x)L'(x) (4)

Where L denotes *LCR* , A denotes AFD and the primes denote derivatives. It is found that the functional from of the LCR(R) is identical to the Nakagami form when the *pdf* was Nakagami. We curve fit to the LCR and AFD data to obtain the *"m"* factor of the Nakagami pdf and the average power "P" in the distribution using the least mean square error method. Thus for each state the Nakagami pdf parameters m and *P* of eq.(4) have been obtained.

c). These *m* and *P* values from step 2 are used as inputs to the Nakagami (single-state) fading generator. Thus generator is based upon the development in [7].

d). The final step involves generating the switching process that models switching between the two regimes obtained. A markov switching generator is used similar to the one used in [5]. As noted in step 2 the data from step 2 is used to obtain "state probabilities", the probabilities of being in a fading state.

For the model developed in [2], the choice of two regimes was made for the following reasons:

(i) convenience and agreement with a visual "fit"

(ii) to agree with the physically justified px(x) division of prior models (Lutz , Loo),

3. RESULTS

The output of the simulator is shown in Fig. 2. where the fading channel amplitude in dB versus time, is shown for a two-state case. The Nakagami parameter (m,P) values of (10,1) and (1, 0.01) are used for the unshadowed and shadowed states, respectively. The time series is filtered to induce correlation in the time series which occurs in actual channels also. The filter bandwidth here is approximately 10% of the sampling rate. This represents very rapid fading.

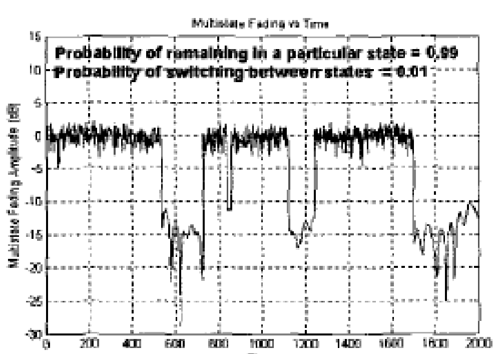

Fig. 2. Fading amplitude time series illustrating

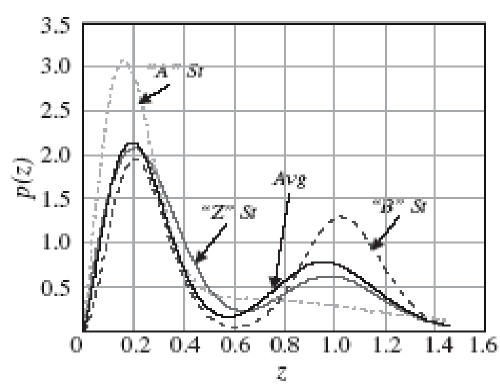

Fig.3 Derived pdfs for 60^0 elevation angle for three

two-state fading.

For the identical regime boundaries, multi-state pdf are derived by obtaining an average value of the pdf parameters *m* and *P*; and an average value of state probability for each regime. The result for three streets at 60^0 elevation angle is shown in Figure 3. The simulation results are validated against the original measured data of [3] by comparing the second order statistics of AFD and LCR gathered from multi-state simulation with those of the original data [3], where, the data in [3] has been used in the derivation of the model in [2]. An example result is shown in Fig.4,

streets .

where the LCR for a single-state case is shown, with the Nakagami parameter m=6.5. Good agreement between simulation and measured data has been observed.
Figure 5. shows the LCR plot for a two state case. Here the first state (bad or shadowed) has the Nakagami parameters m=1 and P = 0.002, while the second state parameters are m = 12 and P = 1.1. The measured data is the data gathered from one of the streets on which the propagation experiments were conducted.

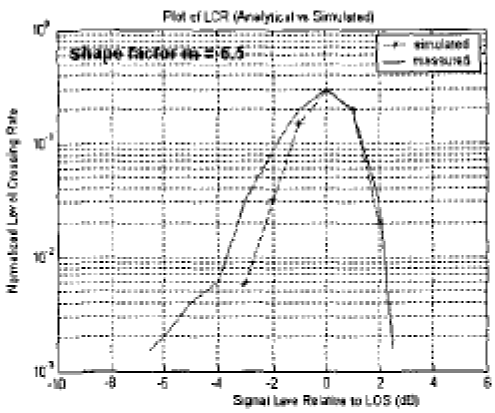

Fig. 4. Normalized LCR vs relative fade level

. 5. N

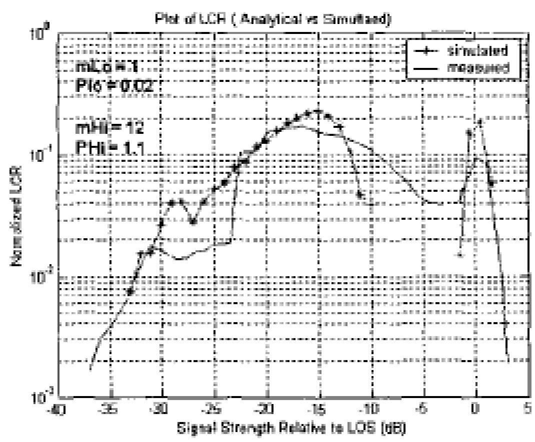

Fig. 5. Normalized LCR plot for a 2-state regime.

CONCLUSIONS

In this paper a multi-state model for the mobile satellite channel has been developed , based upon measurements in an urban environment at 1.8 GHz. The new set of pdfs was derived via the use of level crossing rate and average fade duration data, using Nakagami distribution function for the pdf and LCR. The model development consists of obtaining curve fits to the measured LCR and AFD data using the Nakagami and integral function forms obtained from solution of the differential equation defining the relationship between LCR, AFD, and the fading pdf. The curve fits provide the resulting Nakagami pdf parameters. The procedure has been validated by comparing the cdfs generated from the model pdfs to measured cdf data. This simulator is general. and can

be configured to yield existing models and can be used in developing computer simulations of mobile satellite fading channel amplitude time series realizations The paper concludes that the signal fading is strongly environment dependent, particularly in urban streets and is greatly affected by channel states. The width of the streets, average height of the building blocks, and vegetation at the edges of the streets dominate the channel behavior. The signal attenuation increases as the elevation angle decreases. Indeed, the presence of tall trees on the sidewalks along narrow roads may shadow the transmitted signal and therefore is responsible for increased fade depths even at an elevation angle of 80^0 .

.

Acknowledgments
The authors would like to thank Professor Dharmendra Singh,(Electronics & Computer Science Engineering Department, I.I.T Roorkee, India) for his continuous support and valuable suggestions.

REFERENCES

[1] J. Goldhirsh and W. J. Vogel, "Roadside tree attenuation measurements at UHF for land-mobile satellite systems," IEEE Trans. Antennas Propagation, vol. 35, pp. 589–596, May 1987.
[2] D. W. Matolak, "On The Multi-state Modeling of Mobile Satellite Channels": Proceedings of MILC0A.I 2000. Oct 2000.
[3] A. Kanatas, N. Papadakis. P, Chatzopoulos. T. SofOS. P. Constantinou. "Land-Mobile Satellite Channel Measurements in Athens City Center at 1800 MHz." Proceedings of the 1997 International Mobile Satellite Conference, pp. 169-175. Pasadena, CA, June 16-18, 1997.
[4]C. Loo. J. S. Butterworth "Land Mobile Satellite Channel Measurements and Modeling," Proceeding of theIEEE. vol. 86, No.7. July 1998.
[5] E. Lutz. D. Cygan M. Dippold, F. Dolainsky, and W. Papke, "The Land Mobile Satellite Communication Channel-Recording. Statistics. and Channel Model." IEEE Transactions on Vehicular Tech., vol. 40, No. 2, May 1991.
[6]G.L. Stuber, Principles of Mobile Communication.Kluwer Academic Publishers. Boston MA, 1996.
[7] M. D. Yacoub, 1. Bautista, L Guedes. "On Highcr-Order Statistics of the Nakagami-m Distribution" IEEE Trans. Vehicular Tech., vol. 18. no. 3. pp. 790-794, May 1999.
[8]Zheng Y.R and Xiao Chengshan. 2003., Simulation Models with Correct Statistical Properties for Rayleigh Fading Channels, IEEE Transactions on Communications, vol 51, no.6, pp. 920-928.
[9]Babich F, Lombardi G.2000. "A Markov model for the mobile propagation channel, IEEE Transactions on Vehicular Technology", 49(1):63–73.
[10]Richharia M, Trachtman E. Inmarsat's broadband mobile communication system. Workshop Entitled Advances in Satellite Communications: New Services and Systems, Co-located with Globecom '05, St. Louis, MO, December 2,2005.
[11].Martinez RM, de Domingo MC, Guerra Expo´sito JA. SATSIX PROJECT: a first approach to IPv6 over Satellite Networks. Proceedings of the 16th IST Mobile and Wireless Communications Summit, 2007, July 1–5, 2007; 1–4.
[12]Fontan P.F, Castro M.V, Cabado C.E ,Gracia P, and Kubista E , "Statistical Modeling of the LMS Channel" IEEE Transactions on Vehicular Technology, vol. 50, No. 6, 2001.
[13]Mohamed Ibnkahla, Q.M.Rahman, A.Sulyaman, "High- Speed Satellite Mobile Communications: Technologies and Challenges", Proceeding of the IEEE, vol. 92, No.2,2004.
[14]Chini Paolo , Giovanni GiambeneA,y and Sastri Kota,"A survey on mobile satellite systems,"International Journal Of Satellite Communications Syst.Network 2010; 28:29–57.
[15]Kota SL, Pahlavan K, Leppanen P.Broadband Satellite Communications for Internet Access. Kluwer Academic Publishers: Hingham, MA, 2004