Error Rate Based SNR Estimation in the Railway Satellite Communication Environment

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***Abstract*— The potential of an SNR estimation technique for use in links subject to multipath propagation and periodic shadowing is investigated. The proposed SNR estimator relies on the bit error rate of un-coded pilot sequences. The estimator's performance in the presence of Ricean fading, periodic shadowing and rain attenuation is analyzed by means of simulations. The proposed technique is shown to provide good estimation performance with reduced complexity compared to existing techniques.**

Keywords-component; Error Rate, Railway Satellite Channel, Satellite Communications , SNR Estimation

I. INTRODUCTION

THE congestion of the lower frequency bands as well as the demand for increased system capacity has resulted in a gradual migration of satellite communication systems to higher bands. In addition, satellite communications to nomadic mobile terminals is receiving increased attention. The migration to higher frequency bands and mobile receiving terminals has resulted in the introduction of adaptive fade mitigation techniques (FMT's) in an effort to maximize system availability times and capacity by ensuring efficient use of the satellite resources. FMT's are therefore tasked with mitigating the slow fading effects experienced by satellite communication systems, the most important of which, in Ku band, is rain attenuation. An example of a satellite communication platform employing adaptive fade mitigation is DVB-S2 [1], the successor of the well known and popular DVB-S platform which employs adaptive coding and modulation (ACM) in order to dynamically adapt the physical layer configuration to real time propagation conditions.

In order to facilitate the operation of fade mitigation techniques such as ACM, the receiver requires knowledge of the propagation conditions and/or link quality in real time. In the case of ACM the most suitable link quality metric is the received signal-to-noise ratio (SNR).

SNR estimation has been the topic of several publications available in the literature. Pauluzzi and Beaulieu have produced a detailed review of some of the best performing techniques for AWGN conditions and compared their performance in [2]. The Maximum Likelihood (ML) and a closely related technique the Square Signal to Noise Variance (SNV) method were shown to be the best performing options. The SNV method was first published in [3] and has also been used in [4] where it is termed SNORE. As far as estimation of the average SNR in Rice fading is concerned, the most promising work can be found in [5] where Chen and Beaulieu propose a moment based method for joint estimation of the Rice Factor K and the average SNR.

In this paper we investigate aspects of SNR estimation on a DVB-S2 platform under the assumption that the receiving terminal is a high speed train. We build upon a previously published SNR estimation technique [6] that relies on the estimation of the un-coded error rate of the link to derive the received SNR. The effects of multipath fading and periodic shadowing, both common in the railway satellite environment, on the estimation performance are analyzed and methods for their mitigation are proposed. Estimation performance is analyzed by means of link level simulations performed using a purpose built MATLAB simulator. Given that the objective of the SNR estimator, viewed as a facilitator for ACM, is to track the slow fading experienced by the signal, simulations are also performed in the presence of rain attenuation.

The paper is organized as follows. Section II contains a brief system scenario outline and the description of the simulation model. In section III the performance of the estimator, as per its original design, in the presence of Rice multipath fading conditions is presented and a performance improving technique is proposed and validated by means of simulations. In section IV we analyze the effects of periodic power arch-induced shadowing and mitigate those effects on SNR estimation. Section V contains a discussion on the work presented in the paper and concludes this contribution.

II. SYSTEM AND SIMULATOR DESCRIPTION

A. *System Overview*

In line with the growing trend for provision of multimedia services to nomadic mobile terminals via satellite, we investigate here a system designed for service provision to high speed train terminals. Each train terminal is treated as an end user and the delivery of data to the individual passengers is out of the context of this document. Data transmission is assumed to follow the DVB-S2 standard [1] with the limiting

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assumption that only QPSK modulation is available. For additional information the reader is referred to [1].

The transmitted symbol rate is set to 20Msps. Given the frame format of DVB-S2 and the transmit symbol rate assumed here, the physical layer frame duration is approximately 17ms and each frame contains 849 pilot symbols time multiplexed with the data. The system is assumed to operate in the Ku frequency band, with the carrier frequency set to 12GHz.

B. *Propagation Impairments*

In the railway satellite environment the propagating signal is subject to multipath propagation, shadowing and blocking caused by obstructions in the propagation path, as well as a periodic shadowing process resulting from the power arches located over the rails. A detailed analysis of the railway satellite propagation conditions can be found in [7]. In this paper we focus our attention to the LOS state of the railway satellite channel with only the periodic shadowing taken into account as far as shadowing and blocking effects are concerned. It should be noted that in this contribution we consider rain attenuation as the most significant effect, as it is the only propagation effect that varies slowly enough for FMT's employed by satellite communication systems to mitigate effectively.

While in the LOS state and neglecting the slow variation of the direct signal component the channel envelope follows a Ricean distribution, expressed mathematically by (1).

$$p_R(z) = \frac{z}{\sigma_0^2}\exp\left(-\frac{z^2+a^2}{2\sigma_0^2}\right)I_0\left(\frac{az}{\sigma_0^2}\right) \qquad (1)$$

In (1) α^2 and $2\sigma_0^2$ are the mean power and the variance of the channel respectively, I_0 is the modified Bessel function of the first kind and order zero and z is the envelope value. As discussed in [7], the *Rice factor K* ($K = \alpha^2/2\sigma_0^2$) characterizing the railway satellite channel is of the order of 17dB. For simulation purposes, the Rice channel has been modeled using the sum of sinusoids method [8] under the assumption of a symmetric spectrum. Calculation of the model parameter values was done according to the method of exact Doppler spreads method presented in [9].

In addition to the fast fading process described above, the propagating signal is also subject to periodic shadowing caused by power supply arches along the rail lines. This has also been modeled as per the methodology presented in [7].

The final propagation effect considered in this contribution is rain attenuation, which is the most significant atmospheric attenuation mechanism in the Ku band. The long term statistics of rain attenuation are discussed in [10], while [11] presents a methodology for creating rain attenuation time series that meet those statistics. This methodology has been implemented in the link level simulator used for this work to facilitate the modeling of rain attenuation in the link.

C. *SNR Estimation*

The SNR estimation technique presented in this paper consists of two steps. As a first step, the *un-coded bit error rate* of the received signal is estimated using the pilot symbols. From [12], the error rate of BPSK or QPSK modulated signal in AWGN is given by:

$$p_e(\rho) = (1/2)erfc\left(\sqrt{\rho}\right) \qquad (2)$$

where ρ is the mean SNR and *erfc* is the complementary error function mathematically expressed as:

$$erfc(x) = \frac{2}{\sqrt{\pi}}\int_x^\infty \exp\left(-t^2\right)dt \qquad (3)$$

Estimation of the un-coded BER is done by comparison of the I and Q branches of the known transmitted pilot sequence with the received pilot sequence, after hard decisions are made on the incoming pilot sequence. Any differences are considered as a bit error and increment an error counter which is then divided by the number of observations to yield the BER estimate. The process can be expressed mathematically as:

$$B\hat{E}R = \frac{1}{2N}\sum_{m=1}^{N}\left[\left(r_i(m)\oplus d_i(m)\right)\left(r_q(m)\oplus d_q(m)\right)\right] \qquad (4)$$

In (4) r and d denote the received and known transmitted pilots respectively, while the subscripts i and q denote the in-phase and quadrature components of the pilot sequences. N is the number of pilot symbols used for each BER estimate, given by the product of the number of pilot symbols per DVB-S2 frame with the number of frames observed.

Once the un-coded BER has been estimated the next step is the derivation of the link SNR. This is done by inversion of (2), resulting in:

$$\hat{\rho} = \left[erfcinv\left(2B\hat{E}R\right)\right]^2 \qquad (5)$$

In equation (5) *erfcinv* designates the inverse of the complementary error function. In practical systems this can either be implemented in the form of a look up table or assuming the existence of an onboard processor can be directly calculated.

D. *Simulator Description*

The investigation of the previously described SNR estimator in the railway satellite environment has been performed using a link level simulator developed in MATLAB. The simulator is time-driven with a time granularity defined by the user-defined transmit rate. The top level block diagram of the simulator is presented in figure 1.

The physical layer framing block follows the DVB-S2 standard and the modulation used is QPSK. The transmit symbol rate has been set to 20Msps which is a realistic value for satellite multimedia systems servicing nomadic vehicular terminals. Channel equalization refers to the compensation of the phase shift caused by the multipath channel. In order to enable evaluation of the SNR estimator performance without the effects of equalization errors, ideal channel equalization is used in the simulations.

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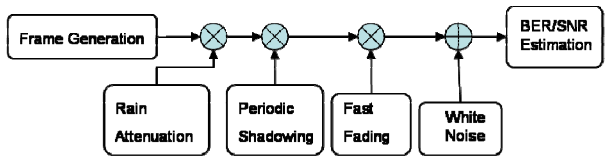

Figure 1. Simulator Block Diagram

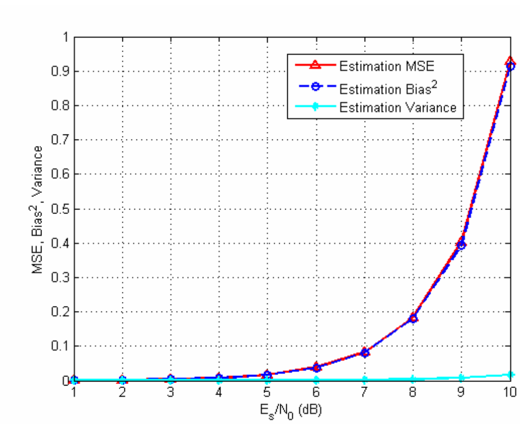

Figure 2. Estimation Mean Square Error, Squared Bias and Variance versus SNR

III. Estimation Performance in Rice Fading

In this section we discuss the performance of the SNR estimator in the presence of Ricean multipath fading only. The periodic shadowing and rain attenuation blocks were deactivated for the production of simulation results presented in this section.

Based on the analysis of the railway satellite channel presented in [7], the multipath channel has been modeled as a Rice process with a Rice factor K=17dB. Simulations for different Rice factor values have not been performed based on two facts. Firstly, the vast majority of the routes followed by high speed trains are located in rural environments, with only the first and last few minutes of the journey taking part in suburban or urban environments. In addition, variation of the Rice factor within a specific environment category has been found to be very infrequent and slow. These two statements indicate that the likelihood of Rice factor variation, as well as the range of that variation, should it occur, are low, and hence performance evaluation for a range of K values is not deemed necessary.

Simulations were run for E_s/N_0 values ranging from 1dB to 10dB in 1dB steps. The two step estimation algorithm used is described by equations (4) and (5). SNR samples were averaged over 100 frames. Given that equation (5) is defined for signals corrupted only by additive white Gaussian noise, the resulting SNR estimates were expected to deviate from the actual SNR somewhat. The purpose of these initial simulations was to characterize and quantify this deviation and identify a method for mitigating it. Figure 2 shows the *mean square error* (*MSE*), the squared *bias* and the *variance* of the estimator, against the actual SNR.

As can be seen in figure 2 the mean square error and squared bias of the estimated SNR values are practically indistinguishable. Given that the mean square error of a random variable x is defined as in (6), we deduce that the MSE of the estimator is dictated primarily by the estimation bias.

$$MSE\{x\} = [Bias\{x\}]^2 + Var\{x\} \tag{6}$$

The cause of the high estimation bias lies in the different error rate observed in AWGN and Rice conditions for the same mean SNR. The error probability in Rice fading is given by [12]:

$$p_{e,Rice}(\rho) = \int_0^\infty p_{e,AWGN}(z^2\rho)\,p_R(z)\,dz \tag{7}$$

In (7) $p_{e,AWGN}$ is the AWGN error function given by (2) and p_R is the Rice envelope pdf given in (1). Clearly, since the Rice pdf depends on the Rice factor, *K*, the estimation bias will also depend on *K*. In addition, as indicated by figure 2 and the inclusion of the *erfc* function in (7), the bias will also be proportional to the mean SNR. However, given the assumption that *K* is limited to or around 17dB, it is reasonable to assume that for our purposes the estimation bias can be considered as a function of only the mean SNR.

The estimation bias curve against actual SNR can be approximated with a third degree polynomial, whose parameter values are acquired by means of curve fitting. The polynomial factors are: $p_0=1.003*10^{-5}$, $p_1=-0.0077$, $p_2=-0.0206$, $p_3=0.0135$. The estimation bias can then be calculated for given SNR value ρ using (8). Figure 3 shows the simulated estimation bias and the analytically calculated bias using (8).

$$Bias_{pred}(\rho) = p_0\rho^3 + p_1\rho^2 + p_2\rho + p_3 \tag{8}$$

After SNR estimation using (5) the true SNR can be calculated by solving the $\rho_{est} = \rho + Bias\{\rho\}$ for ρ, where $Bias\{\rho\}$ is given by (8) and ρ_{est} is the original biased SNR estimate. In order to simplify the calculation of the SNR the cubic term in (8) could be ignored, which results in the roots of the equation being:

$$\hat{\hat{\rho}} = \frac{-(p_2+1) \pm \sqrt{(p_2+1)^2 - 4p_1(p_3-\hat{\rho})}}{2(p_2+1)} \tag{9}$$

In (9), $\hat{\rho}$ is the initial SNR estimate acquired using (5) and $\hat{\hat{\rho}}$ the final SNR estimate after bias compensation. The Bias of the estimator in (9) is plotted in figure 4 against the actual SNR, along with the bias of the original estimator for comparison.

Observation of figure 4 shows clearly the reduction in estimation bias achieved by post processing the original SNR estimates using (9). Although the post-processing of (9) results in a slight increase in the estimation variance, the overall error of the estimator is considerably reduced due to the reduction in estimation bias. This is illustrated in figure 5.

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IV. Effects and Detection of Periodic Shadowing

As mentioned in section II B., one of the propagation effects associated with the railway satellite environment is periodic shadowing caused by power arches along the rail lines. The frequency and duration of these shadowing effects depends on the dimensions of and the distance between power arches as well as the speed of the train terminal. In accordance with [7] the power arches have been assumed to be spaced approximately 50m apart, resulting in a 600ms shadowing period and a 6ms shadowing duration for each event, assuming a train speed of 300km/h.

The depth of the power arch induced fading events is approximately 10dB below the local mean SNR. Consequently, data received during a shadowing event are received in error. In addition to the corruption of portions of the received signal, these deep fades also affect the SNR estimates by causing them to deviate from the actual mean SNR. Given that the average SNR is averaged over several physical layer frames using a moving average filter, this deviation in the estimates will persist until the estimate acquired over the last shadowed frame exits the estimation buffer. Consequently, while each shadowing event will cause the SNR estimates of several frames to be significantly lower than the actual mean SNR. If these estimates are used to facilitate fade mitigation, and in particular ACM, then the resulting mod-cod scheme choice will be suboptimal as it will be based on an underestimated SNR value.

Our goal in this section is to illustrate that a simple method exists for the detection of such periodic shadowing events and their exclusion from the calculation of the average SNR. In this manner, the most efficient physical layer configuration that can be used is selected, thereby ensuring throughput maximization for those portions of time that the signal is not shadowed.

Shadowing event detection can be performed by monitoring of the level of variation of the link BER. Slow processes such as rain attenuation and path loss variation due to terminal motion only cause limited variation in the link BER over a short time span. In contrast, the shadowing process investigated here causes rapid fluctuations in the received SNR, thereby causing significant changes in the link BER. Let us define a BER variation measure as:

$$\Delta BER = \left| \frac{E\{BER\}_{i-1} - BER_i}{E\{BER\}_{i-1}} \right| \quad (10)$$

In (10) $E(BER)_{i-1}$ is the smoothed BER estimate for frame *"i-1"*, BER_i is the single frame BER estimate for frame *"i"* and the operator || designates the absolute value operation. We have found the value of 0.5 to be a good threshold value for ΔBER. This threshold value is used as follows. After the reception of each physical layer frame, the frame BER is calculated according to the methodology described in the previous sections, using the pilot symbols contained within that frame. This single frame BER estimate is then compared the smoothed BER estimate of the previous frame, obtained by filtering the past 100 frames. These two BER estimates are then inserted into (10) and the normalized BER difference ΔBER is calculated. If the value of ΔBER exceeds the threshold then the BER estimate of frame *"i"* is discarded and the mean

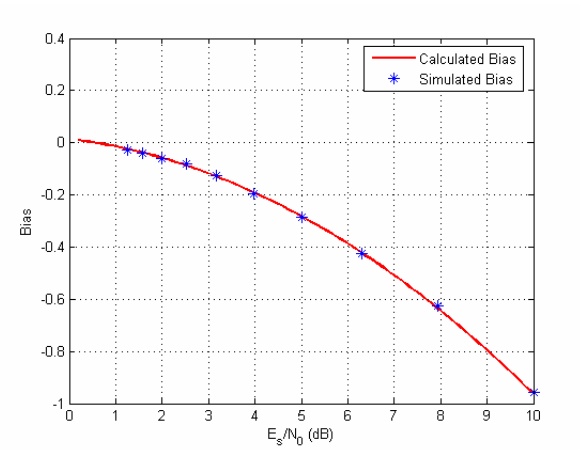

Figure 3. Simulated and Analytically Calculated Estimator Bias in Rice Fading

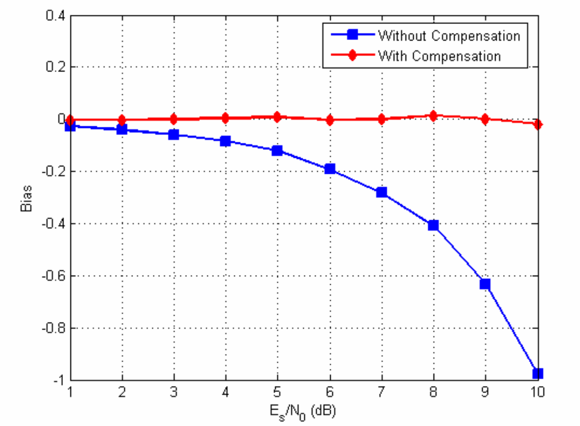

Figure 4. Estimation Bias with and without Bias Compensation

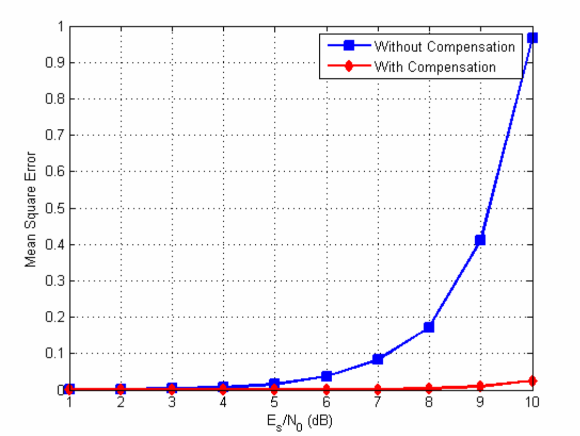

Figure 5. Estimation MSE with and without Bias Compensation

SNR estimate is kept fixed to its previous value. If the value of ΔBER does not exceed the threshold then this single frame BER estimate is used along with the previous 99 estimates to produce a new smoothed BER estimate, which is subsequently used to generate a link SNR estimate. The result of this process is that the BER estimates obtained from shadowed frames are discarded and not allowed to ultimately degrade the mean SNR estimation process.

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To illustrate the improvement in estimation performance, figure 6 shows the estimation MSE achieved with and without the use of fading detection, for an average SNR range of 1dB to 10dB in 1dB steps.

The performance improvement achieved in the presence of periodic shadowing by use of the proposed shadowing detection technique proposed in this section becomes obvious in figure 6. The mean square error of the estimator is reduced significantly, as a result of the reduction in both the estimation variance and bias that is caused by the periodic shadowing process.

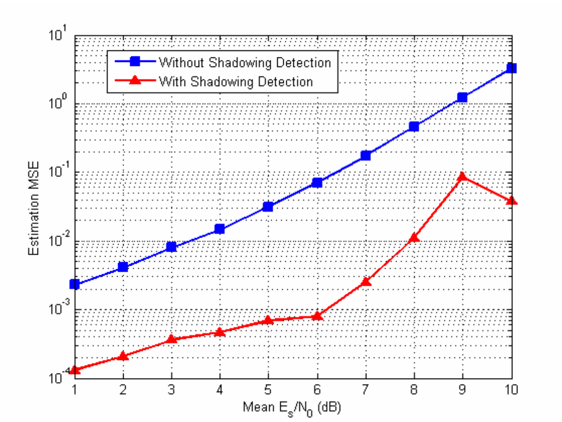

Figure 6. Estimation MSE with and without Shadowing Detection.

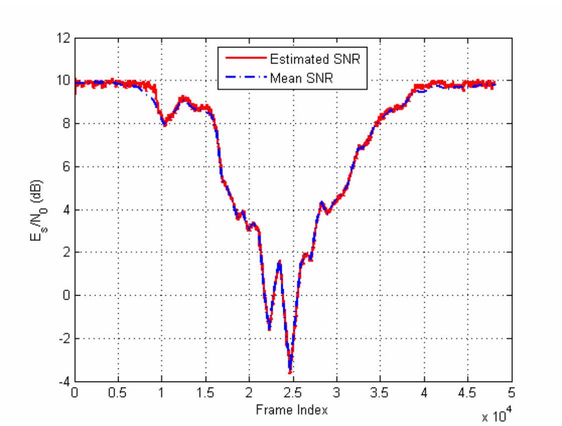

Figure 7. Actual Mean and Estimated Mean SNR in Rain Attenuation.

V. SNR Estimation in the Presence of All Propagation Impairments

In this section we present the performance of the SNR estimator when all propagation impairments considered in this paper are active. The purpose of this section is to illustrate that the estimator is capable of accurately estimating the slow SNR variations caused by rain attenuation.

For this simulation scenario the SNR was fixed to a value of 10dB and the mean received SNR was caused to vary by a rain attenuation time series. Fast fading and periodic shadowing were then applied to the signal. In general, the optimum value for the *ΔBER* parameter depends on the maximum fade slope that the estimator is required to track. Figure 7 illustrates the attenuation time series used and the time series of the SNR estimates. It is clear that the estimated SNR values are in very good agreement with the actual mean SNR. We can therefore safely deduce that the proposed estimator is capable of providing accurate average SNR estimates that follow the slow fading process closely, despite the presence of fast fading and periodic shadowing the further corrupts the signal.

References

[1] ETSI EN 302 307 V1.1.1 ETSI, Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications (2005-03).

[2] D.R. Pauluzzi, C. Beaulieu, "A Comparison of SNR Estimation Techniques for the AWGN Channel", IEEE Transactions on Communications, Vol. 48, No. 10, October 2000, pp1681-1691

[3] C.E. Gilchriest, "Signal-to-noise monitoring", JPL Space Programs Summary, Vol. IV, No. 37-27, pp. 169-184, June 1966

[4] S. Cioni, R. De Gaudenzi, R. Rinaldo, "Adaptive Coding and Modulation for the Forward Link of Broadband Satellite Networks", IEEE Globecomm 2003

[5] Y. Chen, N. C. Beaulieu, "Estimation of Ricean K Parameter and Local Average SNR from Noisy Correlated Channel Samples", IEEE Transactions on Communications, Vol. 6, No. 2, February 2007.

[6] P. Skoutaridis, C. Kasparis and B.G. Evans, "Adaptive Coding and Modulation for Vehicular Satellite Communications", 25th AIAA/ICSSC, Seoul, Korea, April 2007.

[7] G. Sciascia et al.: Statistical Characterization of the Railroad Satellite Channel at Ku-Band. In: Proc. of International Workshop of COST Actions 272.

[8] M. Patzold, et al., "A Deterministic Digital Simulation Model for Suzuki Processes with Application to a Shadowed Rayleigh Land Mobile Radio Channel," IEEE Transactions on Vehicular Technology, Vol. 45, No 2, May, 1996, pp. 318-331.

[9] M. Patzold, F. Laue, "Level-Crossing Rate and Average Duration of Fades of Deterministic Simulation Models for Rice Fading Channels", IEEE Transactions on Vehicular Technology, Vol. 48, Issue 4, July 1999, pp. 1121-1129.

[10] Recommendation ITU-R P.618, "Propagation data and prediction methods required for the design of Earth-Space Telecommunication Systems". ITU-R Recommendation P.618-8. International Telecommunication Union (ITU), Geneva, 2003.

[11] Gremond B.C., Miodrag F., "Spatio-Temporal Rain Attenuation Model for Application to Fade Mitigation Techniques", IEEE Transactions on Antennas and Propagation, Vol 52. No. 5, May 2004.

[12] J.G. Proakis, "Digital Communications", 3rd Edition, McGraw-Hill International, Electrical Engineering Series, 1995, ISBN: 0-07-113814-5

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