The Outage Probability of the Satellite Telecommunication System in the Presence of Fading with Switch and Stay Combining on Satellite and Earth Station

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Abstract—**In this paper, the satellite communication system consisting of the earth transmitting station and the satellite transponder was considered. Switch and Stay Combining (SSC) diversity technics are used on receiving satellite and receiving earth stations to reduce fading influence to the system performances. The presence of Nakagami-*m* and Rice fading on receiving satellite and receiving earth stations is observed. The probability density functions (PDFs) of the signal at the Earth receiver station output are determined for different parameters. The outage probability, as standard performance criterion of communication systems operating over fading channels, is calculated under upper conditions. The results are shown graphically in several figures and made to assess the influence of various parameters. This is very useful for mitigation the influence of fading in the design of satellite communication systems in the presence of fading**

Keywords- satellite telecommunication system; Nakagami-m fading; Rice fading; SSC combining; probability density function; the outage probability.

I. INTRODUCTION

Satellite communication systems are now a major part of most telecommunications networks as well as every-day lives through mobile personal communication systems and broadcast television [2]. A fundamental understanding of such systems is therefore important for a wide range of system designers, engineers and users.

The fading and shadow effect are factors which degrade the system performances in telecommunication systems at the most. They derogate the power of transmitted signal. When a received signal experiences shadow effect or fading during transmission, its envelope and phase fluctuate over time. The most often are Rayleigh, Rice, Nakagami, Weibull and log-normal fading, and they are considered in the literature [3], [4].

Rayleigh and Rice distributions can be used to model the envelope of fading channels in many cases of interest The Rice fading is present very often in wireless telecommunication systems with direct line of site. When the fading appeared in the channel because of signal propagation by more paths, and dominate component exists because of optical visibility from transmitter to receiver, signal amplitude is modeled by Rice distribution [5]. It has been found experimentally, that Nakagami distribution offers better fit for wider range of fading conditions in wireless communications [6].

In wireless communication systems, various techniques for reducing fading effect and influence of shadow effect are used. Such techniques are diversity reception, dynamic channel allocation and power control. Upgrading transmission reliability and increasing channel capacity without increasing transmission power and bandwidth is the main goal of diversity techniques.

Diversity reception, based on using multiple antennas at the receiver, space diversity, with two or more branches, is very efficient methods used for improving system's quality of service, so it provides efficient solution for reduction of signal level fluctuations in fading channels. Multiple received copies of signal could be combined on various ways.

Several principal types of combining techniques can be generally performed by their dependence on complexity restriction put on the communication system and amount of channel state information available at the receiver. Combining techniques like maximal ratio combining (MRC) and equal gain combining (EGC) require all or some of the amount of the channel state information of received signal. Second, MRC and EGC require separate receiver chain for each branch of the diversity system, which increase its complexity of system.

Maximal-Ratio Combining (MRC) is one of the most widely used diversity combining schemes whose SNR is the sum of the SNR's of each individual diversity branches. MRC is the optimal combining scheme, but its price and complexity are higher. Also, MRC requires cognition of all channel parameters and admit in the same phase all input signals, because it is the most complicated for realization [7]-[9].

Signal at the EGC diversity system output is equal to the sum of its' input signals. The input signals should be admitted in the same phase, but it is not necessary to know the channel parameters. Therefore, EGC provides comparable performances to MRC technique, but has lower implementation complexity; therefore, it is an intermediate solution [10].

One of the least complicated combining methods is selection combining (SC). In opposition to previous combining techniques, SC receiver processes only one of the diversity branches, and it is much simpler for practical realization. Generally, selection combining, selects the branch with the highest signal-to-noise ratio (SNR), that is the branch with the strongest signal [10], [11], assuming that noise power is equally distributed over branches. Abu-Dayya and Beaulieu in [12] consider switched diversity on microcellular Ricean channels.

Similarly to the previous approaches, there is type of selection combining that chooses the branch with highest signal and noise sum. In fading environments, where the level of the cochannel interference is sufficiently high comparing with the thermal noise, SC selects the branch with the highest signal-to-interference ratio (SIR-based selection diversity) [13].

Switch and stay combining (SSC) is an attempt at simplifying the complexity of the system but with loss in performance. In this case, rather than continually connecting the antenna with the best fading conditions, the receiver selects a particular antenna until its quality drops below a predetermined threshold. When this happens, the receiver switches to another antenna and stays with it for the next time slot, regardless of whether or not the channel quality of that antenna is above or below the predetermined threshold. The consideration of SSC systems in the literature has been restricted to low-complexity mobile units where the number of diversity antennas is typically limited to two [14], [15]. Furthermore, in all these publications, only predetection SSC has thus far been considered wherein the switching of the receiver between the two receiving antennas is based on a comparison of the instantaneous SNR of the connected antenna with a predetermined threshold. This results in a reduction in complexity relative to SC in that the simultaneous and continuous monitoring of both branches SNRs is no longer necessary.

II. Related Work

An analytical technique well suited to numerical analysis is presented for computing the average bit-error rate (BER) and outage probability of M-ary phase-shift keying (PSK) in the land-mobile satellite channel (LMSC) with microdiversity reception in [16]. The closed-form expressions are found for *L*-branch microdiversity using both selection diversity combining (SDC) and maximal ratio combining (MRC). These expressions are extended to include both M-ary coherent PSK (M-PSK) and differential PSK [M-differential PSK (DPSK)]. Following previous empirical studies, the LMSC is modeled as a weighted sum of Rice and Suzuki distributions. Numerical results are provided illustrating the achievable performance of both M-PSK and M-DPSK with diversity reception. Using measured channel parameters, the performance in various mobile environments for various satellite elevation angles is also found.

An exact analytical technique is presented for computing the average bit error rate (BER) and outage probability of differentially detected PSK in the land mobile satellite channel (LMSC) when L branch maximal ratio combining (MRC) is employed in [17]. Following empirical study, the LMSC is modeled as a weighted sum of Rice and Suzuki distributions.

Empirical studies confirm that the received radio signals in certain cellular systems are well modeled by Nakagami statistics. Therefore, performing relevant systems studies can be potentially useful to a system designer. A very useful statistical measure for characterizing the performance of a mobile radio system is the probability of outage, which describes the fraction of time that the signal-to-interference ratio (SIR) drops below some threshold. A more refined criterion for the outage is the failure to simultaneously obtain a sufficient SIR and a minimum power level for the desired signal. Thus, in [18] the authors derived new expressions for the probability of outage where a mobile unit receives a Nakagami desired signal and multiple, independent, cochannel Nakagami interferers. A salient feature of their results is that the outage expressions do not restrict the Nakagami fading parameter, *m*, to strictly integer values. Furthermore, since the received signals in mobile radio also experience log-normal shadowing, they analyzed the case where the received signals are modeled by a composite of Nakagami and log-normal distributions. The outage probabilities are computed and graphically presented for several cases. The effect of specifying a minimum signal requirement for adequate reception is found to introduce a floor on the outage probability. It is also found that shadowing in macrocellular systems severely degrades the desired quality of service by increasing the reuse distance necessary for a given outage level.

In this paper, the satellite communication system consisting of the earth transmitting station and the satellite transponder was considered. SSC diversity technics are used on receiving satellite and receiving earth stations to reduce fading influence to the system performances. The presence of Nakagami-*m* fading on receiving satellite and receiving earth stations is observed in [1], and the presence of Rice fading on both, receiving satellite and receiving earth stations is observed here. The probability density functions (PDFs) and the outage probability of the signal at the Earth receiver station output are given for different parameters.

Beside generally used first Section, introduction, and the last, conclusion, the paper has further four core sections. The second Section of the paper presents related works, the third one shows and interprets the system model. The statistics of the output SNR is given in the fourth Section and numerical results in the fifth one.

III. System Model

The use of SSC combiner with great number of branches can minimize the bit error rate (BER) [19]. We determined

SSC combiner with two inputs because the gain is the greatest when we use the SSC combiner with two inputs instead of one-channel system. When we enlarge the number of inputs (branches) the gain becomes less. Because of that it is more economic using SSC combiner with two inputs.

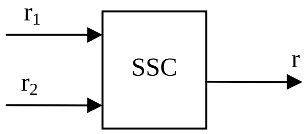

Figure 1. Model of the SSC combiner with two inputs

The model of this system is shown in Figure 1. The signals at the combiner input are r_1 and r_2, and r is the combiner output signal. Let see how the SSC combiner with two inputs works.

The probability of the event that the combiner first examines the signal at the first input is P_1, and for the second input is P_2. If the combiner examines first the signal at the first input and if the value of the signal at the first input is above the treshold, r_T, SSC combiner forwards this signal to the circuit for the decision. If the value of the signal at the first input is below the treshold r_T, SSC combiner forwards the signal from the other input to the circuit for the decision, regardless it is above or below the predetermined threshold. If the SSC combiner first examines the signal from the second combiner input it works in the similar way. The probability for the first input to be examined first is P_1 and for the second input to be examined first is P_2.

There are two diversity branches on satellite and on Earth receiver station. The SSC combining is used on both, receiver satellite and Earth station. System model is shown in Figure 2

Let Nakagami-*m* fading is present on both, receiver satellite and Earth station. The signals at the input are A_1 and A_2. In this case the probability density of signal A, at the satellite station output, is, for $0<A<A_T$:

$$p_A(A) = P_{1A} p_{A_2}(A) F_{A1}(A_T) + P_{2A} p_{A_1}(A) F_{A2}(A_T) \tag{1}$$

and for $A_T<A$

$$p_A(A) = P_{1A} p_{A_1}(A) + P_{1A} p_{A_2}(A) F_{A1}(A_T) + $$
$$+ P_{2A} p_{A_2}(A) + P_{2A} p_{A_1}(A) F_{A2}(A_T) \tag{2}$$

A_T is the threshold of the decision.

The probability density of signal a, at the Earth receiver station output is, for $0<a<a_T$:

$$p_a(a) = P_{1a} p_{a_2}(a) F_{a1}(a_T) + P_{2a} p_{a_1}(a) F_{a2}(a_T) \tag{3}$$

and for $a_T<a$:

$$p_a(a) = P_{1a} p_{a_1}(a) + P_{1a} p_{a_2}(a) F_{a1}(a_T) + $$
$$+ P_{2a} p_{a_2}(a) + P_{2a} p_{a_1}(a) F_{a2}(a_T) \tag{4}$$

The signals at the input are a_1 and a_2, a_T is the threshold of the decision.

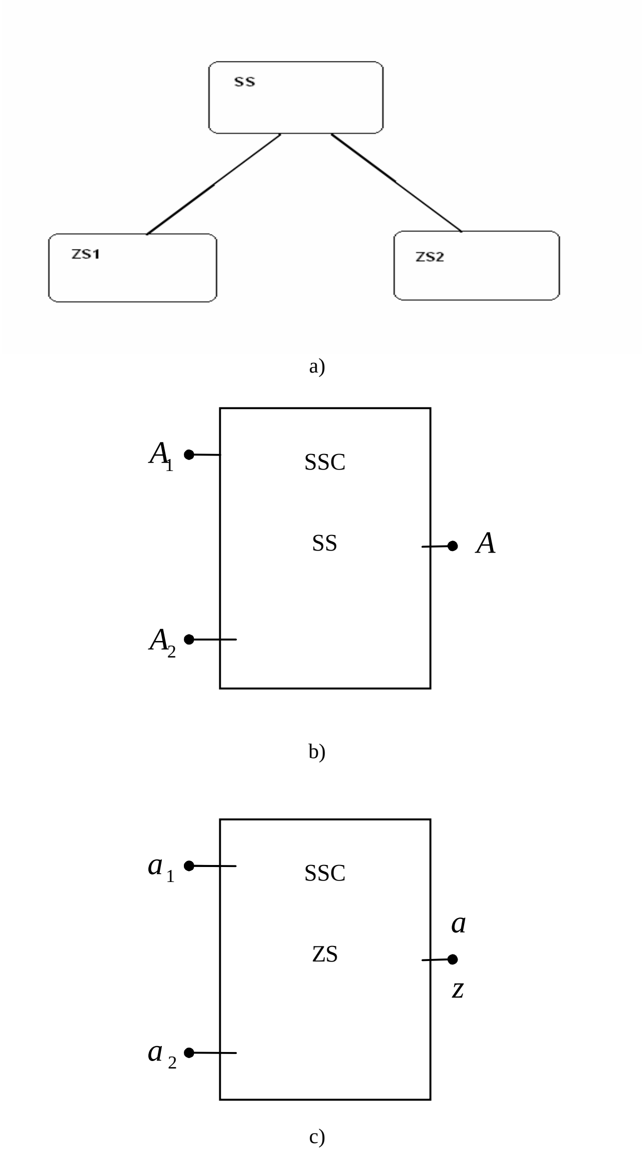

Figure 2. System model - a) entire system; b) Satellite Station (SS); c) Earth Station (ZS)

The signal z at the Earth receiver station output is [2]:

$$z = a\cos\varphi + y_1 = a\frac{A + x_1}{\sqrt{(A+x_1)^2 + y_1^{\,2}}} + y_1 \tag{5}$$

where x_1 and y_1 are the Gaussian components in phase and quadrature, respectively.

The conditional probability density of the signal z is:

$$p_z(z/x_1,y_1,A,a)=\frac{1}{\sqrt{2\pi}\sigma_2}e^{-\frac{\left[z-f_1(a,A,x_1,y_1)\right]^2}{2\sigma_2^{\,2}}} \tag{6}$$

where σ_i, i=1,2, are standard deviation of appropriate variables.

The probability density of the signal z is:

$$p_z(z)=\int dx_1\int dy_1\int da\int dA\frac{1}{\sqrt{2\pi}\sigma_2}e^{-\frac{\left[z-f_1(a,A,x_1,y_1)\right]^2}{2\sigma_2^{\,2}}}\cdot$$
$$\cdot p_A(A)\,p_a(a)\,p_{x_1y_1}(x_1,y_1) \tag{7}$$

The joint probability density of the Gaussian components x_1 and y_1 is:

$$p_{x_1y_1}(x_1,y_1)=\frac{1}{2\pi\sigma_1^{\,2}}e^{-\frac{x_1^{\,2}+y_1^{\,2}}{2\sigma_1^{\,2}}} \tag{8}$$

The function $f_1(a,A,x_1,y_1)$ is defined with:

$$f_1(a,A,x_1,y_1)=a\frac{A+x_1}{\sqrt{(A+x_1)^2+y_1^{\,2}}} \tag{9}$$

The probability density of output signal z, after some substitutions, is:

$$p_z(z)=\int_{-\infty}^{+\infty}dx_1\int_{-\infty}^{+\infty}dy_1\int_{0}^{+\infty}da\int_{0}^{+\infty}dA\frac{1}{\sqrt{2\pi}\sigma_2}\cdot$$
$$\cdot e^{-\frac{\left[z-f_1(a,A,x_1,y_1)\right]^2}{2\sigma_2^{\,2}}}\frac{1}{2\pi\sigma_1^{\,2}}e^{-\frac{x_1^{\,2}+y_1^{\,2}}{2\sigma_1^{\,2}}}p_a(a)p_A(A)=$$
$$=\int_{-\infty}^{+\infty}dx_1\int_{-\infty}^{+\infty}dy_1\int_{0}^{a_T}da\int_{0}^{A_T}dA\frac{1}{\sqrt{2\pi}\sigma_2}\cdot$$
$$\cdot e^{-\frac{\left[z-f_1(a,A,x_1,y_1)\right]^2}{2\sigma_2^{\,2}}}\frac{1}{2\pi\sigma_1^{\,2}}e^{-\frac{x_1^{\,2}+y_1^{\,2}}{2\sigma_1^{\,2}}}\cdot$$
$$\cdot[P_{1A}p_{A_2}(A)F_{A1}(A_T)+P_{2A}p_{A_1}(A)F_{A2}(A_T)]\cdot$$
$$\cdot[P_{1a}p_{a_2}(a)F_{a1}(a_T)+P_{2a}p_{a_1}(a)F_{a2}(a_T)]+$$
$$+\int_{-\infty}^{+\infty}dx_1\int_{-\infty}^{+\infty}dy_1\int_{a_T}^{+\infty}da\int_{0}^{A_T}dA\frac{1}{\sqrt{2\pi}\sigma_2}\cdot$$
$$\cdot e^{-\frac{\left[z-f_1(a,A,x_1,y_1)\right]^2}{2\sigma_2^{\,2}}}\frac{1}{2\pi\sigma_1^{\,2}}e^{-\frac{x_1^{\,2}+y_1^{\,2}}{2\sigma_1^{\,2}}}\cdot$$
$$\cdot[P_{1A}p_{A_2}(A)F_{A1}(A_T)+P_{2A}p_{A_1}(A)F_{A2}(A_T)]\cdot$$
$$\cdot[P_{1a}p_{a_1}(a)+P_{1a}p_{a_2}(a)F_{a1}(a_T)+$$
$$+P_{2a}p_{a_2}(a)+P_{2a}p_{a_1}(a)F_{a2}(a_T)]+$$
$$+\int_{-\infty}^{+\infty}dx_1\int_{-\infty}^{+\infty}dy_1\int_{0}^{a_T}da\int_{A_T}^{+\infty}dA\frac{1}{\sqrt{2\pi}\sigma_2}\cdot$$
$$\cdot e^{-\frac{\left[z-f_1(a,A,x_1,y_1)\right]^2}{2\sigma_2^{\,2}}}\frac{1}{2\pi\sigma_1^{\,2}}e^{-\frac{x_1^{\,2}+y_1^{\,2}}{2\sigma_1^{\,2}}}\cdot$$
$$\cdot[P_{1A}p_{A_1}(A)+P_{1A}p_{A_2}(A)F_{A1}(A_T)+$$
$$+P_{2A}p_{A_2}(A)+P_{2A}p_{A_1}(A)F_{A2}(A_T)]\cdot$$
$$\cdot[P_{1a}p_{a_2}(a)F_{a1}(a_T)+P_{2a}p_{a_1}(a)F_{a2}(a_T)]+$$
$$+\int_{-\infty}^{+\infty}dx_1\int_{-\infty}^{+\infty}dy_1\int_{a_T}^{+\infty}da\int_{A_T}^{+\infty}dA\frac{1}{\sqrt{2\pi}\sigma_2}\cdot$$
$$\cdot e^{-\frac{\left[z-f_1(a,A,x_1,y_1)\right]^2}{2\sigma_2^{\,2}}}\frac{1}{2\pi\sigma_1^{\,2}}e^{-\frac{x_1^{\,2}+y_1^{\,2}}{2\sigma_1^{\,2}}}\cdot$$
$$\cdot[P_{1A}p_{A_1}(A)+P_{1A}p_{A_2}(A)F_{A1}(A_T)+$$
$$+P_{2A}p_{A_2}(A)+P_{2A}p_{A_1}(A)F_{A2}(A_T)]\cdot$$
$$\cdot[P_{1a}p_{a_1}(a)+P_{1a}p_{a_2}(a)F_{a1}(a_T)+$$
$$+P_{2a}p_{a_2}(a)+P_{2a}p_{a_1}(a)F_{a2}(a_T)] \tag{10}$$

The signals A_1, A_2, a_1, a_2 have Nakagami-m distributions:

$$p_{A_1}(A_1)=\frac{2m_1^{\,m_1}A_1^{\,2m_1-1}}{\Omega_1^{\,m_1}\Gamma(m_1)}e^{-\frac{m_1A_1^{\,2}}{\Omega_1}} \tag{11}$$

$$p_{A_2}(A_2)=\frac{2m_2^{\,m_2}A_2^{\,2m_2-1}}{\Omega_2^{\,m_1}\Gamma(m_2)}e^{-\frac{m_2A_2^{\,2}}{\Omega_1}} \tag{12}$$

$$p_{a_1}(a_1)=\frac{2{m_3}^{m_3}{a_1}^{2m_3-1}}{{\Omega_3}^{m_3}\Gamma(m_3)}e^{-\frac{m_3 a_1^2}{\Omega_3}} \tag{13}$$

$$p_{a_2}(a_2)=\frac{2{m_4}^{m_4}{a_2}^{2m_4-1}}{{\Omega_4}^{m_4}\Gamma(m_4)}e^{-\frac{m_4 a_2^2}{\Omega_4}} \tag{14}$$

The signals for up and down links are not simetrical.

There is two parameters of Nakagami-*m* distribution: a shape parameter *m*, and a second parameter controlling spread, *Ω*.

The cumulative probability densities (CDFs) are given by:

$$F_{A_1}(A_1)=\gamma\left(\frac{m_1}{\Omega_1}{A_1}^2, m_1\right) \tag{15}$$

$$F_{A_2}(A_2)=\gamma\left(\frac{m_2}{\Omega_2}{A_2}^2, m_2\right) \tag{16}$$

$$F_{a_1}(a_1)=\gamma\left(\frac{m_3}{\Omega_3}{A_3}^2, m_3\right) \tag{17}$$

$$F_{a_2}(a_2)=\gamma\left(\frac{m_4}{\Omega_4}{A_4}^2, m_4\right) \tag{18}$$

where $\gamma\,(x,\,a)$ is incomplete gamma function defined by [20].

After putting the expressions (11) to (18) into (10) we obtain the probability density of the output signal *z* in the presence of Nakagami-*m* fading.. The other system performances could be calculated by means of the output signal probability density function.

When the signals A_1, A_2, a_1, a_2 have Rice distributions, probability density functions are [11]:

$$p_{A_1}(A_1)=\frac{A_1}{{\sigma_{A_1}}^2}e^{-\frac{{A_1}^2+{\Omega_{A_1}}^2}{2{\sigma_{A_1}}^2}}I_0\left(\frac{A_1\Omega_{A_1}}{{\sigma_{A_1}}^2}\right) \tag{19}$$

$$p_{A_2}(A_2)=\frac{A_2}{{\sigma_{A_2}}^2}e^{-\frac{{A_2}^2+{\Omega_{A_2}}^2}{2{\sigma_{A_2}}^2}}I_0\left(\frac{A_2\Omega_{A_2}}{{\sigma_{A_2}}^2}\right) \tag{20}$$

$$p_{a_1}(a_1)=\frac{a_1}{{\sigma_{a_1}}^2}e^{-\frac{{a_1}^2+{\Omega_{a_1}}^2}{2{\sigma_{a_1}}^2}}I_0\left(\frac{a_1\Omega_{a_1}}{{\sigma_{a_1}}^2}\right) \tag{21}$$

$$p_{a_2}(a_2)=\frac{a_2}{{\sigma_{a_2}}^2}e^{-\frac{{a_2}^2+{\Omega_{a_2}}^2}{2{\sigma_{a_2}}^2}}I_0\left(\frac{a_2\Omega_{a_2}}{{\sigma_{a_2}}^2}\right) \tag{22}$$

The parameters of Rice distribution are the signal amplitudes *Ω* and variances *σ*.

The cumulative probability densities (CDFs) for Rice distribution are given by:

$$F_{A_1}(A_1)=1-Q\left(\Omega_{A_1}/\sigma_{A_1}, A_1/\sigma_{A_1}\right) \tag{23}$$

$$F_{A_2}(A_2)=1-Q\left(\Omega_{A_2}/\sigma_{A_2}, A_2/\sigma_{A_2}\right) \tag{24}$$

$$F_{a_1}(a_1)=1-Q\left(\Omega_{a_1}/\sigma_{a_1}, a_1/\sigma_{a_1}\right) \tag{25}$$

$$F_{a_2}(a_2)=1-Q\left(\Omega_{a_2}/\sigma_{a_2}, a_2/\sigma_{a_2}\right) \tag{26}$$

Q(a,b) is the Marcum Q function defined as [21]:

$$Q\left(a,b\right)=\int_b^\infty t\exp\left[-\frac{t^2+a^2}{2}\right]I_0(at)dt \tag{27}$$

After putting the expressions (19) to (28) into (10) we obtain the probability density of the output signal *z* in the presence of Rice fading.

IV. System Performances

The obtained expressions for the probability density function (PDF) of the output signal after diversity combining can be used to study the moments, the amount of fading, the outage probability and the average bit error rate of proposed system.

The outage probability P_{out} is standard performance criterion of communication systems operating over fading channels. This performance measure is commonly used to control the noise or cochannel interference level, helping the designers of wireless communications system's to meet the quality-of-service (QoS) and grade of service (GoS) demands.

In the interference-limited environment, the outage probability P_{out} is defined as the probability which combined SIR falls below a given outage threshold γ_T, also known as a protection ratio. Protection ratio depends on modulation technique and expected QoS.

The outage probability, $P_{out}(r_{th})$, is defined as:

$$P_{out}(z_{th})=\int_0^{z_{th}}p_z(z)dz\,. \tag{28}$$

After putting $p_z(z)$ from (10), the outage probability can be expressed as

$$P_{out}(r_{th}) = \int_0^{r_{th}} dz \int_{-\infty}^{+\infty} dx_1 \int_{-\infty}^{+\infty} dy_1 \int_0^{+\infty} da \int_0^{+\infty} dA \frac{1}{\sqrt{2\pi}\sigma_2} \cdot$$

$$\cdot e^{-\frac{[z-f_1(a,A,x_1,y_1)]^2}{2\sigma_2^2}} \frac{1}{2\pi\sigma_1^2} e^{-\frac{x_1^2+y_1^2}{2\sigma_1^2}} p_a(a) p_A(A) =$$

$$= \int_0^{r_{th}} dz \int_{-\infty}^{+\infty} dx_1 \int_{-\infty}^{+\infty} dy_1 \int_0^{a_T} da \int_0^{A_T} dA \frac{1}{\sqrt{2\pi}\sigma_2} \cdot$$

$$\cdot e^{-\frac{[z-f_1(a,A,x_1,y_1)]^2}{2\sigma_2^2}} \frac{1}{2\pi\sigma_1^2} e^{-\frac{x_1^2+y_1^2}{2\sigma_1^2}} \cdot$$

$$\cdot [P_{1A} p_{A_2}(A) F_{A1}(A_T) + P_{2A} p_{A_1}(A) F_{A2}(A_T)] \cdot$$

$$\cdot [P_{1a} p_{a_2}(a) F_{a1}(a_T) + P_{2a} p_{a_1}(a) F_{a2}(a_T)] +$$

$$+ \int_0^{r_{th}} dz \int_{-\infty}^{+\infty} dx_1 \int_{-\infty}^{+\infty} dy_1 \int_{a_T}^{+\infty} da \int_0^{A_T} dA \frac{1}{\sqrt{2\pi}\sigma_2} \cdot$$

$$\cdot e^{-\frac{[z-f_1(a,A,x_1,y_1)]^2}{2\sigma_2^2}} \frac{1}{2\pi\sigma_1^2} e^{-\frac{x_1^2+y_1^2}{2\sigma_1^2}} \cdot$$

$$\cdot [P_{1A} p_{A_2}(A) F_{A1}(A_T) + P_{2A} p_{A_1}(A) F_{A2}(A_T)] \cdot$$

$$\cdot [P_{1a} p_{a_1}(a) + P_{1a} p_{a_2}(a) F_{a1}(a_T) +$$

$$+ P_{2a} p_{a_2}(a) + P_{2a} p_{a_1}(a) F_{a2}(a_T)] +$$

$$+ \int_0^{r_{th}} dz \int_{-\infty}^{+\infty} dx_1 \int_{-\infty}^{+\infty} dy_1 \int_0^{a_T} da \int_{A_T}^{+\infty} dA \frac{1}{\sqrt{2\pi}\sigma_2} \cdot$$

$$\cdot e^{-\frac{[z-f_1(a,A,x_1,y_1)]^2}{2\sigma_2^2}} \frac{1}{2\pi\sigma_1^2} e^{-\frac{x_1^2+y_1^2}{2\sigma_1^2}} \cdot$$

$$\cdot [P_{1A} p_{A_1}(A) + P_{1A} p_{A_2}(A) F_{A1}(A_T) +$$

$$+ P_{2A} p_{A_2}(A) + P_{2A} p_{A_1}(A) F_{A2}(A_T)] \cdot$$

$$\cdot [P_{1a} p_{a_2}(a) F_{a1}(a_T) + P_{2a} p_{a_1}(a) F_{a2}(a_T)] +$$

$$+ \int_0^{r_{th}} dz \int_{-\infty}^{+\infty} dx_1 \int_{-\infty}^{+\infty} dy_1 \int_{a_T}^{+\infty} da \int_{A_T}^{+\infty} dA \frac{1}{\sqrt{2\pi}\sigma_2} \cdot$$

$$\cdot e^{-\frac{[z-f_1(a,A,x_1,y_1)]^2}{2\sigma_2^2}} \frac{1}{2\pi\sigma_1^2} e^{-\frac{x_1^2+y_1^2}{2\sigma_1^2}} \cdot$$

$$\cdot [P_{1A} p_{A_1}(A) + P_{1A} p_{A_2}(A) F_{A1}(A_T) +$$

$$+ P_{2A} p_{A_2}(A) + P_{2A} p_{A_1}(A) F_{A2}(A_T)] \cdot$$

$$\cdot [P_{1a} p_{a_1}(a) + P_{1a} p_{a_2}(a) F_{a1}(a_T) +$$

$$+ P_{2a} p_{a_2}(a) + P_{2a} p_{a_1}(a) F_{a2}(a_T)] \tag{29}$$

For binary phase shift keying (BPSK) modulation scheme, the bit error rate (BER) is given by

$$P_b(e) = \int_0^{\infty} P_b(e/\gamma) p_\gamma(\gamma) d\gamma \tag{30}$$

where $P_b(e/\gamma)$ is conditional BER and $p(\gamma)$ is the PDF of the instantaneous SNR. $P_b(e/\gamma)$ can be expressed in terms of the Gaussian Q-function as

$$P_b(e/\gamma) = Q\left(\sqrt{2g\gamma}\right); \tag{31}$$

Q is the one-dimensional Gaussian Q-function

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{-t^2/2} dt \,. \tag{32}$$

Gaussian Q-function can be defined using alternative form as

$$Q(x) = \frac{1}{\pi} \int_0^{\pi/2} \exp\left(-\frac{x^2}{2\sin^2\phi}\right) d\phi \,. \tag{33}$$

For coherent BPSK modulation parameter g is determined as $g=1$ and $P_b(e/\gamma)$ is given by

$$P_b(e/\gamma) = Q\left(\sqrt{2\gamma}\right). \tag{34}$$

V. NUMERICAL RESULTS

The probability density function curves (PDFs), $p(z)$, of the signal z at the Earth receiver station output, in the presence of Nakagami-*m* fading are given in Figures 3 to 6 for diferent parameters.

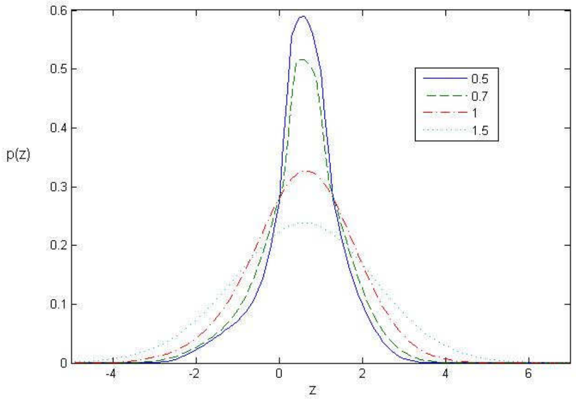

Figure 3. The probability density function $p(z)$ for Nakagami-*m* fading present on receiver satellite and Earth station, for different parameters: $\sigma_1 = 1, \sigma_2 = 0.5, 0.7, 1, 1.5,$ $m_1 = m_2 = 1, \Omega_1 = \Omega_2 = 1, m_3 = m_4 = 1, \Omega_3 = \Omega_4 = 1, a_t = 2, A_t = 2$

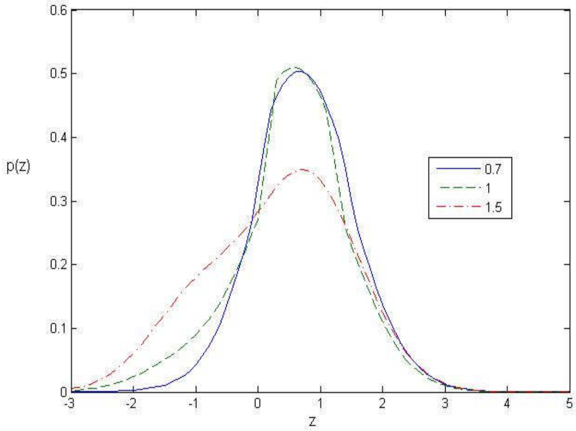

Figure 4. The probability density function $p(z)$ for Nakagami-*m* fading present on receiver satellite and Earth station, for different parameters: $\sigma_1 = 0.7, 1, 1.5, \sigma_2 = 0.7, m_1 = m_2 = 1, \Omega_1 = \Omega_2 = 1, m_3 = m_4 = 1, \Omega_3 = \Omega_4 = 1,$ $\alpha_t = 1, A_t = 1$

We can see from these figures the influence of two parameters of Nakagami-*m* distribution, a shape parameter, *m*, and a second parameter, Ω, the standard deviations σ_i, and the signal amplitudes A_1, A_2, a_1 and a_2.

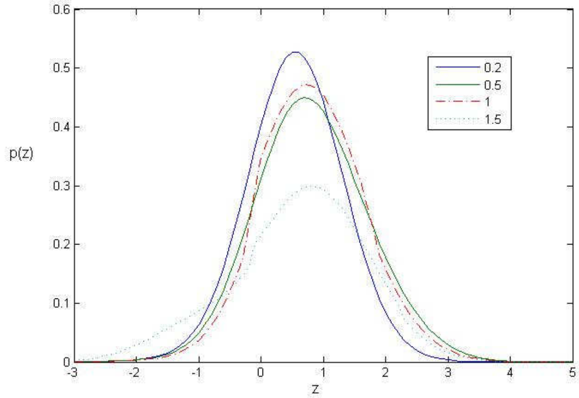

Figure 5. The probability density function $p(z)$ for Nakagami-*m* fading present on receiver satellite and Earth station, for different parameters: $\sigma_1 = 0.7, \sigma_2 = 0.7, , m_1 = m_2 = 1, \Omega_1 = \Omega_2 = 0.2, 0.5, 1, 1.5, m_3 = m_4 = 1,$ $\Omega_3 = \Omega_4 = 1, \alpha_t = 1, A_t = 1$

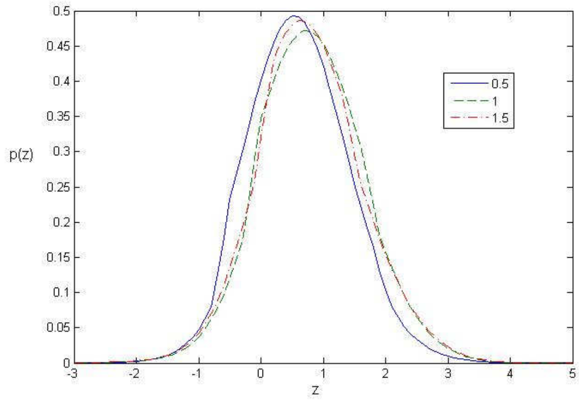

Figure 6. The probability density function $p(z)$ for Nakagami-*m* fading present on receiver satellite and Earth station, for different parameters: $\sigma_1 = 0.7, \sigma_2 = 0.7, , m_1 = m_2 = 1, \Omega_1 = \Omega_2 = 1, m_3 = m_4 = 1, \Omega_3 = \Omega_4 = 1, A_t = 1,$ $a_t = 0.5, 1, 1.5$

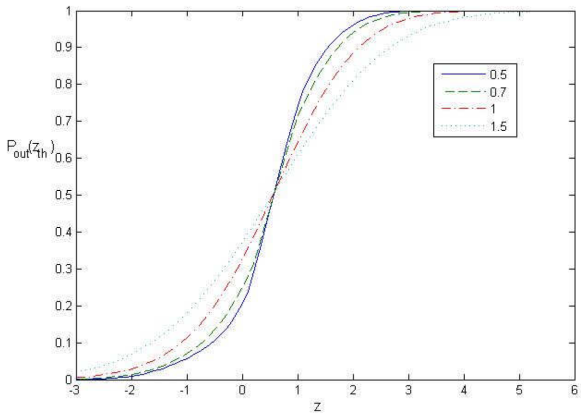

Figure 7. The outage probability $P_{out}(z)$ for Nakagami-*m* fading present on receiver satellite and Earth station, for different parameters: $\sigma_1 = 1, \sigma_2 = 0.5, 0.7, 1, 1.5, m_1 = m_2 = 1, \Omega_1 = \Omega_2 = 1, m_3 = m_4 = 1, \Omega_3 = \Omega_4 = 1,$ $\alpha_t = 2, A_t = 2$

The outage probability curves $P_{out}(z)$, in the presence of Nakagami-*m* fading are given in Figures 7 and 8 for diferent parameters.

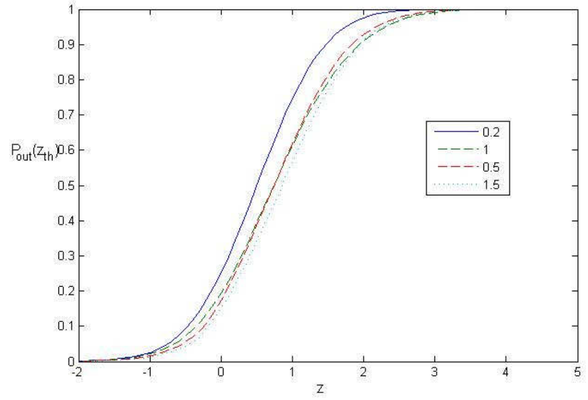

Figure 8. The outage probability $P_{out}(z)$ for Nakagami-*m* fading present on receiver satellite and Earth station, for different parameters: $\sigma_1=0.7, \sigma_2=0.7, m_1= m_2=1, \Omega_1= \Omega_2=0.2, 0.5, 1, 1.5, m_3= m_4=1, \Omega_3= \Omega_4=1, \alpha_t=1, A_t=1$

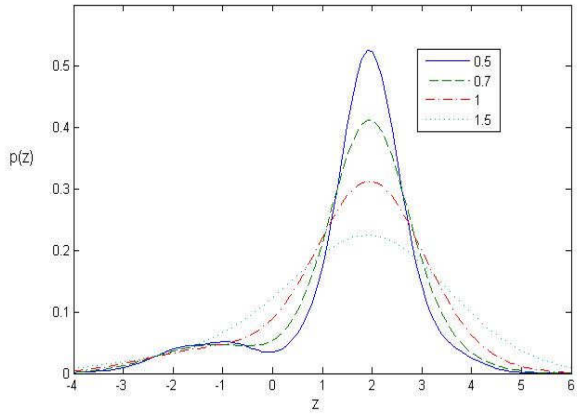

Figure 9. The probability density function $p(z)$ for Rice fading present on receiver satellite and Earth station, for different parameters: $\sigma_1 =1, \sigma_2 = 0.5, 0.7, 1, 1.5, \sigma_{A1} = \sigma_{A2} =1, \Omega_{A1} = \Omega_{A2} =1, \sigma_{a2} = \sigma_{a2} =1,$ $\Omega_{a1}= \Omega_{a24}=1,$ $a_t=2$, $A_t=2$

The probability density function curves (PDFs), $p(z)$, of the signal z at the Earth receiver station output, in the presence of Rice fading are given in Figures 9 to 12, for diferent parameters.

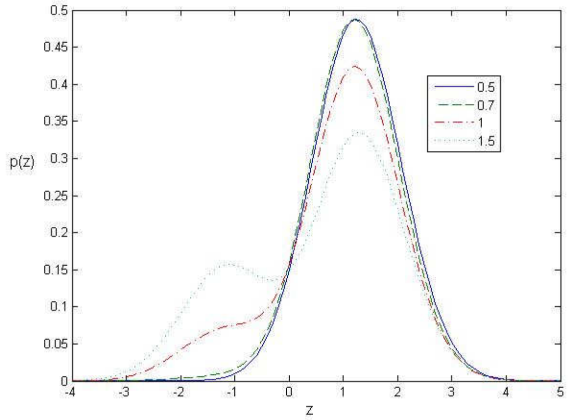

Figure 10. The probability density function $p(z)$ for Rice fading present on receiver satellite and Earth station, for different parameters: $\sigma_1= 0.7, 1, 1.5, \sigma_2=0.7,$ $\sigma_{A1} =\sigma_{A2} =0.5, \Omega_{A1} = \Omega_{A2} =1, \sigma_{a2} = \sigma_{a2} =0.5,$ $\Omega_{a1}= \Omega_{a24}=1,$ $a_t=1$, $A_t=1$

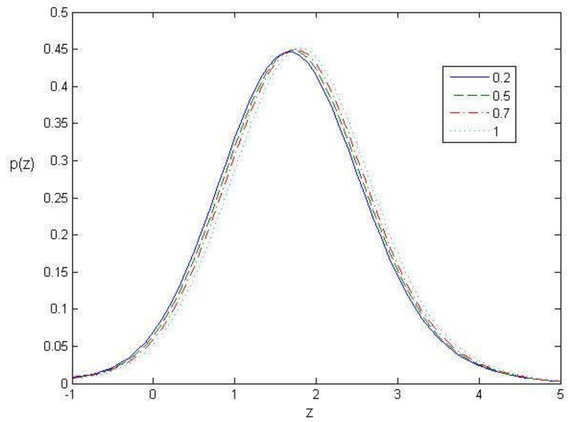

Figure 11. The probability density function $p(z)$ for Rice fading present on receiver satellite and Earth station, for different parameters: $\sigma_1= 0.7, \sigma_2=0.7, \sigma_{A1} = \sigma_{A2} =1, \Omega_{A1} = \Omega_{A2} =0.2, 0.5, 0.7, 1, \sigma_{a2} = \sigma_{a2} =1,$ $\Omega_{a1}= \Omega_{a24}=1,$ $a_t=1, A_t=1$

We can see from these figures the influence of two parameters of Rice distribution, the signal amplitudes Ω and variances σ, and the standard deviations σ_i, and the signal amplitudes A_1, A_2, a_1 and a_2.

The outage probability curves $P_{out}(z)$, in the presence of Rice fading are given in Figures 13 and 14 for diferent parameters.

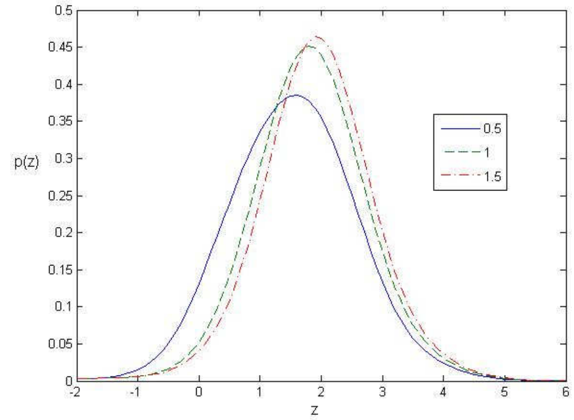

Figure 12. The probability density function $p(z)$ for Rice fading present on receiver satellite and Earth station, for different parameters: $\sigma_1 = 0.7$, $\sigma_2 = 0.7$, $\sigma_{A1} = \sigma_{A2} = 1$, $\Omega_{A1} = \Omega_{A2} = 1$, $\sigma_{a2} = \sigma_{a2} = 1$, $\Omega_{a1} = \Omega_{a24} = 1$, $a_t = 0.5, 1, 1.5, 2$, $A_t = 1$

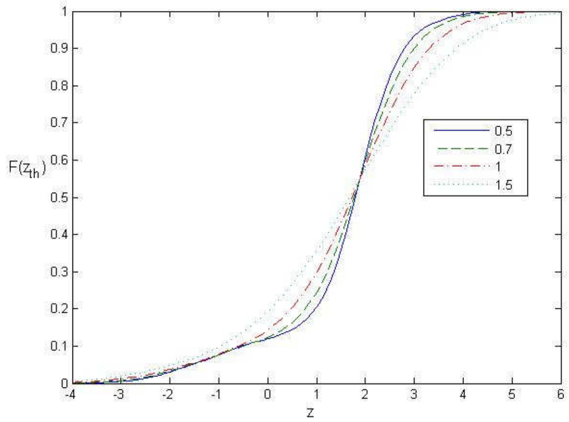

Figure 13. The outage probability $P_{out}(z)$ for Rice fading present on receiver satellite and Earth station, for different parameters: $\sigma_1 = 1$, $\sigma_2 = 0.5, 0.7, 1, 1.5$, $\sigma_{A1} = \sigma_{A2} = 1$, $\Omega_{A1} = \Omega_{A2} = 1$, $\sigma_{a2} = \sigma_{a2} = 1$, $\Omega_{a1} = \Omega_{a24} = 1$, $a_t = 2$, $A_t = 2$

The dependence of probability density functions, pdf $p(z)$, from z, the Earth receiver station output signal, are given in Figures 3 to 6 in the presence of Nakagami-m fading, and in Figures 9 to 12 in the presence of Rice fading, present on receiver satellite and Earth stations for some values of distribution parameters. In every graph one or several parameters are given by few values and one can see the variation of pdf versus values of selected parameters for constant other parameters.

The expression for probability density function (PDF) of the output signal after diversity combining is used to study the outage probability of proposed system. The outage probability is standard performance criterion of communication systems operating over fading channels.

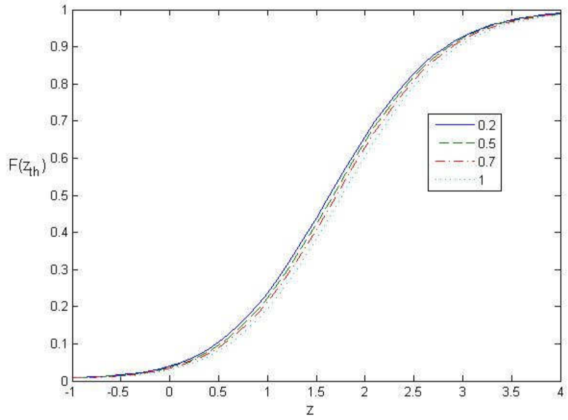

Figure 14. The outage probability $P_{out}(z)$ for Rice fading present on receiver satellite and Earth station, for different parameters: $\sigma_1 = 0.7$, $\sigma_2 = 0.7$, $\sigma_{A1} = \sigma_{A2} = 1$, $\Omega_{A1} = \Omega_{A2} = 0.2, 0.5, 0.7, 1$, $\sigma_{a2} = \sigma_{a2} = 1$, $\Omega_{a1} = \Omega_{a24} = 1$, $a_t = 1$, $A_t = 1$

The outage probability curves $P_{out}(z)$, are shown in Figures 7, 8, 13, 14 for determined values of distribution parameters: parameters of fadings on receiver satellite and Earth station, the standard deviations σ_i, and the signal values at the system inputs.

The values of $P_{out}(z)$ for some values of parameters σ_2, and constant other parameters, are shown in Figures 7 and 13. From this figure can be seen that $P_{out}(z)$ decreases with increase of parameter σ_2, for the same value of z, if z is bigger than threshold decision. From Figures 8 and 14, it can be seen that $P_{out}(z)$ decreases with increasing of spread parameters $\Omega_1 = \Omega_2$.

VI. CONCLUSION

In this paper the satellite communication system consisting of the earth transmitting station and the satellite transponder was considered. Switch and stay combining (SSC) diversity technics are used on receiving satellite and receiving Earth stations. SSC is used, as the simplest and the cheapest combining method, to reduce fading influence to the system performances. The presence of Nakagami-m and Rice fading on receiving satellite and receiving Earth stations is observed. Rice distribution is used to model the envelope of fading channels in wireless telecommunication systems with direct line of site, when dominate component exists. This type of the satellite communication system can be used for propagation channels consisting of one strong direct LOS (line of sight) component and many random weaker components for both, receiving satellite and receiving earth stations and for satellite propagation channels that obey a Nakagami m distribution. The fading is the limiting factor in both directions. Because it has been found experimentally that Nakagami distribution offers better fit for wider range of fading conditions in wireless communications, the influence of this kind of fading is analyzed also.

The probability density functions (PDFs) of the signal at the Earth receiver station output are represented for different parameter values. The other system performances, such as the system error probability and the outage probability, could be calculated by the output signal probability density function. In this paper, the outage probability, as standard performance criterion of communication systems operating over fading channels, is calculated and the curves are shown also.

In the future work the other combining techniques, such as Maximal Ratio Combining, (MRC), Equal Gain Combining, (EGC), and Selection Combining, (SC), could be investigated and the results compared with appropriate in this paper.

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