Selection Combining Receiver in the Presence of Ricean fading

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Abstract: - This paper focuses on comparing performances of the selection combining (SC) diversity system in the presence of independent and correlated Ricean fading. For the case of correlated fading, we have presented closed form expressions for probability density function (PDF), and cumulative density function (CDF), at the output of dual branch SC. Also we have presented closed form expressions for system performances such as: average bit error-rate (ABER), outage probability (OP) and average output moments, which is the main contribution of our work. For the case of independent fading between the diversity branches, we have analyzed performances of SC diversity system which consists of two and four input branches. All obtained results are graphically presented.

Key-Words: - Ricean fading, Selection combining, System performances

1 Introduction

In mobile radio communications, the emitted electromagnetic waves often do not reach the receiving antenna directly due to obstacles blocking the line-of sight path.

In fact, the received waves are a superposition of waves coming from all directions due to reflection, diffraction, and scattering caused by buildings, trees, and other obstacles. The signal on these different paths can constructively or destructively interfere with each other. This effect is known as multipath propagation.

If either the transmitter or the receiver is moving, then this propagation phenomena will be time varying, and fading occurs.

The multipath fading in wireless communications, is modeled by several distributions including Weibull, Nakagami-*m* Hoyt, Rayleigh, and Ricean. Moreover, several problems in wireless communications theory involve bivariate and, in the general case, multivariate distributions.

Increasing demands for untethered and lightweight communication devices has triggered the need for higher power and bandwidth effciencies together with improved quality of service.

Research into the optimal use of the available radio spectrum has lead to the development of various modulation and coding schemes together with the application of adaptive antenna arrays to exploit the time, space and frequency varying environment.

The design goal is to make the received power adequate to overcome background noise over each link, while minimizing interference to other more distant links operating at the same frequency.

Recently, diversity combining techniques have been used to combat the effects of multipath fading and to enhance system performance. It has proven especially helpful in reducing the occurrence of deep fades and error probability.

The simplest method is a single transmitting antenna furnishing a signal to several well-separated remote receiving antennas. This is known as antenna diversity or space diversity. Antenna diversity is especially effective at mitigating the phase shifts, time delays and attenuation of multipath situations. Because multiple antennas supply a receiver with several observations of the same signal, each antenna will experience a different interference. Therefore, the signals will not experience deep fades at the same time.

The performance of maximal-ratio combining (MRC) over fading channels has long been of interest to researchers. MRC is the optimal combining scheme but comes with the expense of complexity. Signals from each path are added together.

Then, the gain of each channel is made proportional to signal level, and inversely proportional to the noise level.

Proportionality constants are used for each path. MRC provides the maximum performance enhancement by maximizing the SNR at the combiner output. Nevertheless, MRC has the highest complexity because it requires knowledge of the fading amplitude in each signal branch.

Equal-gain combining (EGC) is the alternative combining technique, often used because of its reduced complexity. EGC equally weighs each branch before combination, and therefore does not require estimation of channel fading amplitudes.

Switched combining (SWC) can be used in conjunction with coherent, non-coherent, and differentially coherent modulation schemes. In general, with SWC diversity the receiver selects a particular branch until its signal-to-noise ratio (SNR) drops below a predetermined threshold. When this happens, the combiner switches to another branch and stays there regardless of whether the SNR of that branch is above or below the predetermined threshold.

With SC receiver, the processing is performed at only one of the diversity branches, which is selectively chosen, and no channel information is required. That is why SC is much simpler for practical realization.

Standard, for the case when equal distribution of noise power over branches is assumed, SC chooses the branch with the highest signal-to-noise ratio (SNR) that is the branch with the strongest signal [1].

However, in cellular communications systems, and other fading environments with sufficiently high level of the co-channel interference comparing to the thermal noise, SC chooses the branch with the highest signal-to-interference ratio (SIR- based selection diversity).

Diversity combining techniques mainly discussed in many previous studies are: MRC (Maximal Ratio Combining) technique [2], EGC (Equal-Gain Combining) technique [3], SWC (Switched Combining) technique [4] and SC (Selection Combining) technique [5-11]. Hybrid techniques like GSC (Generalized Selection Combining) [12] are proposed recently.

As far as the Ricean fading channel is concerned, a performance analysis limited to the non-coherent reception of orthogonal M-ary FSK with postdetection EGC over correlated fading channels was given in [13]. Moreover, a study for dual-branch EGC in slow, correlated, Ricean time selective fading has been presented in [14] for the special case of non-coherent detection of orthogonal binary shift keying (BFSK).

The performance analyze of SWC diversity receivers operating over correlated Ricean fading satellite channels can be found in [15], where the performance is evaluated based on a novel analytical formulae for the outage probability P_{out} , average error probability ABEP, channel capacity (CC), the amount of fading (AoF), and the average output signal-to-noise ratio (SNR) obtained in infinite series form.

This paper deals with performances of the selection combining (SC) diversity system in the presence of independent and correlated Ricean fading.

For the case of independent fading between the diversity branches, we are analyzing output statistical performances of SC diversity system which consists of two and four input branches. Also we are discussing bit error rate probability, when SC combiners output is connected with coherent system.

For the case of correlated fading, we are analyzing probability density function (PDF), and cumulative density function (CDF), at the output of dual branch SC. Also this paper deals with system performances such as: outage probability (OP) average bit error-rate (ABER) and average output moments.

This paper is organized as follows: first section is introduction. In the second section we are considering influence of independent Ricean fading. Subsection 2.1 is dedicated to numerical results for SC combiner with two inputs.

The model of SC combiner with four input branches is given in section three. In the subsection 2.3 numerical results for SC combiner with four inputs are represented. The next, third section, deals with performances of SC diversity system with two branches in the presence of correlated Ricean fading. The last section is conclusion.

2 Independent Ricean fading

The Ricean fading distribution is often used to model propagation paths, consisting of one strong direct line-of-sight (LoS) signal, and many randomly reflected and usually weaker signals.

Such fading environments are typically encountered in microcellular and mobile satellite radio links. The Ricean fading is also applicable for modeling the fading channels in frequency domain. In particular, for mobile satellite communications, the Ricean distribution is used to accurately model the mobile satellite channel for single, clear-state channel conditions.

Also the Ricean K-factor characterizes the land mobile satellite channel, during unshadowed periods. Independent fading assumes antenna elements to be placed sufficiently apart.

2.1 SC combiner with two inputs

Selection combining receiver with two input branches is shown at Fig.1. Signal r_1 is at first SC combiners input, and at second SC combiners input is signal r_2. Signals r_1 and r_2 have Ricean distribution.

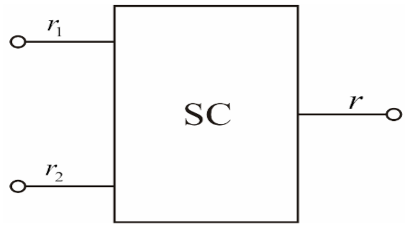

Fig.1. SC combiner with two inputs.

The probability density functions of the signals r_1 and r_2 are [16]:

$$p_{r_1}(r_1)=\frac{r_1}{\sigma^2}e^{-\frac{r_1^2+A^2}{2\sigma^2}}I_0\left(\frac{r_1A}{\sigma^2}\right) \qquad r_1\geq 0 \quad (1)$$

$$p_{r_2}(r_2)=\frac{r_2}{\sigma^2}e^{-\frac{r_2^2+A^2}{2\sigma^2}}I_0\left(\frac{r_2A}{\sigma^2}\right) \qquad r_2\geq 0 \quad (2)$$

Variances of those signals are denoted as σ. A denotes the amplitude of the dominant component. Output signal of the SC combiner with two inputs is:

$$r=\max\{r_1,r_2\} \qquad (3)$$

Cumulative distribution functions are necessary to determine probability density functions of output signal from SC combiner with two inputs and bit error rate probability:

$$F_{r_1}(r)=\int_0^r p_{r_1}(r_1)dr_1=\int_0^r \frac{r_1}{\sigma^2}e^{-\frac{r_1^2+A^2}{2\sigma^2}}I_0\left(\frac{r_1A}{\sigma^2}\right)dr_1 \quad (4)$$

$$F_{r_2}(r)=\int_0^r p_{r_2}(r_2)dr_2=\int_0^r \frac{r_2}{\sigma^2}e^{-\frac{r_2^2+A^2}{2\sigma^2}}I_0\left(\frac{r_2A}{\sigma^2}\right)dr_2 \quad (5)$$

The probability density function of output signal from SC combiner with two inputs is [4,5]:

$$p_r(r)=p_{r_1}(r)F_{r_2}(r)+p_{r_2}(r)F_{r_1}(r) \qquad (6)$$

Bit error rate probability, when SC combiners output is connected with coherent system, is [12]:

$$P_e=\int_0^\infty \frac{1}{2}erfc(\alpha r^2)p_r(r)dr \qquad (7)$$

2.2 Numerical results

Fig.2. shows plots of the probability density function versus SC combiners output signal for different values of signal variances σ and dominant component amplitude A=4.

The probability density function of SC combiners output signal for different values of amplitude A and $\sigma=1$ is shown in Fig.3.

Plots of bit error rate probability are represented in Fig.4. when SC combiners output is connected with coherent system and σ varying.

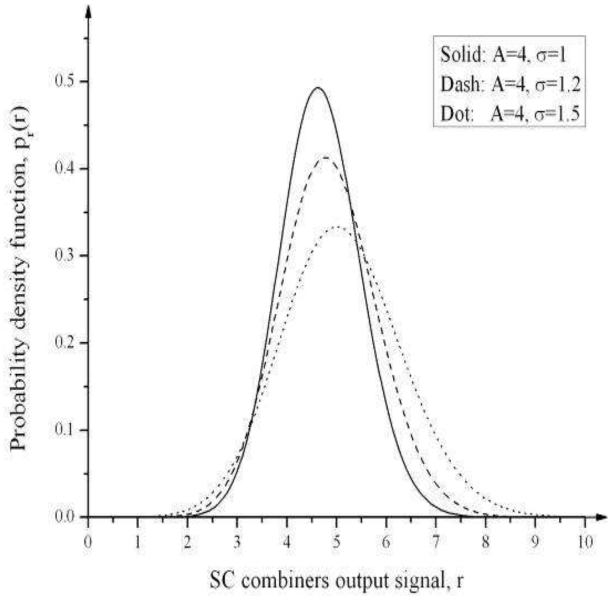

Fig.2. Probability density function of SC combiners output signal for different values of σ and A=4.

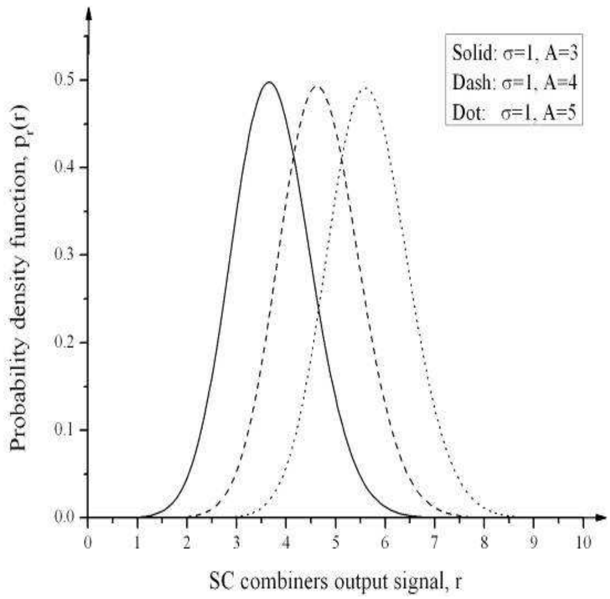

Fig.3. Probability density function of SC combiners output signal for different values of amplitude A and $\sigma=1$.

2.3 SC combiner with four inputs

Fig.5. shows selection combining receiver with four input branches. Input signals of SC combiner

r_1, r_2, r_3 and r_4, have Ricean distribution.Variances of those signals are σ

The probability density functions of SC combiners input signals are:

$$p_{r_1}(r_1) = \frac{r_1}{\sigma^2} e^{-\frac{r_1^2+A^2}{2\sigma^2}} I_0\left(\frac{r_1 A}{\sigma^2}\right) \qquad r_1 \geq 0 \quad (8)$$

$$p_{r_2}(r_2) = \frac{r_2}{\sigma^2} e^{-\frac{r_2^2+A^2}{2\sigma^2}} I_0\left(\frac{r_2 A}{\sigma^2}\right) \qquad r_2 \geq 0 \quad (9)$$

$$p_{r_3}(r_3) = \frac{r_3}{\sigma^2} e^{-\frac{r_3^2+A^2}{2\sigma^2}} I_0\left(\frac{r_3 A}{\sigma^2}\right) \qquad r_3 \geq 0 \quad (10)$$

$$p_{r_4}(r_4) = \frac{r_4}{\sigma^2} e^{-\frac{r_4^2+A^2}{2\sigma^2}} I_0\left(\frac{r_4 A}{\sigma^2}\right) \qquad r_4 \geq 0 \quad (11)$$

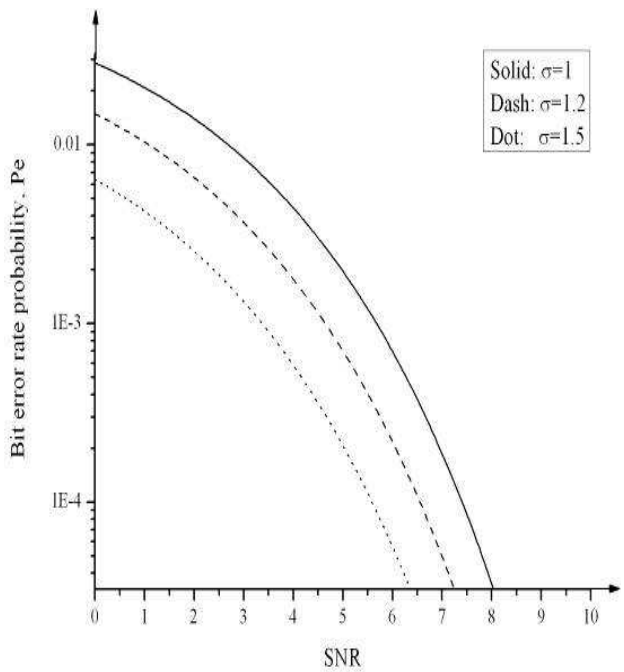

Fig.4. Bit error rate probability of SC combiner with two inputs, for different values of σ.

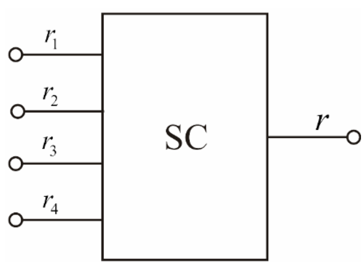

Fig.5. SC combiner with four inputs.

Output signal of the SC combiner with four inputs is:

$$r = \max\{r_1, r_2, r_3, r_4\} \qquad (12)$$

Cumulative distribution functions are also necessary to determine probability density functions of SC combiners with four inputs output signal and bit error rate probability:

$$F_{r_1}(r) = \int_0^r p_{r_1}(r_1)dr_1 = \int_0^r \frac{r_1}{\sigma^2} e^{-\frac{r_1^2+A^2}{2\sigma^2}} I_0\left(\frac{r_1 A}{\sigma^2}\right) dr_1 \quad (13)$$

$$F_{r_2}(r) = \int_0^r p_{r_2}(r_2)dr_2 = \int_0^r \frac{r_2}{\sigma^2} e^{-\frac{r_2^2+A^2}{2\sigma^2}} I_0\left(\frac{r_2 A}{\sigma^2}\right) dr_2 \quad (14)$$

$$F_{r_3}(r) = \int_0^r p_{r_3}(r_3)dr_3 = \int_0^r \frac{r_3}{\sigma^2} e^{-\frac{r_3^2+A^2}{2\sigma^2}} I_0\left(\frac{r_3 A}{\sigma^2}\right) dr_3 \quad (15)$$

$$F_{r_4}(r) = \int_0^r p_{r_4}(r_4)dr_4 = \int_0^r \frac{r_4}{\sigma^2} e^{-\frac{r_4^2+A^2}{2\sigma^2}} I_0\left(\frac{r_4 A}{\sigma^2}\right) dr_4 \quad (16)$$

The probability density function of SC combiners with four inputs output signal is:

$$\begin{aligned} p_r(r) = & \, p_{r_1}(r)F_{r_2}(r)F_{r_3}(r)F_{r_4}(r) + \\ & + p_{r_2}(r)F_{r_1}(r)F_{r_3}(r)F_{r_4}(r) + \\ & + p_{r_3}(r)F_{r_1}(r)F_{r_2}(r)F_{r_4}(r) + \\ & + p_{r_4}(r)F_{r_1}(r)F_{r_2}(r)F_{r_3}(r) + \end{aligned} \qquad (17)$$

If SC combiners output is connected with coherent system, bit error rate probability is determined according to the next formula:

$$P_e = \int_0^\infty \frac{1}{2} erfc\left(\alpha r^2\right) p_r(r) dr \qquad (18)$$

here *erfc(x)* denotes complementary error function, defined in [17-18].

2.4 Numerical results

Fig.6. shows the probability density function of SC combiners output signal, when amplitude of effective signal is constant *A*=4, and σ varying.

Plots of the probability density function of SC combiner output signal for different values of amplitude of effective signal *A*, and variance $\sigma = 1$ are given in Fig.7.

Plots of bit error rate probability when SC combiners output is connected with coherent system, and when σ varying, are shown in Fig.8.

2.4 Comparing pervious numerical results

From Fig. 8 we can se that the best performances are obtained for the case of σ=1.5 (the lowest value of bit error rate probability, almost the size rang lower than for the case of σ=1)

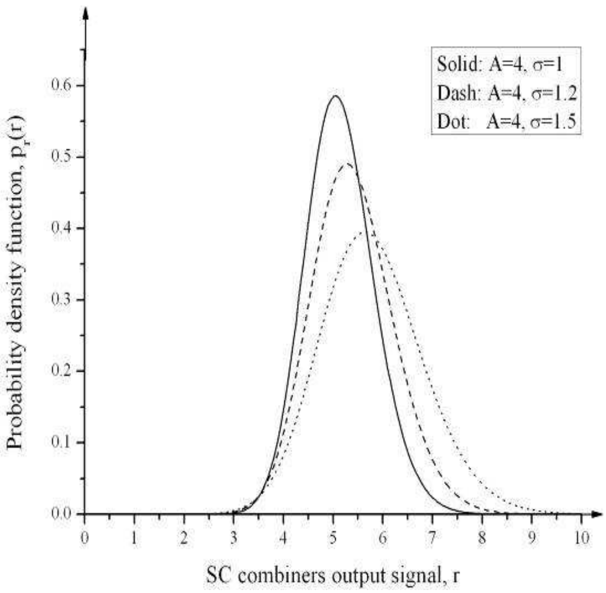

Fig.6. Probability density function of SC combiners output signal, *A*=4 and for different values of σ.

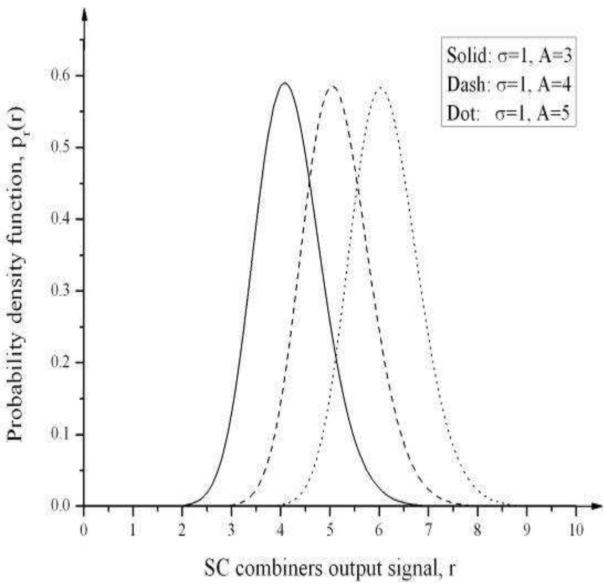

Fig.7. Probability density function of SC combiners output signal for different amplitude values *A*, and $\sigma = 1$.

Fig. 9. shows probability density function of the SC combiners with two inputs output signal (dashed curve) and probability density function of the SC combiners with four inputs output signal (solid curve), when amplitude of effective signal is *A*=4 and $\sigma = 1$. It is obvious that dashed curve is wider and has lower maximum.

Plots of the bit error rate probability for SC combiner with two inputs (solid curve) and the bit error rate probability of SC combiner with four inputs (dashed curve), for the value $\sigma=1$, are shown at Fig.10.

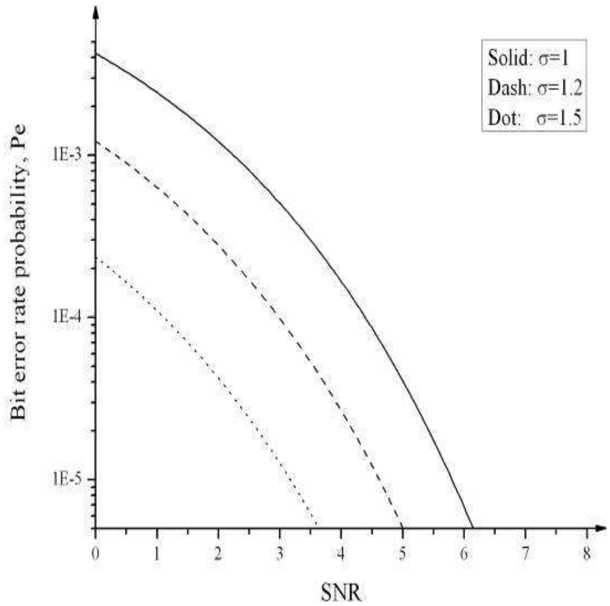

Fig.8. Bit error rate probability of SC combiner with four inputs, for different values of the value σ.

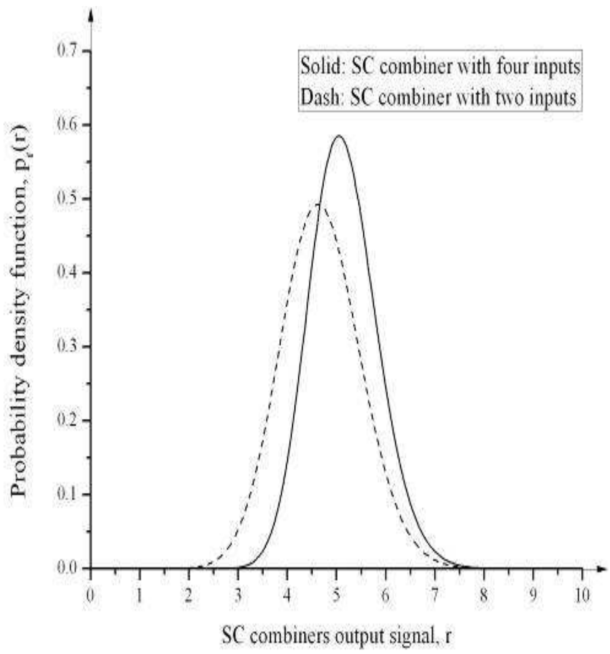

Fig.9. Probability density function of the SC combiners with two inputs output signal (dashed curve) and probability density function of the SC combiners with four inputs output signal (solid curve).

This results are accomplished in case that there is coherent communication system, connected at SC combiners output.

We note that bit error rate probability of SC combiner with four inputs is almost size range lower than bit error rate probability of SC combiner with two inputs.

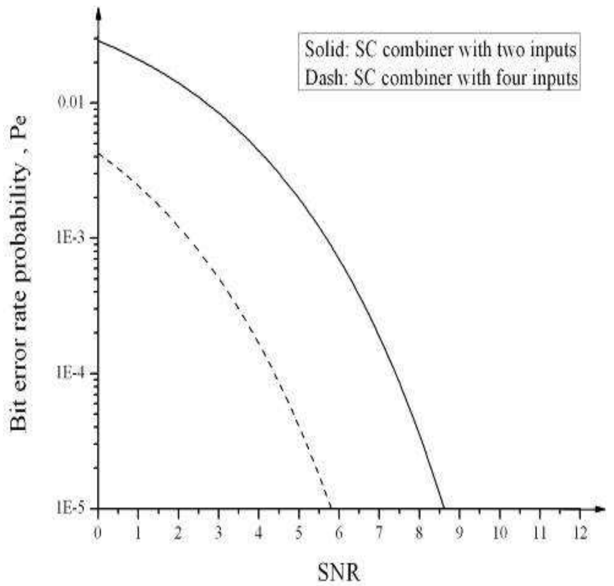

Fig.10. Bit error rate probability for SC combiner with two inputs (solid curve) and bit error rate probability for SC combiner with four inputs (dashed curve), for $\sigma = 1$.

3 Correlated Ricean fading

However, independent fading assumes antenna elements to be placed sufficiently apart, which is not general case in practice due to insufficient spacing between antennas.

When diversity system is applied on small terminals with multiple antennas, correlation arises between branches [19].

Now, due to insufficient antennae spacing, desired signal, envelopes experience correlative multivariate Ricean fading, with joint distribution, given in the form of [20]:

$$p_{R_1,R_2}(R_1,R_2)=\frac{R_1R_2(K+1)^2}{\beta^2(1-\rho^2)}\exp\left(-\frac{(R_1^2+R_2^2)(K+1)+4K\beta(1-\rho)}{2\beta(1-\rho^2)}\right)$$
$$\times\sum_{k=0}^{\infty}\varepsilon_k I_k\left(\frac{R_1R_2\rho(K+1)}{\beta(1-\rho^2)}\right)I_k\left(\frac{R_1}{(1+\rho)}\sqrt{\frac{2K(K+1)}{\beta}}\right)I_k\left(\frac{R_2}{(1+\rho)}\sqrt{\frac{2K(K+1)}{\beta}}\right) \quad (19)$$

with ξ_k =1(k=0), and ξ_k =2 (k>0) . Here β denotes the average power of input signal, defined as $\beta = \overline{R_1^2}/2=\overline{R_2^2}/2$; I_k is the modified Bessel function of the first kind of k-th order.

K factor defines ratio of signal power in dominant component over the scattered power, for desired signal. Ricean K-factor characterizes the land mobile satellite channel during unshadowed periods. ρ is the power correlation coefficient defined as [19]:

$$\rho = \frac{\operatorname{cov}\left(R_i^2, R_j^2\right)}{\sqrt{\operatorname{var}\left(R_i^2, R_j^2\right)}} \quad (20)$$

with $0 \le \rho \le 1$. Here cov and var stand for covariance and variance operators of statistical random variables. For this case joint cumulative distribution function can be written as

$$F(r_1,r_2)=\int_0^{r_1}\int_0^{r_2} p_{r_1,r_2}(x_1,x_2)\,dx_1dx_2\ , \quad (21)$$

After substituting expression (20) in (21), and integration joint cumulative distribution function becomes:

$$F(r_1,r_2)=\sum_{k=0}^{\infty}\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}\sum_{l=0}^{\infty}\varepsilon_k\Bigg[\frac{\exp\left(-\frac{2K}{1+\rho}\right)(1-\rho^2)^{m+n+k+1}\rho^{2l+k}K^{m+n+k}}{(1+\rho)^{2m+2n+2k}\,\Gamma(m+k+1)}$$
$$\times\frac{\gamma\left(l+m+k+1,\sqrt{\frac{K+1}{2\beta(1-\rho^2)}}r_1\right)\gamma\left(l+n+k+1,\sqrt{\frac{K+1}{2\beta(1-\rho^2)}}r_2\right)}{\Gamma(l+k+1)\,\Gamma(n+k+1)\,m!n!l!}\Bigg] \quad (22)$$

here $\gamma(a,x)$ denotes lower incomplete Gamma function defined in [17,18]. Cumulative distribution function of output, could be derived from (22) by equating the arguments r_1=r_2=r as in [11]:

$$F(r)=\sum_{k=0}^{\infty}\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}\sum_{l=0}^{\infty}\varepsilon_k\Bigg[\frac{\exp\left(-\frac{2K}{1+\rho}\right)(1-\rho^2)^{m+n+k+1}\rho^{2l+k}K^{m+n+k}}{(1+\rho)^{2m+2n+2k}\,\Gamma(m+k+1)}$$
$$\times\frac{\gamma\left(l+m+k+1,\sqrt{\frac{K+1}{2\beta(1-\rho^2)}}r\right)\gamma\left(l+n+k+1,\sqrt{\frac{K+1}{2\beta(1-\rho^2)}}r\right)}{\Gamma(l+k+1)\,\Gamma(n+k+1)\,m!n!l!}\Bigg] \quad (23)$$

PDF of the output SIR can be obtained easily from previous expression:

$$p_r(r)=\frac{d}{dr}F_r(r) \quad (24)$$

By substituting (23) in (24), PDF of the output SIR can be given in the following form:

$$p_r(r)=\sum_{k=0}^{\infty}\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}\sum_{l=0}^{\infty}G_1\Bigg[\left(r\sqrt{\frac{K+1}{2\beta(1-\rho^2)}}\right)^{l+m+k}\exp\left(-r\sqrt{\frac{K+1}{2\beta(1-\rho^2)}}\right)$$
$$\times\gamma\left(l+k+n+1,r\sqrt{\frac{K+1}{2\beta(1-\rho^2)}}\right)+\left(r\sqrt{\frac{K+1}{2\beta(1-\rho^2)}}\right)^{l+k+n}$$
$$\times\exp\left(-r\sqrt{\frac{K+1}{2\beta(1-\rho^2)}}\right)\gamma\left(l+k+m+1,r\sqrt{\frac{K+1}{2\beta(1-\rho^2)}}\right)\Bigg] \quad (25)$$

with:

$$G_1 = \varepsilon_k \frac{\exp\left(-\frac{2K}{1+\rho}\right)(1-\rho^2)^{m+n+k+1}}{(1+\rho)^{2m+2n+2k}\,\Gamma(m+k+1)} \times \frac{\rho^{2l+k} K^{m+n+k}}{\Gamma(l+k+1)\,\Gamma(n+k+1)\,m!\,n!\,l!} \quad (26)$$

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

Outage probability (OP), P_{out} is defined as the probability that combined output falls below a given outage threshold r_{th}, also known as a protection ratio. Protection ratio depends on modulation technique and expected QoS. If the environment is interference limited, P_{out} is defined as the probability that the output SIR of used combiner falls below protection ratio:

$$P_{out} = P_R(r < r_{th}) = \int_0^{r_{th}} p_r(r)\,dt = F_r(r_{th}) \quad . \quad (27)$$

Average bit-error rate evaluation gives a good indication of system's performance, altought it does not provide information about the type of error. The average bit-error rate (ABER), $\bar{P}_e$,at the combiner's output is derived for non-coherent binary signalling, by averaging the conditional error probability, over the PDF of the output, according to following expression:

$$\bar{P}_e = \int_0^{\infty} p_r(r)\frac{1}{2}\exp(-gr)\,dr \quad (28)$$

where g denotes modulation constant, i.e. g=1 for BDPSK and g = 1/2 for BFSK modulation. Substituting (25) in (28), we derive closed form expressions for average BER in the form of:

$$P_e = \sum_{k=0}^{\infty}\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}\sum_{l=0}^{\infty} \frac{G_1}{2} \frac{\left(\sqrt{\frac{K+1}{2\beta(1-\rho^2)}}\right)^{2l+2k+n+m+1}\Gamma(2l+2k+n+m+2)}{\left(2\sqrt{\frac{K+1}{2\beta(1-\rho^2)}}+g\right)^{2l+2k+n+m+2}} \left[\frac{{}_2F_1\left(1, 2l+2k+n+m+2; l+n+k+2; \frac{\sqrt{\frac{K+1}{2\beta(1-\rho^2)}}}{2\sqrt{\frac{K+1}{2\beta(1-\rho^2)}}+g}\right)}{l+n+k+1} + \frac{{}_2F_1\left(1, 2l+2k+n+m+2; l+m+k+2; \frac{\sqrt{\frac{K+1}{2\beta(1-\rho^2)}}}{2\sqrt{\frac{K+1}{2\beta(1-\rho^2)}}+g}\right)}{l+m+k+1}\right] \quad (29)$$

with G_1 given above and ${}_2F_1(u_1,u_2;u_3;x)$, being the Gaussian hypergeometric function, given in [17]

By definition, the average output moment of p^{th} order is given as:

$$E\langle r^p \rangle \equiv \int_0^{\infty} r^p p_r(r)\,dr \quad (30)$$

Obtaining closed form expressions for average output moments of desired order is very important because trough average output moments of desired order we can analyze some very important system performances like amount of fading.

Amount of fading (AoF) is an unified measure of fading severity. This performance criterion is independent of the average fading power.

The AoF of the SC's output is defined as the ratio of the variance to the square mean SC output SIR and using (30) can be evaluated as:

$$AoF = \frac{var(t)}{\bar{S}^2} = \frac{E(t^2)}{\bar{S}^2} - 1 \quad (31)$$

Substituting (25) in (30), we derive closed form expressions for the average output moment of p^{th} order:

$$E\langle r^p \rangle = \sum_{k=0}^{\infty}\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}\sum_{l=0}^{\infty} G_1 \frac{\left(\sqrt{\frac{K+1}{2\beta(1-\rho^2)}}\right)^{2l+2k+n+m+1}\Gamma(2l+2k+n+m+p+2)}{\left(2\sqrt{\frac{K+1}{2\beta(1-\rho^2)}}\right)^{2l+2k+n+m+p+2}} \left[\frac{{}_2F_1\left(1, 2l+2k+n+m+p+2; l+n+k+2; \frac{1}{2}\right)}{l+n+k+1} + \frac{{}_2F_1\left(1, 2l+2k+n+m+p+2; l+m+k+2; \frac{1}{2}\right)}{l+m+k+1}\right] \quad (32)$$

3.1 Numerical results

CDF of the SC output, for various values of correlation coefficient ρ and fading severity parameter K is graphically presented in Fig.11.

PDF of the SC output, for various values of correlation coefficient ρ and fading severity parameter K is graphically presented in Fig.12.

Outage probability versus average power β normalized with protection ratio r_{th} for various values of correlation coefficient ρ and fading severity parameter K is graphically presented in Fig.13.

Outage probability versus correlation coefficient ρ for various values of fading severity parameter K is graphically presented in Fig.14.

Average bit error probability is shown on Fig. 15 for various values of correlation coefficient ρ and fading severity parameter K for BDPSK and BFSK modulation case. Average output moment of first order is shown on Fig. 16 versus correlation coefficient ρ for various values of fading severity parameter K.

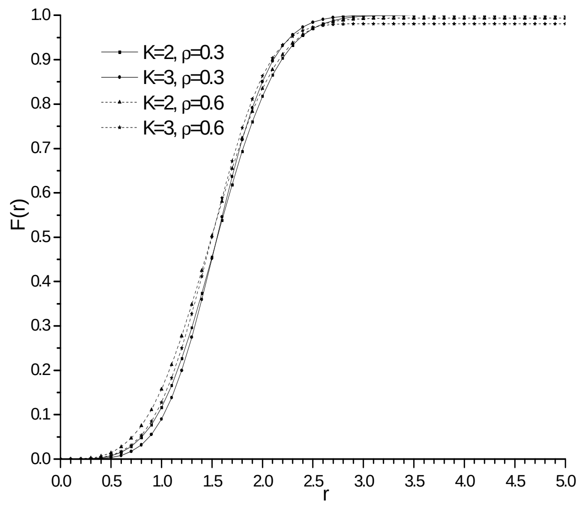

Fig.11. CDF of the SC output, for various values of correlation coefficient ρ and fading severity parameter K.

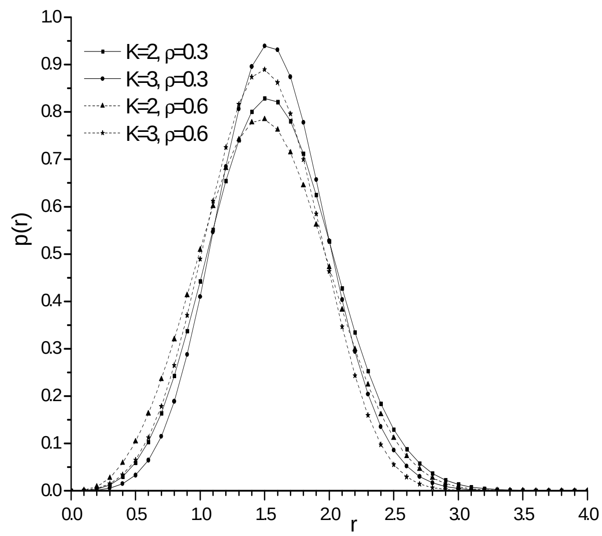

Fig.12. PDF of the SC output, for various values of correlation coefficient ρ and fading severity parameter K.

3.2 Comparing pervious numerical results

Plots of outage probability versus average power β normalized with protection ratio r_{th} for various values of correlation coefficient ρ and fading severity parameter K are graphically presented for SC combiner with two inputs are shown at Fig.13. It is obvious that for the outage probability increases slowly as the correlation coefficient increases. Also, the outage probability behavior improves as the value of K factor, which defines ratio of signal power in dominant component over the scattered power, increases (lower values of outage probability).

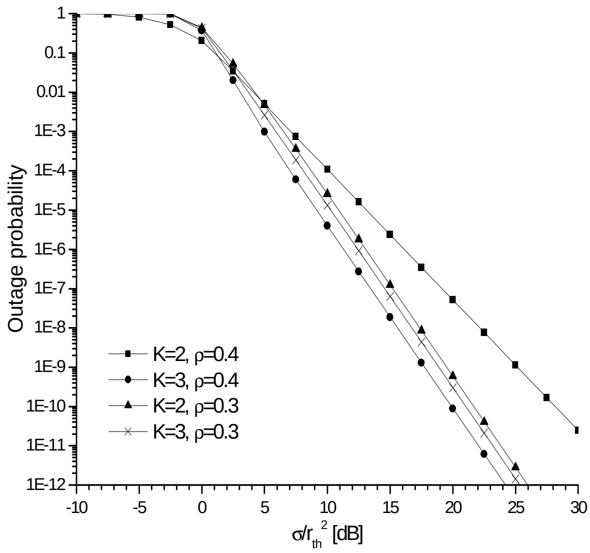

Fig. 13 Outage probability versus average power β normalized with protection ratio r_{th} for various values of correlation coefficient ρ and fading severity parameter K.

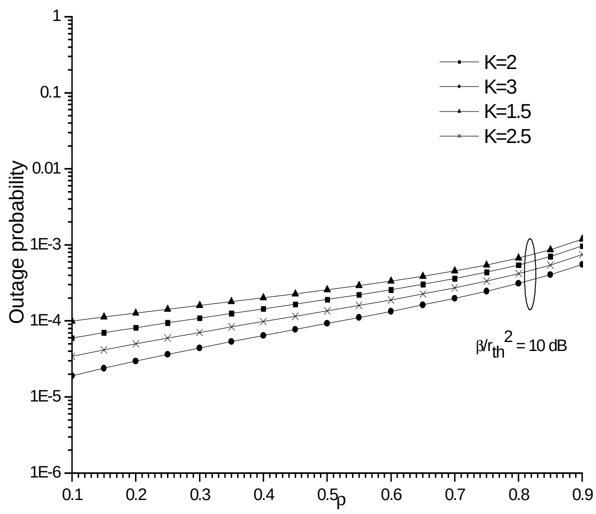

Fig. 14. Outage probability versus correlation coefficient ρ for various values of and fading severity parameter K

Plots of average bit error rate probability for SC combiner with two inputs are shown at Fig.15. It's shown that while as the signal correlation coefficient, ρ increases, the ABEP increases at the same time. Also we can see that increase of K factor value leads to decreasing of ABEP. Comparison of performances given in Fig.15 shows better performance of BDPSK modulation scheme versus BFSK modulation scheme.

Plots of average output moment of first order for SC combiner with two inputs are shown at Fig.16. It's shown that while as the signal correlation coefficient, ρ increases, diversity gain decreases with an increase of power correlation coefficient ρ, as expected. Also we can see that increase of K factor value leads to diversity gain increasing.

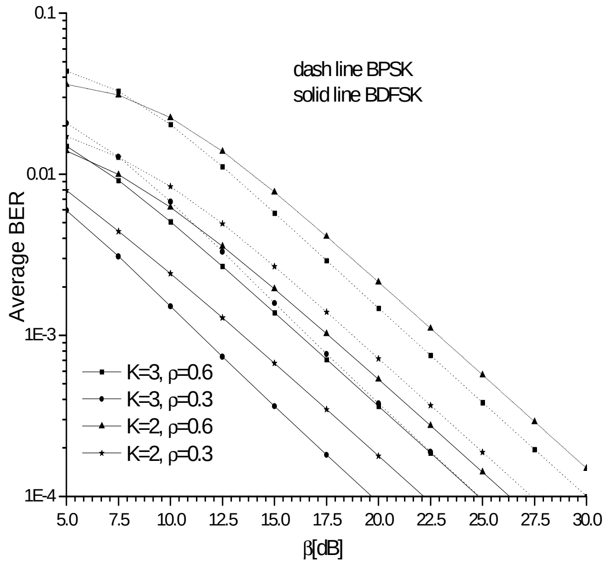

Fig. 15 Average bit error probability for various values of correlation coefficient ρ and fading severity parameter K.

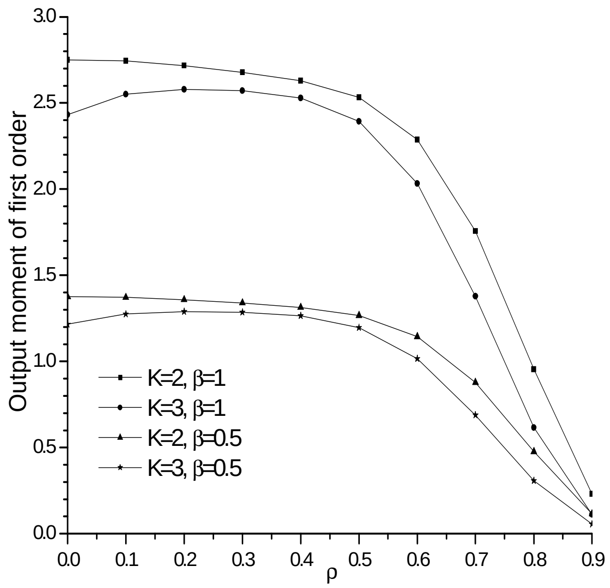

Fig. 16 Average output moment of first order versus correlation coefficient ρ for various fading severity parameter K.

4 Conclusion

In this paper we have discussed performances of the selection combining (SC) diversity system in the presence of independent and correlated Ricean fading. The main contribution of our work is deriving closed-form expressions, for probability density function (PDF), and cumulative density function (CDF), at the output of dual branch SC in the presence of correlated Ricean fading. Using these expressions we have presented closed form expressions for system performances such as: average bit error-rate and average output moments. All obtained results are graphically presented. Based on obtained numerical results, and their graphical presentation, we have discussed the influence of arbitrary values of correlation coefficient and Ricean K factor on dual branch SC diversity system performances. Based on results obtained for ABER, we have discussed the implementation of different modulation techniques and determined that BDPSK modulation gives better results. For the case of independent fading between the diversity branches, we have analyzed performances of SC diversity system which consists of two and four input branches. Comparison of obtained results leads to conclusion that diversity system which contains SC combiner with four inputs has much better performances than diversity system which contains SC combiner with two inputs.

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