ISSN 1330-3651(Print), ISSN 1848-6339 (Online)
UDC/UDK 621.391.81/.82

PERFORMANCE ANALYSIS OF DUAL-BRANCH SELECTION DIVERSITY RECEIVER THAT USES DESIRED SIGNAL ALGORITHM IN CORRELATED WEIBULL FADING ENVIRONMENT

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Original scientific paper

This paper focuses on performance analysis of dual-branch selection combining (SC) diversity system where both, desired signal as well as co-channel interference (CCI), are subjected to Weibull fading. For the case when desired signal algorithm is used as decision criterion, closed form expressions for joint probability density function (PDF) of desired signal and interference as well as PDF for instantaneous signal-to-interference ratio (SIR) at the system output are derived. These expressions are used for overall system performance analysis using outage probability, average bit error probability (ABEP) and average output SIR as system performance measures. Finally, the results obtained in this paper are compared to the previously published results for the same system that uses SIR based algorithm.

Keywords: *co-channel interference, correlated Weibull fading channels, desired signal algorithm, selection combining diversity*

Analiza karakteristika prijemnika višestrukog selektivnog kombiniranja s dvije grane koji koristi algoritam željenog signala u korelacijskom Weibull fedingu

Izvorni znanstveni članak

Rad je usmjeren na analizu karakteristika višestrukog sustava selektivnog kombiniranja (SC) s dvije grane gdje su i interferencija željenog signala i ko-kanalna interferencija (CCI) izložene Weibull fedingu. Za slučaj kada se algoritam željenog signala rabi kao kriterij za donošenje odluke izvedeni su izrazi zatvorenog oblika za zajedničku funkciju raspodjele vjerojatnosti (PDF) željenog signala i interferencije kao i PDF za trenutačni odnos signal-interferencija (SIR) na izlazu sustava. Ovi se izrazi rabe za analizu karakteristika cijeloga sustava rabeći vjerojatnost otkaza sustava, prosječnu vjerojatnost greške bita (ABEP) i prosječni izlaz SIR kao mjere za karakteristike sustava. Konačno, rezultati dobiveni u ovom radu uspoređeni su s ranije objavljenim rezultatima za isti sustav koji rabi algoritam na bazi SIR-a.

Ključne riječi: *ko-kanalna interferencija, korelacijski kanali Weibull fedinga, algoritam željenog signala, višestrukost selektivnog kombiniranja*

1 Introduction

Fading and co-channel interference (CCI) represent the main limitation of performance in many wireless communication systems. Fading is a result of multipath propagation while CCI represents the result of unavoidable frequency reuse. In order to control their effect, various models are used by system designers for describing the envelope of receiving signal. In the open technical literature, the most frequently used are Rayleigh, Rician, Nakagami-*m* and Weibull model, depending on propagation environment and communication scenario. Weibull model is simple and flexible and exhibits an excellent fit to experimental fading channel measurements for both indoor [1] and outdoor [2] environments.

Diversity reception is widely used as one of the simplest but also most efficient techniques for mitigating the destructive effects of fading and CCI in wireless communication systems. It is based on receiving the same information bearing signal over two or more paths and combining these multiple replicas [3]. The diversity paths can be based on space, frequency, and/or time diversity. Diversity techniques require some redundancy in time, frequency and/or spatial domain [4]. Compared with other diversity techniques, space diversity is power- and bandwidth-efficient, therefore it is the most common form of diversity [5]. The three principal types of space diversity combining techniques are maximal-ratio combining (MRC), equal-gain combining (EGC) and selection combining (SC). MRC is optimal combining technique in the sense that it achieves the highest output signal-to-noise ratio (SNR) but it requires estimations of channel fading amplitudes and phases of each diversity branch. These estimations require separate receiver chain for each branch of diversity system which increases its complexity. EGC combines signals from all branches with the same weighting factor. Among these types of diversity combining, SC is the least complicated for practical realization since the processing is performed only on one of the diversity branches.

In interference-limited environment, where the level of CCI is sufficiently high compared to noise, SC receiver can employ one of the combining algorithms: the desired signal algorithm, the total signal algorithm and the signal-to-interference ratio (SIR) algorithm [6]. In the desired signal algorithm, the receiver selects the branch with strongest desired signal power. In total signal algorithm, the combiner selects the branch with the strongest total received power (desired and interference) while in the SIR based algorithm, the branch with the highest SIR is selected.

The performance of uncorrelated *L*-branch SC receiver with non-identical Weibull statistic is presented in [7]. A dual SC receiver over correlated Weibull fading channels with arbitrary parameters is explored in [8]. SC diversity in interference-limited environment is studied in [9 ÷ 17]. Paper [9] conducted the analysis of the interference-limited case of SC in Nakagami fading environment for the desired signal algorithm, the SIR based algorithm and the total signal algorithm. Paper [10] introduced a unified approach for system performance analysis using the three decision algorithms where an analysis of dual-branch SC receiver subjected to multiple interferers over Rayleigh fading channels was presented as the specific application example. In [11], assuming that diversity branches are uncorrelated, the performance, in terms of outage probability, of SC diversity with different number of branches under Weibull/Weibull fading scenario (desired signals as well as interfering signals are Weibull faded) is analytically evaluated for two selection algorithms, maximum desired signal algorithm and maximum output SIR algorithm. The performance of dual-branch, triple-branch and *L*-branch SC operating over correlated Weibull fading channels based on SIR algorithm is considered in [12], [13] and [14], respectively. A closed form expression for probability density function (PDF) of SIR at the output of triple-branch SC receiver based on desired signal algorithm over correlated Weibull fading channels was derived in [15]. The same paper analyzes average bit error probability (ABEP) as a system performance measure, while [16] and [17] investigate average output SIR and outage probability of the same system, respectively.

This paper analytically evaluates the performance of dual-branch SC receiver over correlated Weibull fading channels in the presence of Weibull distributed CCI when desired signal algorithm is used. Exact closed form expressions for joint PDF of desired signal and interference as well as PDF for instantaneous SIR at the system output are derived. These results are used for system performance analysis and finally, they are compared to the results obtained in [12].

The rest of the paper is organized as follows. In Section 2, the system and channel model are presented and analytical expression for the PDF of SIR at the output of dual-branch SC receiver over correlated Weibull fading channels is derived. In Section 3, the graphical analysis of outage probability, ABEP and average output SIR of considered system is presented and discussed, while Section 4 concludes the paper.

2 System and channel model

This paper considers dual-branch SC diversity system operating over correlated Weibull fading channels. Both desired signal and interference are subjected to Weibull fading and their joint PDFs can be written as [18, Eq. (11)]

$$p_{x_1x_2}(x_1,x_2)=\exp\left[-\frac{1}{1-\rho}\left(\frac{x_1^{\beta_1}}{\Omega_{d_1}}+\frac{x_2^{\beta_2}}{\Omega_{d_2}}\right)\right]\times \\ \times\frac{\beta_1\beta_2}{\Omega_{d_1}\Omega_{d_2}}\frac{x_1^{\beta_1-1}x_2^{\beta_2-1}}{1-\rho}\mathrm{I}_0\left(\frac{2\sqrt{\rho}}{1-\rho}\frac{x_1^{\frac{\beta_1}{2}}x_2^{\frac{\beta_2}{2}}}{\sqrt{\Omega_{d_1}\Omega_{d_2}}}\right), \tag{1}$$

$$p_{y_1y_2}(y_1,y_2)=\exp\left[-\frac{1}{1-\rho}\left(\frac{y_1^{\beta_1}}{\Omega_{c_1}}+\frac{y_2^{\beta_2}}{\Omega_{c_2}}\right)\right]\times \\ \times\frac{\beta_1\beta_2}{\Omega_{c_1}\Omega_{c_2}}\frac{y_1^{\beta_1-1}y_2^{\beta_2-1}}{1-\rho}\mathrm{I}_0\left(\frac{2\sqrt{\rho}}{1-\rho}\frac{y_1^{\frac{\beta_1}{2}}y_2^{\frac{\beta_2}{2}}}{\sqrt{\Omega_{c_1}\Omega_{c_2}}}\right), \tag{2}$$

where ρ represents correlation coefficient, β_i is Weibull fading parameter $\beta_i>0$, which shows fading severity, and $\Omega_{di}=\overline{x_i^{\beta}}$ and $\Omega_{ci}=\overline{y_i^{\beta}}$ are the average powers of desired and interference signal at *i*-th branch ($i=\overline{1,2}$), respectively. $\mathrm{I}_n(\cdot)$ is the modified Bessel function of the first kind and *n*-th order [19, Eq. (8.445)].

Joint PDF of desired signal and interference at the output of dual-branch SC receiver based on desired signal algorithm can be calculated using the following equation

$$p_{xy}(x,y)=\int_0^x\int_0^\infty p_{x_1x_2}(x,x_2)p_{y_1y_2}(y,y_2)\,\mathrm{d}x_2\mathrm{d}y_2+ \\ +\int_0^x\int_0^\infty p_{x_1x_2}(x_1,x)p_{y_1y_2}(y_1,y)\,\mathrm{d}x_1\mathrm{d}y_1. \tag{3}$$

Substituting Eq. (1) and Eq. (2) in Eq. (3) and after several mathematical transformations, the joint PDF has the following form

$$p_{xy}(x,y)=y^{\beta_3-1}\sum_{i=0}^{\infty}\frac{\beta_1\beta_3}{\Omega_{d_1}^{i+1}\Omega_{c_1}}\frac{x^{i\beta_1+\beta_1-1}}{(i!)^2}\times \\ \times\exp\left[-\frac{x^{\beta_1}}{(1-\rho)\Omega_{d_1}}-\frac{y^{\beta_3}}{\Omega_{c_1}}\right]\times \\ \times\frac{\rho^i}{(1-\rho)^i}\gamma\left(i+1,\frac{x^{\beta_2}}{(1-\rho)\Omega_{d_2}}\right)+ \\ +y^{\beta_4-1}\sum_{j=0}^{\infty}\frac{\beta_2\beta_4}{\Omega_{d_2}^{j+1}\Omega_{c_2}}\frac{x^{j\beta_2+\beta_2-1}}{(j!)^2}\times \\ \times\exp\left[-\frac{x^{\beta_2}}{(1-\rho)\Omega_{d_2}}-\frac{y^{\beta_4}}{\Omega_{c_2}}\right]\times \\ \times\frac{\rho^j}{(1-\rho)^j}\gamma\left(j+1,\frac{x^{\beta_1}}{(1-\rho)\Omega_{d_1}}\right). \tag{4}$$

In this equation, $\gamma(a, b)$ is incomplete gamma function [19, Eq. (8.350/1)].

The PDF of instantaneous SIR at the output of dual SC diversity system can be calculated using

$$p_z(z)=\int_0^\infty y p_{xy}(zy,y)\,\mathrm{d}y. \tag{5}$$

After Eq. (4) is substituted in Eq. (5), the PDF for instantaneous SIR at the output of dual SC diversity system operating over Weibull fading channels for the case when $\beta_1=\beta_2=\beta$

$$p_z(z)=\frac{\beta}{\Omega_{c_1}}\sum_{i=0}^{\infty}\frac{\rho^i}{(1-\rho)^i}\frac{z^{i\beta+\beta-1}}{i!\Omega_{d_1}^{i+1}}\times \\ \times\left[\Gamma(i+2)\left(\frac{z^\beta}{(1-\rho)\Omega_{d_1}}+\frac{1}{\Omega_{c_1}}\right)^{-i-2}-\right. \\ -\sum_{m=0}^{i}\frac{1}{m!}\frac{z^{\beta m}}{(1-\rho)^m}\frac{\Gamma(i+m+2)}{\Omega_{d_2}^m}\times$$

$$\times\left(\frac{z^{\beta}}{(1-\rho)}\left(\frac{1}{\Omega_{d_1}}+\frac{1}{\Omega_{d_2}}\right)+\frac{1}{\Omega_{c_1}}\right)^{-i-m-2}\Bigg]+$$
$$+\frac{\beta}{\Omega_{c_2}}\sum_{j=0}^{\infty}\frac{\rho^{j}}{(1-\rho)^{j}}\frac{z^{j\beta+\beta-1}}{j!\,\Omega_{d_2}^{j+1}}\times$$
$$\times\left[\Gamma(j+2)\left(\frac{z^{\beta}}{(1-\rho)\Omega_{d_2}}+\frac{1}{\Omega_{c_2}}\right)^{-j-2}-\right. \quad (6)$$
$$-\sum_{n=0}^{j}\frac{1}{n!}\frac{z^{\beta n}}{(1-\rho)^{n}}\frac{\Gamma(i+n+2)}{\Omega_{d_1}^{n}}\times$$
$$\times\left.\left(\frac{z^{\beta}}{(1-\rho)}\left(\frac{1}{\Omega_{d_1}}+\frac{1}{\Omega_{d_2}}\right)+\frac{1}{\Omega_{c_2}}\right)^{-j-n-2}\right],$$

where $\Gamma(\alpha)$ represents the gamma function [19, Eq. (8.310/1)].

To the best of authors' knowledge, the presented results for joint PDF of desired and interfered signal and PDF of SIR at the output of dual branch SC receiver operating over correlated Weibull fading channels when system employs desired signal algorithm are novel in open technical literature.

As an illustrative example, Fig. 1 shows the PDF of SIR at the output of dual-branch SC receiver using desired signal algorithm for different values of correlation coefficient and average powers of desired signal and CCI.

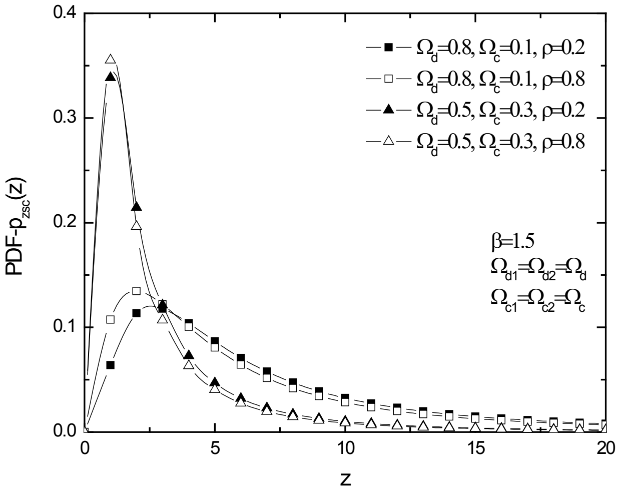

Figure 1 PDF of instantaneous SIR at the output of dual branch SC receiver employing desired signal algorithm

3 System performance measures

The system performance analysis is done using obtained expression for PDF of instantaneous SIR at the system output. Performance indicators that are considered in this section are outage probability, ABEP and average output SIR.

3.1 Outage probability

Outage probability represents one of the significant performance measures in fading environment. It is defined as the probability for the output SIR of the SC to fall below the specific threshold that depends on modulation technique applied and expected QoS.

$$P_{\text{out}} = \int_{0}^{z_{\text{th}}} p_z(z)\,\mathrm{d}z. \quad (7)$$

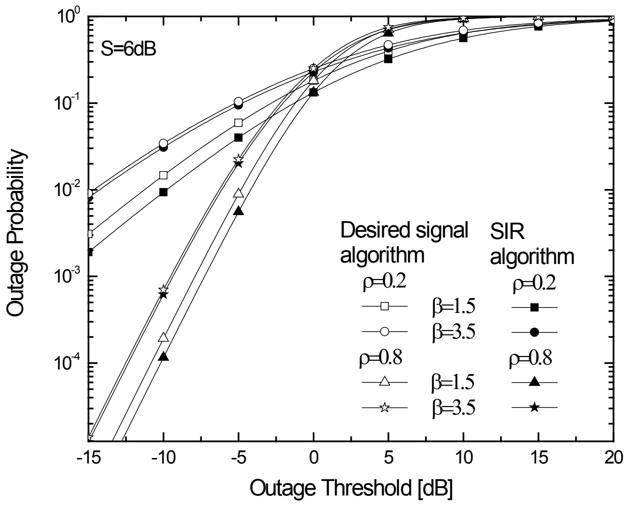

Figure 2 The comparison of system outage probability when desired signal algorithm and SIR based algorithm are employed for different values of correlation coefficient and fading parameter

Fig. 2 shows outage probability versus outage threshold for different values of fading parameters and correlation coefficient for the case when desired signal algorithm and SIR based algorithm are applied. It is obvious that for the same system parameters, in the case when desired signal algorithm is used, outage probability is higher therefore, SIR based algorithm gives better results for any given value of z_{th}. It is interesting to notice that for lower values of outage threshold, the outage probability decreases as correlation coefficient increases, while in the case of higher values of outage threshold (when desired signal dominates), the increasing of correlation coefficient leads to deterioration of system performance.

3.2 Average bit error probability (ABEP)

ABEP is another useful wireless communication system performance criterion. The most straightforward approach for obtaining it is averaging the conditional BEP over the PDF of the output SNR [20]

$$P_e = \int_{0}^{\infty} P_{ec}(\gamma) f_{\gamma}(\gamma)\,\mathrm{d}\gamma. \quad (8)$$

The comparison of the results obtained using desired signal algorithm and SIR based algorithm for the case when ABEP serves as a system performance measure is plotted in Fig. 3 and Fig. 4. The results are shown for BDPSK and BFSK signalling. ABEP is shown as a function of S. $S_i=\Omega_{di}/\Omega_{ci}$ represents the average SIR at the input of the i-th ($i=\overline{1,2}$) branch of balanced ($S_1=S_2=S$) selection combiner. Both figures show that in the case of SIR based algorithm, ABEP has lower values; therefore, system performance is better.

Fig. 3 illustrates the influence of correlation coefficient on ABEP. As the correlation coefficient decreases, the distance between antennas increases and system performance improves. For the case when correlation is too high, it is possible for deep fades in the branches to occur simultaneously resulting in low improvement degree of considered space diversity.

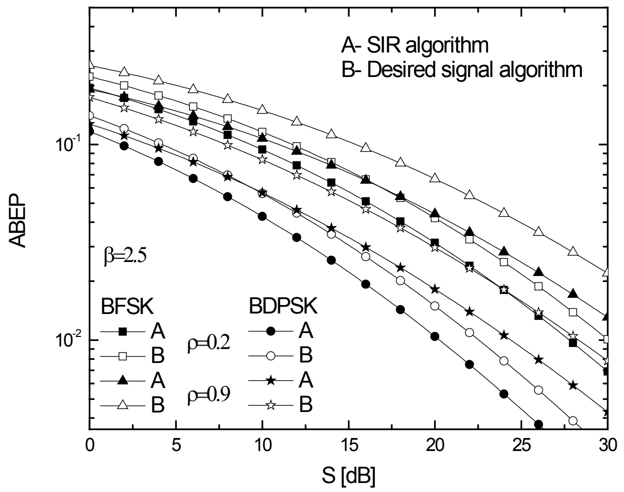

Figure 3 The influence of correlation coefficient on ABEP for system that uses desired signal algorithm and SIR based algorithm

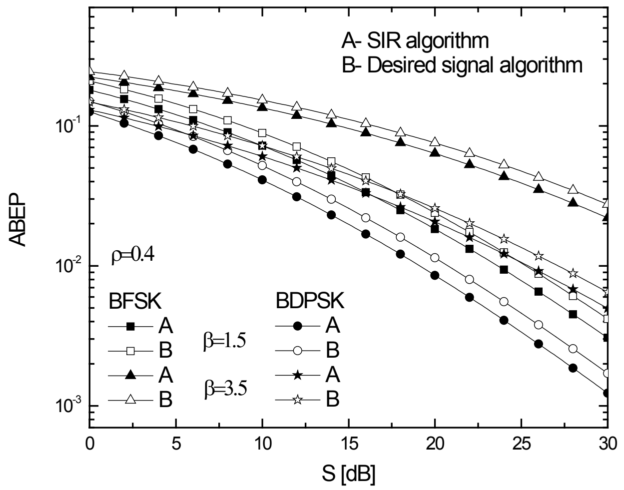

Figure 4 The influence of Weibull fading parameter on ABEP for desired signal algorithm and SIR based algorithm

In Fig. 4, ABEP of balanced dual-branch SC receiver for BFSK and BDPSK signalling for different fading severity is presented. It is notable that as the Weibull fading parameter increases, ABEP increases as well, therefore, the system performance deteriorates. It is interesting to note that for lower values of S, BDPSK signalling with higher value of β shows better system performance than BFSK signalling with lower value of β, while for the case when higher values of S are observed, the situation is vice versa. For comparison purpose of decision algorithms it is very convenient to define gain in dB achieved with SIR algorithm compared with desired signal algorithm as the reduction of S for the same ABEP. When ABEP has value of 0,1 and 0,01, the gain obtained with SIR algorithm in comparison with desired signal algorithm for ρ=0,4 is 4,3 dB and 3,3 dB, respectively, regardless of fading severity and signal modulation. The gain strongly depends on correlation coefficient and it is more expressed for higher values of correlation coefficient. As an illustrative example, for ABEP value of 0,01, the gain for ρ=0,2 is 4,3 dB and for ρ=0,9 the gain is 8 dB.

3.3 Average output SIR

One more parameter that is used in wireless communications when CCI is present is average output SIR. It can be calculated as

$$\overline{\mu}_{sc} = \int_0^\infty z p_z(z)\,\mathrm{d}z. \tag{9}$$

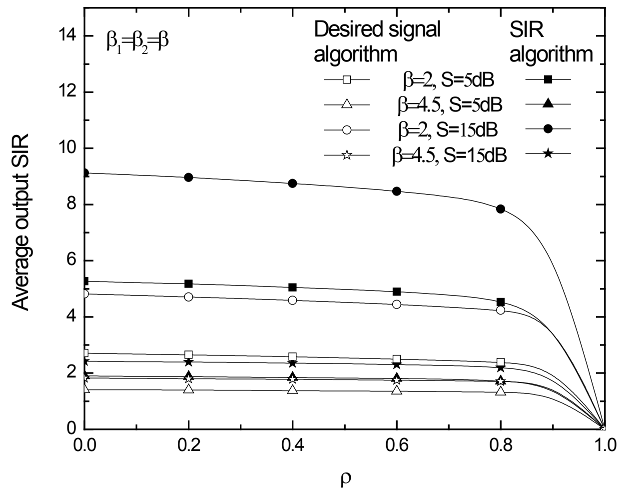

Figure 5 Comparison of the effect of correlation coefficient and fading severity on Average output SIR for a system that employs desired signal algorithm and SIR based algorithm

Fig. 5 shows the average output SIR of dual-branch SC system based on two deciding algorithms, desired signal and SIR based. The figure shows again that SIR based algorithm gives better results. The difference between these two algorithms is more significant for lower fading parameter and higher average SIR at the input of the corresponding branch. It is also notable that diversity gain decreases as ρ or fading parameters increase. The system performance degrades rapidly when values of correlation coefficient increases (as antennas are getting closer to each other) while it improves for higher values of S.

4 Conclusion

This paper considers dual-branch SC diversity system that operates over correlated Weibull channels for the case when desired signal algorithm is used. Closed forms for joint PDF of desired signal and interference as well as PDF for instantaneous SIR at the system output are derived. The overall system performance was evaluated using outage probability, ABEP and average output SIR as system performance measures. The results were compared with the previously published results obtained for the same system that uses SIR based algorithm. The outcome shows that the system that uses SIR based algorithm shows better overall performance results than the system that uses desired signal algorithm.

Acknowledgment

This work was supported by the Ministry of Science of Serbia within the project TR-32051 and TR-32052.

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Location

Renowned as a secluded seaside resort of the rich and famous, the town of Opatija is situated to the west of the city of Rijeka on the Adriatic coast. Opatija means “abbey” in Croatian, and the town is named after an abbey that was established by Benedictine monks in the 14th century of which its centre-point, St James’s Church, still stands.

The town of Opatija developed as an elite holiday resort in the mid-19th Century, and was frequented by European kings and emperors of the Austro-Hungarian monarchy. Tourism in this area has thrived and Opatija is still a popular location today, especially for European tourists. In the summer months, Opatija is a well-known setting for culture and the arts, hosting concerts, theatrical performances, film, literature and multimedia events.

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