Performance Analysis of Complex Combiner at Two Time Instants in Weibull Fading Channel

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Abstract **—The expressions for joint probability density function (PDF) of the Switch and Stay Combiner (SSC) output signal at two time instants in the presence of Weibull fading are determined in the closed form. Then, in this paper, these equations are used for calculation of the outage probability and amount of fading for complex Switch and Stay Combining/Maximal Ratio Combining (SSC/MRC) combiner versus different parameter values. The results are shown graphically in some figures and the analysis of the parameters influence and different types of combiners is given.**

Keywords - Probability Density Function; Joint Probability Density Function; Outage Probability, Amount of Fading, Weibull Fading; SSC/MRC Combiner

I. INTRODUCTION

In wireless communication, the main causes of signal degradations are random fluctuations of signal envelope and phase, which are caused by multipath scattering (fast fading) and shadowing (slow fading) [1]. The multipath fading is modeled by several distributions such as: Rayleigh, Rice, Nakagami-*m*, The Hoyt (Nakagami-*q*), Weibull.

The Weibull fading, named after Waloddi Weibull, is a simple statistical model of fading, is based on the Weibull distribution and used in wireless communications [2]-[4], particularly with mobile radio systems operating in the 800/900 MHz frequency range [5]. Empirical studies have shown it to be an effective model in both indoor [5] and outdoor [6] environments.

Theoretical model for a particular class of Weibull distributions was described by Sagias and Karagiannidis [7]. Also, they analyzed the channel capacity of wireless channels in the presence of Weibull fading [8].

Various techniques for reducing fading and shadow effects are used in wireless communication systems. They 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.

Multiple received copies of signal could be combined in different ways. Among the most popular are maximal ratio combining (MRC) and equal gain combining (EGC) [9]-[11]. Their complexity of implementation is relatively high since they require a separate channel for each diversity branch. Selection combining (SC) and switch and stay combining (SSC) are simpler diversity combining models, because they process only one from *L* diversity branches. SSC combiner usually chooses between two receiving antennas based on comparation of the signal value or SNR of connected antenna with previously determined threshold. This is reflected in less complexity toward SC combiner and it is not necessarily at the same time continued to monitor the two antennas. Because of that there is some loss in performances.

The probability density function (PDF) of the SSC combiner output signal at one time instant and the joint probability density function of the SSC combiner output signal at two time instants in the presence of Weibull fading are determined in [12].

The authors showed that the error probability and the outage probability are significantly reduced if the decision is performed in two time instants. The analysis of the complex SSC/SC combiner over outage probability at two time instants in the presence of Rayleigh and log-normal fading is done in [13] [14] and the bit error rate for complex SSC/MRC combiner at two time instants in the presence of Rayleigh, Nakagami-*m*, Hoyt and log-normal fading is done in [15]-[18], respectively.

The bit error rate for complex SSC/MRC combiner at two time instants in the presence of Weibull fading will be given in this paper since Weibull fading has great importance in the study of telecommunications systems. This investigation could be useful for designers of wireless telecommunication systems.

This paper is organized as follows: after Introduction, Section II introduces the model of complex combiner which performances will be considered in the next section. In Section III, the joint PDF of the SSC combiner output SNR at two time instants is calculated. Subsequently, in fourth Section the outage probability and amount of fading for complex Switch and Stay Combining/Maximal Ratio Combining (SSC/MRC) combiner are calculated and then in the fifth Section the numerical results are presented graphically. Final part of this paper is conclusion with an analysis of the obtained results.

II. SYSTEM MODEL

The complex SSC/MRC combiner, considered in this paper, is presented in Fig. 1. The complex combiner is with two inputs, at two time instants. The SSC combiner output signals are the input signals for MRC combiner.

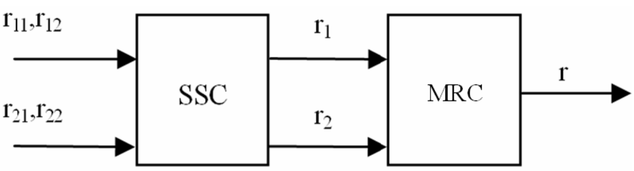

Figure 1. Model of complex combiner

At the inputs of the first part of complex combiner the signals are r_{11} and r_{21} at first time moment and they are r_{12} and r_{22} at second time moment. The first index represents the branch ordinal number and the other one signs the time instant observed.

The output signals from SSC part of complex combiner are r_1 and r_2. The indices at the output signal correspond to the time instants considered. These signals, r_1 and r_2, are the inputs for the MRC combiner. Finally, the overall output signal is r.

III. PERFORMANCE DERIVATION

The joint probability density function of correlated signals r_1 and r_2 at the SSC combiner output, at two time instants, Weibull distributed and with same parameters Ω_i and β_i [19], can be obtained in closed form from expressions in [12, eq. (15)-(18)] as

For $r_1<r_t$, $r_2<r_t$:

$$p_{r_1r_2}(r_1,r_2)=P_1A(r_1,\beta_2,\Omega_2)A(r_2,\beta_1,\Omega_1)+$$
$$+P_2A(r_1,\beta_1,\Omega_1)A(r_2,\beta_2,\Omega_2) \qquad (1)$$

For $r_1\geq r_t$, $r_2<r_t$

$$p_{r_1r_2}(r_1,r_2)=P_1A(r_1,\beta_1,\Omega_1)\frac{\beta_2}{\Omega_2}r_2^{\beta_2-1}e^{-\frac{r_2^{\beta_2}}{\Omega_2}}+$$
$$+P_1A(r_1,\beta_2,\Omega_2)A(r_2,\beta_1,\Omega_1)+$$
$$+P_2A(r_1,\beta_2,\Omega_2)\frac{\beta_1}{\Omega_1}r_2^{\beta_1-1}e^{-\frac{r_2^{\beta_1}}{\Omega_1}}+P_2A(r_1,\beta_1,\Omega_1)A(r_2,\beta_2,\Omega_2) \qquad (2)$$

For $r_1<r_t$, $r_2\geq r_t$

$$p_{r_1r_2}(r_1,r_2)=P_1\left(1-e^{-\frac{r_t^{\beta_1}}{\Omega_1}}\right)\frac{\beta_2^{\,2}(r_1r_2)^{\beta_1-1}}{\Omega_2^{\,2}(1-\rho)}e^{-\frac{1}{1-\rho}\left(\frac{r_1^{\beta_2}}{\Omega_2}+\frac{r_2^{\beta_2}}{\Omega_2}\right)}I_0\left[\frac{2\sqrt{\rho}r_1^{\beta_2/2}r_2^{\beta_2/2}}{(1-\rho)\Omega_2}\right]+$$
$$+P_1A(r_1,\beta_2,\Omega_2)A(r_2,\beta_1,\Omega_1)+$$
$$+P_2\left(1-e^{-\frac{r_t^{\beta_2}}{\Omega_2}}\right)\frac{\beta_1^{\,2}(r_1r_2)^{\beta_1-1}}{\Omega_1^{\,2}(1-\rho)}e^{-\frac{1}{1-\rho}\left(\frac{r_1^{\beta_1}}{\Omega_1}+\frac{r_2^{\beta_1}}{\Omega_1}\right)}I_0\left[\frac{2\sqrt{\rho}r_1^{\beta_1/2}r_2^{\beta_1/2}}{(1-\rho)\Omega_1}\right]+$$
$$+P_2A(r_1,\beta_1,\Omega_1)A(r_2,\beta_2,\Omega_2) \qquad (3)$$

For $r_1\geq r_t$, $r_2\geq r_t$

$$p_{r_1r_2}(r_1,r_2)=P_1\frac{\beta_1^{\,2}(r_1r_2)^{\beta_1-1}}{\Omega_1^{\,2}(1-\rho)}e^{-\frac{1}{1-\rho}\left(\frac{r_1^{\beta_1}}{\Omega_1}+\frac{r_2^{\beta_1}}{\Omega_1}\right)}I_0\left[\frac{2\sqrt{\rho}r_1^{\beta_1/2}r_2^{\beta_1/2}}{(1-\rho)\Omega_1}\right]+$$
$$+P_1A(r_1,\beta_1,\Omega_1)\frac{\beta_2}{\Omega_2}r_2^{\beta_2-1}e^{-\frac{r_2^{\beta_2}}{\Omega_2}}+P_1A(r_1,\beta_2,\Omega_2)A(r_2,\beta_1,\Omega_1)+$$
$$+P_1\left(1-e^{-\frac{r_t^{\beta_1}}{\Omega_1}}\right)\frac{\beta_2^{\,2}(r_1r_2)^{\beta_1-1}}{\Omega_2^{\,2}(1-\rho)}e^{-\frac{1}{1-\rho}\left(\frac{r_1^{\beta_2}}{\Omega_2}+\frac{r_2^{\beta_2}}{\Omega_2}\right)}I_0\left[\frac{2\sqrt{\rho}r_1^{\beta_2/2}r_2^{\beta_2/2}}{(1-\rho)\Omega_2}\right]+$$
$$+P_2\frac{\beta_1^{\,2}(r_1r_2)^{\beta_1-1}}{\Omega_1^{\,2}(1-\rho)}e^{-\frac{1}{1-\rho}\left(\frac{r_1^{\beta_1}}{\Omega_1}+\frac{r_2^{\beta_1}}{\Omega_1}\right)}I_0\left[\frac{2\sqrt{\rho}r_1^{\beta_1/2}r_2^{\beta_1/2}}{(1-\rho)\Omega_1}\right]+$$
$$+P_2A(r_1,\beta_2,\Omega_2)\frac{\beta_1}{\Omega_1}r_2^{\beta_1-1}e^{-\frac{r_2^{\beta_1}}{\Omega_1}}+P_2A(r_1,\beta_1,\Omega_1)A(r_2,\beta_2,\Omega_2)+$$
$$+P_2\left(1-e^{-\frac{r_t^{\beta_2}}{\Omega_2}}\right)\frac{\beta_1^{\,2}(r_1r_2)^{\beta_1-1}}{\Omega_1^{\,2}(1-\rho)}e^{-\frac{1}{1-\rho}\left(\frac{r_1^{\beta_1}}{\Omega_1}+\frac{r_2^{\beta_1}}{\Omega_1}\right)}I_0\left[\frac{2\sqrt{\rho}r_1^{\beta_1/2}r_2^{\beta_1/2}}{(1-\rho)\Omega_1}\right]+ \qquad (4)$$

where

$$A(r,\beta,\Omega)=\frac{\beta}{\Omega}r^{\beta-1}e^{-\frac{r^{\beta}}{\Omega}}\left[1-Q_1\left(\frac{\sqrt{2\rho}}{\sqrt{\Omega(1-\rho)}}r^{\beta/2},\frac{\sqrt{2}}{\sqrt{\Omega(1-\rho)}}r_t^{\beta/2}\right)\right].$$

The outputs of SSC combiner are used as inputs for MRC combiner. The PDF at the output of SSC/MRC combiner with two branches is given by [18]:

$$p_r(r)=\int_0^r p_{r_1r_2}(r_1,r-r_1)dr_1 \qquad (5)$$

Partials PDFs $p_i(r)$ for the SSC/MRC combiner output signal can be obtained substituting (1 - 4) in (5). For $r_1<r_T$, $r-r_1<r_T$ it is:

$$p_1(r) = \int_0^r dr_1 \left[P_1 A(r_1, \beta_2, \Omega_2) A(r_2, \beta_1, \Omega_1) + \right.$$

$$\left. + P_2 A(r_1, \beta_1, \Omega_1) A(r_2, \beta_2, \Omega_2) \right] \tag{6}$$

For $r_1 \geq r_T,\ r - r_1 < r_T$

$$p_2(r) = \int_{r_t}^r dr_1 \left[P_1 A(r_1, \beta_1, \Omega_1) \frac{\beta_2}{\Omega_2} r_2^{\beta_2 - 1} e^{-\frac{r_2^{\beta_2}}{\Omega_2}} + \right.$$

$$+ P_1 A(r_1, \beta_2, \Omega_2) A(r_2, \beta_1, \Omega_1) +$$

$$\left. + P_2 A(r_1, \beta_2, \Omega_2) \frac{\beta_1}{\Omega_1} r_2^{\beta_1 - 1} e^{-\frac{r_2^{\beta_1}}{\Omega_1}} + P_2 A(r_1, \beta_1, \Omega_1) A(r_2, \beta_2, \Omega_2) \right] \tag{7}$$

For $r_1 < r_T,\ r - r_1 \geq r_T$:

$$p_3(r) = \int_0^{r_t} dr_1 \left[P_1 \left(1 - e^{-\frac{r_t^{\beta_1}}{\Omega_1}} \right) \frac{\beta_2^{\,2} (r_1 r_2)^{\beta_1 - 1}}{\Omega_2^{\,2} (1-\rho)} e^{-\frac{1}{1-\rho}\left(\frac{r_1^{\beta_2}}{\Omega_2} + \frac{r_2^{\beta_2}}{\Omega_2} \right)} I_0 \left[\frac{2\sqrt{\rho}\, r_1^{\beta_2/2} r_2^{\beta_2/2}}{(1-\rho)\Omega_2} \right] + \right.$$

$$+ P_1 A(r_1, \beta_2, \Omega_2) A(r_2, \beta_1, \Omega_1) +$$

$$+ P_2 \left(1 - e^{-\frac{r_t^{\beta_2}}{\Omega_2}} \right) \frac{\beta_1^{\,2} (r_1 r_2)^{\beta_1 - 1}}{\Omega_1^{\,2} (1-\rho)} e^{-\frac{1}{1-\rho}\left(\frac{r_1^{\beta_1}}{\Omega_1} + \frac{r_2^{\beta_1}}{\Omega_1} \right)} I_0 \left[\frac{2\sqrt{\rho}\, r_1^{\beta_1/2} r_2^{\beta_1/2}}{(1-\rho)\Omega_1} \right] +$$

$$\left. + P_2 A(r_1, \beta_1, \Omega_1) A(r_2, \beta_2, \Omega_2) \right] \tag{8}$$

For $r_1 \geq r_T,\ r - r_1 \geq r_T$

$$p_4(r) = \int_{r_t}^r dr_1 \left[P_1 \frac{\beta_1^{\,2} (r_1 r_2)^{\beta_1 - 1}}{\Omega_1^{\,2} (1-\rho)} e^{-\frac{1}{1-\rho}\left(\frac{r_1^{\beta_1}}{\Omega_1} + \frac{r_2^{\beta_1}}{\Omega_1} \right)} I_0 \left[\frac{2\sqrt{\rho}\, r_1^{\beta_1/2} r_2^{\beta_1/2}}{(1-\rho)\Omega_1} \right] + \right.$$

$$+ P_1 A(r_1, \beta_1, \Omega_1) \frac{\beta_2}{\Omega_2} r_2^{\beta_2 - 1} e^{-\frac{r_2^{\beta_2}}{\Omega_2}} + P_1 A(r_1, \beta_2, \Omega_2) A(r_2, \beta_1, \Omega_1) +$$

$$+ P_1 \left(1 - e^{-\frac{r_t^{\beta_1}}{\Omega_1}} \right) \frac{\beta_2^{\,2} (r_1 r_2)^{\beta_1 - 1}}{\Omega_2^{\,2} (1-\rho)} e^{-\frac{1}{1-\rho}\left(\frac{r_1^{\beta_2}}{\Omega_2} + \frac{r_2^{\beta_2}}{\Omega_2} \right)} I_0 \left[\frac{2\sqrt{\rho}\, r_1^{\beta_2/2} r_2^{\beta_2/2}}{(1-\rho)\Omega_2} \right] +$$

$$+ P_2 \frac{\beta_1^{\,2} (r_1 r_2)^{\beta_1 - 1}}{\Omega_1^{\,2} (1-\rho)} e^{-\frac{1}{1-\rho}\left(\frac{r_1^{\beta_1}}{\Omega_1} + \frac{r_2^{\beta_1}}{\Omega_1} \right)} I_0 \left[\frac{2\sqrt{\rho}\, r_1^{\beta_1/2} r_2^{\beta_1/2}}{(1-\rho)\Omega_1} \right] +$$

$$+ P_2 A(r_1, \beta_2, \Omega_2) \frac{\beta_1}{\Omega_1} r_2^{\beta_1 - 1} e^{-\frac{r_2^{\beta_1}}{\Omega_1}} + P_2 A(r_1, \beta_1, \Omega_1) A(r_2, \beta_2, \Omega_2) +$$

$$\left. + P_2 \left(1 - e^{-\frac{r_t^{\beta_2}}{\Omega_2}} \right) \frac{\beta_1^{\,2} (r_1 r_2)^{\beta_1 - 1}}{\Omega_1^{\,2} (1-\rho)} e^{-\frac{1}{1-\rho}\left(\frac{r_1^{\beta_1}}{\Omega_1} + \frac{r_2^{\beta_1}}{\Omega_1} \right)} I_0 \left[\frac{2\sqrt{\rho}\, r_1^{\beta_1/2} r_2^{\beta_1/2}}{(1-\rho)\Omega_1} \right] + \right] \tag{9}$$

The PDF at the output of MRC/SSC combiner is the sum of components $p_i(r)$:

$$p_r(r) = p_1(r) + p_2(r) + p_3(r) + p_4(r) \tag{10}$$

Relatively simple closed form expressions for representing $p_r(r)$ can not be derived, because (6) – (9) are too complex for tractable communication system analyses, but the PDF can be evaluated numerically using software tools.

IV. OUTAGE PROBABILITY AND AMOUNT OF FADING

The outage probability is a very useful performance measure for diversity systems operating in fading environments. The outage probability is defined as the probability that the combiner output signal value falls below a given threshold r_{th}, also known as a protection ratio. The outage probability $P_{out}(r_{th})$ is defined as [17]:

$$P_{out}(r_{th}) = \int_0^{r_{th}} p_r(r) dr \tag{11}$$

Substituting (10) in (11), $P_{out}(r_{th})$ can be written as:

$$P_{out}(r_{th}) = \int_0^{r_{th}} \left[p_1(r) + p_2(r) + p_3(r) + p_4(r) \right] dr \tag{12}$$

Amount of fading (AF) is a unified measure of the severity of fading for particular channel model and is typically independent of the average fading power, but is dependent of the instantaneous SNR. Amount of fading for MRC combiner is defined by [17]:

$$AF = \frac{E[r^2]}{(E[r])^2} - 1 = \frac{E[(r_1 + r_2)^2]}{(E[(r_1 + r_2)])^2} - 1 \tag{13}$$

where $E(r)$ is N-th moment of r. By putting (6) – (9) into (13), AF is finally:

$$AF = \frac{\int_0^\infty \left[p_1(r) + p_2(r) + p_3(r) + p_4(r) \right] r^2 dr}{\left(\int_0^\infty \left[p_1(r) + p_2(r) + p_3(r) + p_4(r) \right] r dr \right)^2} - 1 \tag{14}$$

V. NUMERICAL RESULTS

The bit error rate curves, for different types of combiners and correlation parameters, are presented in Figs. 2 and 3.

It is assumed that both branches at the input have the same channel parameters. r_t is the optimal decision threshold. It is defined as [14]:

$$r_t = \Omega^{\frac{1}{\beta}}\Gamma\left(1+\frac{1}{\beta}\right) \quad (15)$$

The family of curves for the outage probabilities is given in Fig. 2 for four different cases: 1) one channel receiver, 2) MRC combiner at one time instant, 3) SSC/MRC combiner at two time instants for uncorrelated case and 4) SSC/MRC combiner at two time instants for very strong correlation.

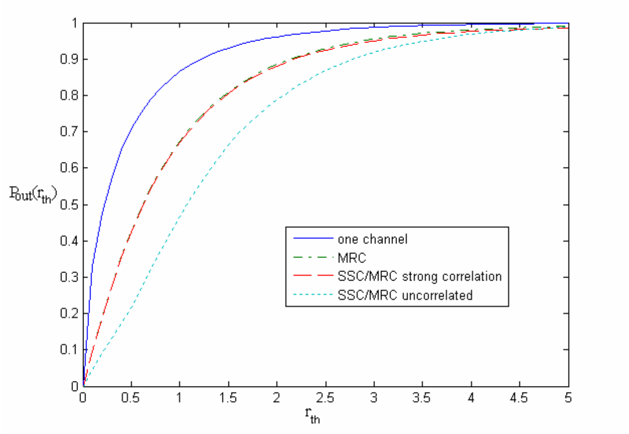

Figure 2. Outage probability for different types of combiners for parameters β=0.7 and Ω=0.5

One can see from this figure that SSC/MRC combiner has significant better performance for both, uncorrelated case and for completely correlated signals (ρ =1), regarding classical MRC combiner at one time instant and one single channel receiver.

The outage probability curves for SSC/MRC combiner, for different values of correlation coefficient ρ, are presented in Fig. 3.

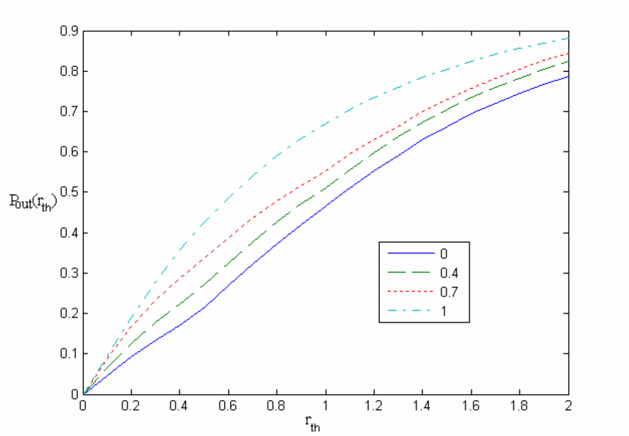

Figure 3. Outage probability for SSC/MRC combiner for parameters β=0.7 and Ω=0.5 and for different values of correlation coefficient ρ

It can be seen from Fig. 3 that SSC/MRC combiner has better performance for uncorrelated signals.

The amount of fading for one channel receiver, for MRC combiner at one time instant and for SSC/MRC combiner at two time instants, for uncorrelated case and for very strong correlation, is shown in Fig. 4.

It can be seen from Fig. 4 that SSC/MRC combiner has, once again, the best performance for uncorrelated case then the other combiners. The worst case is the case with one channel, i.e., without diversity combining at all.

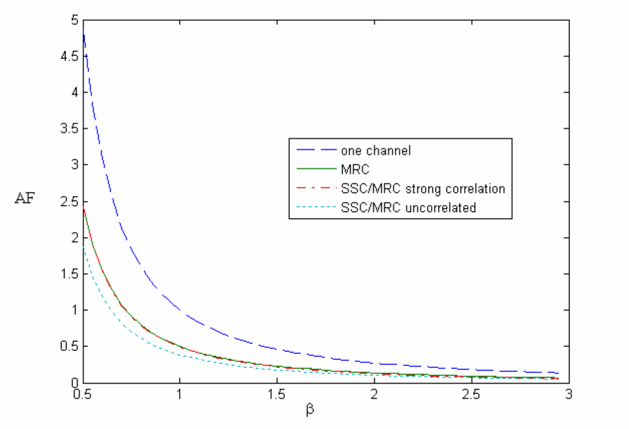

Figure 4. Amount of fading for different types of combiners for Ω=0.5

One can conclude from these figures that complex SSC/MRC combiner has better performance for uncorrelated case then MRC combiner at one time instant. For the value of correlation coefficient ρ = 1, the results of complex SSC/MRC combiner follows the results for MRC combiner. It is evident that usage of this complex SSC/MRC combiner gives better performance in the entire range, except in the case of strongly correlated signals. In this situaton it is not economic to use complex combiner. Thus, the advantages of utilization such type of complex combiner increases with decreasing of correlation between input signals.

VI. CONCLUSION

In diversity systems, SSC and MRC combining are often used techniques for combining signals. The performance of systems which make decision by two samples could be determined by the joint probability density function of SSC combiner output signals at two time instants. Then, they are involved in MRC combiner. Here, the joint PDF of SSC/MRC combiner output signal at two time instants in the presence of Weibull fading, derived earlier in closed form expressions, is used for outage probability and amount of fading determination.

The results are presented in some figures versus different parameters. It is evident that system performance is upgraded by use the mannerism of this complex combiner and sampling at two time moments. Obtained results are better compared with classical SSC and MRC combiners

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except for very strong correlation between signals. In that case the performance curves for complex combiner and MRC combiner are coinciding.

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