Reducing the Impact of Different Distributed Fading and Shadowing in Channels Using the Diversity Technique

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Characteristics of the SSC Combiner

- Model of the system at one time instant
- Model of the system at two time instants

- Joint PDF for SSC Combiner Output Signal at Two Time Instants in Fading Channel
- Probability density function of signal derivatives at the output of SSC combiner at two time instants

- Various statistical models explain the nature of fading and several distributions describe fading statistics: Rayleigh, Rice, Nakagami-*m*, Hoyt, Weibull, α-μ,…

- Nakagami-*m* distribution is preferred because wide range of its applicability and mathematical tractability
- It can be reduced to Rayleigh distribution for appropriate value of parameter *m*

- The main problem is to find such distribution which adequately fit to measured data
- One of the distributions that show good fit with experimental data is Weibull distribution

- To describe the fading models, besides the Weibull, there is a more generalized α-μ distribution
- It is valid for the non-linearity of the propagation medium as well as for the multipath clustering

- The α-μ distribution is a general fading distribution that can be used to represent the small-scale variation of the fading signal in a non-line-of-sight fading condition
- This fading model providing a very good fit to measured data over a wide range of fading conditions

- This distribution has two physical parameters, α and μ
- The parameter α is related to the non-linearity of the environment, whereas the parameter μ is associated to the number of multipath clusters

- Diversity technique is one of the most used methods for minimizing fading effect and increasing the communication reliability without enlarging either transmitting power or channel's bandwidth
- Diversity techniques combine the multiple received signals in reception device, on different ways

- There are several types of diversity combining techniques:
- \- Maximum ratio combining (MRC) and
- -Equal gain combining (EGC) techniques

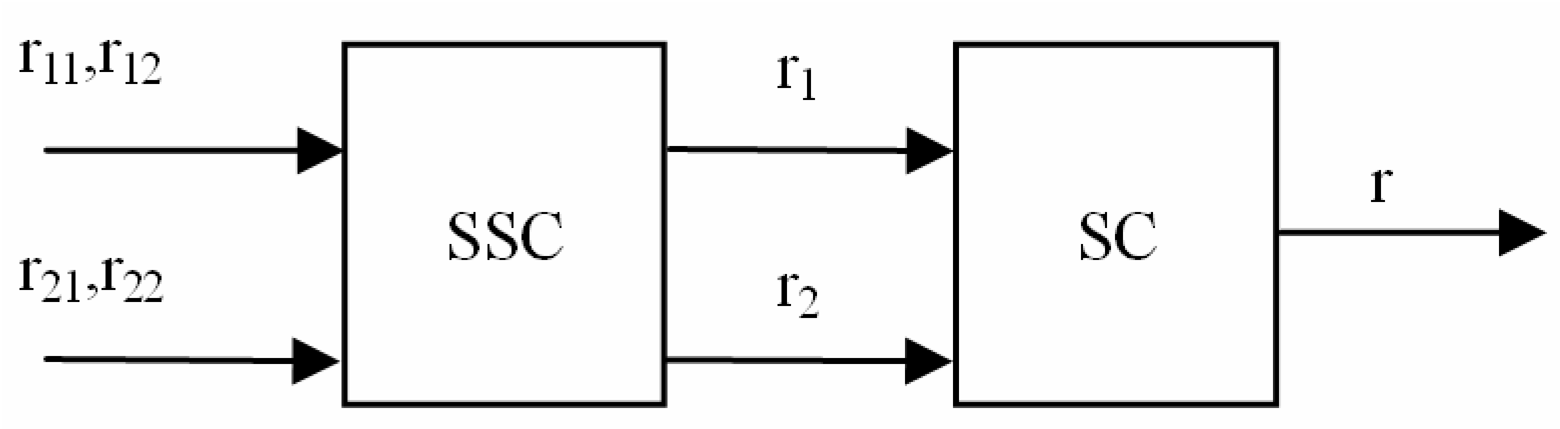
- They require more information about channel: fading amplitude, phase and delay

- The implementation of these diversity techniques is quite complex and expensive since they require a separate receiver for each branch

- Selection combining (SC) diversity technique is simpler for implementation because the SC systems process only one of the diversity branches
- If the noise power is equally distributed over branches, SC receiver selects the branch with the highest signal-to-noise ratio (SNR) and that is the branch with the strongest signal.

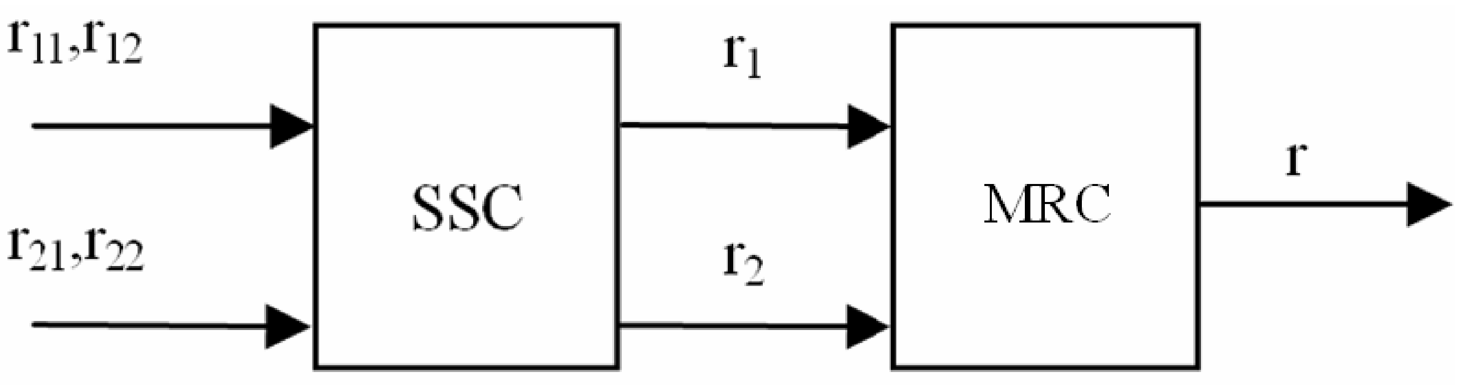
- In fading environments, when the level of noise is sufficiently low compared with the level of co-channel interference (CCI) SC combiner processes the branch with the highest signal-to-interference ratio (SIR-based selection diversity)

- SSC receiver selects one antenna until its quality falls below a predetermined threshold
- After this, receiver switches to second antenna whereas the signal from this antenna is below or above the threshold



System model for complex dual SSC/SC combiner

System model



System model for complex dual SSC/MRC combiner

Introduction

- The complex Switch and Stay Combining/ Selection Combining or Maximal Ratio Combining (SSC/SC or SSC/MRC) combiner are considered
- All SSC, SC and MRC combiners are dual-branches
- Up to now, composite combiner at two time instants, has not been considered

System model

- At the inputs of the first part of complex combiner the signals are r_{11} and r_{21} at first time moment
- They are r_{12} and r_{22} at second time moment
- The output signals from SSC part of complex combiner are r_1 and r_2

System model

- The first index represents the branch ordinal number and the other one signs the time instant observed
- The SSC combiner output signals r_1 and r_2 are the inputs for the MRC combiner
- Signals at antennas in branches are independent

- Different fading distributions are determined here:
- - Weibull,
- - Gamma,
- - Rayleigh,
- -Rice...

PDF of the combiner output signal at two time instants

for $r_1 < r_T, r_2 < r_T$

$$p_{r_1 r_2}(r_1, r_2) = P_1 \cdot \int_0^{r_T} dr_{11} \int_0^{r_T} dr_{22}\, p_{r_{11} r_{22} r_{21} r_{12}}(r_{11}, r_{22}, r_1, r_2) + P_2 \cdot \int_0^{r_T} dr_{21} \int_0^{r_T} dr_{12}\, p_{r_{21} r_{12} r_{11} r_{22}}(r_{21}, r_{12}, r_1, r_2)$$

for $r_1 \geq r_T,\ r_2 < r_T$

$$p_{r_1 r_2}(r_1, r_2) = P_1 \cdot \int_0^{r_T} dr_{12}\, p_{r_{12} r_{11} r_{22}}(r_{12}, r_1, r_2) + P_1 \cdot \int_0^{r_T} dr_{11} \int_0^{r_T} dr_{22}\, p_{r_{11} r_{22} r_{21} r_{12}}(r_{11}, r_{22}, r_1, r_2) +$$

$$+ P_2 \cdot \int_0^{r_T} dr_{22}\, p_{r_{22} r_{21} r_{12}}(r_{22}, r_1, r_2) + P_2 \cdot \int_0^{r_T} dr_{21} \int_0^{r_T} dr_{12}\, p_{r_{21} r_{12} r_{11} r_{22}}(r_{21}, r_{12}, r_1, r_2)$$

for $r_1 < r_T,\ r_2 \geq r_T$

$$p_{r_1 r_2}(r_1, r_2) = P_1 \cdot \int_0^{r_T} dr_{11}\, p_{r_{11} r_{21} r_{22}}(r_{11}, r_1, r_2) + P_1 \cdot \int_0^{r_T} dr_{11} \int_0^{r_T} dr_{22}\, p_{r_{11} r_{22} r_{21} r_{12}}(r_{11}, r_{22}, r_1, r_2) +$$

$$+ P_2 \cdot \int_0^{r_T} dr_{21}\, p_{r_{21} r_{11} r_{12}}(r_{21}, r_1, r_2) + P_2 \cdot \int_0^{r_T} dr_{21} \int_0^{r_T} dr_{12}\, p_{r_{21} r_{12} r_{11} r_{22}}(r_{21}, r_{12}, r_1, r_2)$$

PDF of the combiner output signal at two time instants

for $r_1 \ge r_T, r_2 \ge r_T$

$$\begin{aligned}
p_{r_1 r_2}(r_1, r_2) &= P_1 \cdot p_{r_{11} r_{12}}(r_1, r_2) + P_1 \cdot \int_0^{r_T} dr_{12}\, p_{r_{12} r_{11} r_{22}}(r_{12}, r_1, r_2) + \\
&+ P_1 \cdot \int_0^{r_T} dr_{11}\, p_{r_{11} r_{21} r_{22}}(r_{11}, r_1, r_2) + P_1 \cdot \int_0^{r_T} dr_{11} \int_0^{r_T} dr_{22}\, p_{r_{11} r_{22} r_{21} r_{12}}(r_{11}, r_{22}, r_1, r_2) + \\
&+ P_2 \cdot p_{r_{21} r_{22}}(r_1, r_2) + P_2 \cdot \int_0^{r_T} dr_{22}\, p_{r_{22} r_{21} r_{12}}(r_{22}, r_1, r_2) + \\
&+ P_2 \cdot \int_0^{r_T} dr_{21}\, p_{r_{21} r_{11} r_{12}}(r_{21}, r_1, r_2) + P_2 \cdot \int_0^{r_T} dr_{21} \int_0^{r_T} dr_{12}\, p_{r_{21} r_{12} r_{11} r_{22}}(r_{21}, r_{12}, r_1, r_2)
\end{aligned}$$

The joint PDF at the SSC combiner output at two time instants (Weibull)

$r_1 < r_T$, $r_2 < r_T$

(2)

$$p_{r_1 r_2}(r_1, r_2) = P_1 A(r_1, \beta_2, \Omega_2) A(r_2, \beta_1, \Omega_1) +$$
$$+ P_2 A(r_1, \beta_1, \Omega_1) A(r_2, \beta_2, \Omega_2)$$

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 joint PDF at the SSC combiner output at two time instants

$r_1 \geq r_T,\ r_2 < r_T$

(2)

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

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

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

The joint PDF at the SSC combiner output at two time instants

$r_1 < r_T,\ r_2 \geq r_T$

(2)

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

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

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

$$+ P_2 A(r_1, \beta_1, \Omega_1) A(r_2, \beta_2, \Omega_2)$$

The joint PDF at the SSC combiner output at two time instants

$r_1 \geq r_T,\ r_2 \geq r_T$

(2)

$$
\begin{aligned}
p_{r_1 r_2}(r_1, r_2) = {} & P_1 \frac{\beta_1^{\,2} (r_1 r_2)^{\beta_1 - 1}}{\Omega_1^{\,2}(1-\rho)} e^{-\frac{1}{1-\rho}\left(\frac{r_1^{\beta_1}}{\Omega_1} + \frac{r_2^{\beta_1}}{\Omega_1}\right)} I_0\left[\frac{2\sqrt{\rho}\, r_1^{\beta_1/2} r_2^{\beta_1/2}}{(1-\rho)\Omega_1}\right] + \\
& + P_1 A(r_1, \beta_1, \Omega_1) \frac{\beta_2}{\Omega_2} r_2^{\beta_2 - 1} e^{-\frac{r_2^{\beta_2}}{\Omega_2}} + P_1 A(r_1, \beta_2, \Omega_2) A(r_2, \beta_1, \Omega_1) + \\
& + P_1 \left(1 - e^{-\frac{r_1^{\beta_1}}{\Omega_1}}\right) \frac{\beta_2^{\,2} (r_1 r_2)^{\beta_1 - 1}}{\Omega_2^{\,2}(1-\rho)} e^{-\frac{1}{1-\rho}\left(\frac{r_1^{\beta_2}}{\Omega_2} + \frac{r_2^{\beta_2}}{\Omega_2}\right)} I_0\left[\frac{2\sqrt{\rho}\, r_1^{\beta_2/2} r_2^{\beta_2/2}}{(1-\rho)\Omega_2}\right] + \\
& + P_2 \frac{\beta_1^{\,2} (r_1 r_2)^{\beta_1 - 1}}{\Omega_1^{\,2}(1-\rho)} e^{-\frac{1}{1-\rho}\left(\frac{r_1^{\beta_1}}{\Omega_1} + \frac{r_2^{\beta_1}}{\Omega_1}\right)} I_0\left[\frac{2\sqrt{\rho}\, r_1^{\beta_1/2} r_2^{\beta_1/2}}{(1-\rho)\Omega_1}\right] + \\
& + P_2 A(r_1, \beta_2, \Omega_2) \frac{\beta_1}{\Omega_1} r_2^{\beta_1 - 1} e^{-\frac{r_2^{\beta_1}}{\Omega_1}} + P_2 A(r_1, \beta_1, \Omega_1) A(r_2, \beta_2, \Omega_2) +
\end{aligned}
$$

Joint PDF of two correlated signals

- The joint probability density function of correlated signals r_1 and r_2 with Gamma distribution and the same σ is

$$p_{r_1 r_2}(r_1, r_2) = \frac{\rho^{-\frac{c-1}{2}}}{\Gamma(c)(1-\rho)\Omega^{c+1}} \left(x_1 x_2\right)^{\frac{c-1}{2}} e^{-\frac{x_1+x_2}{(1-\rho)\Omega}} I_{c-1}\left(\frac{2\sqrt{\rho x_1 x_2}}{(1-\rho)\Omega}\right)$$

Joint PDF of SSC combiner in the presence of Rayleigh fading

Za $r_1<r_T$, $r_2<r_T$

$$p_{r_1r_2}(r_1,r_2)=P_1\frac{r_1}{\sigma_2^{\,2}}e^{-\frac{r_1^2}{2\sigma_2^2}}\frac{r_2}{\sigma_1^{\,2}}e^{-\frac{r_2^2}{2\sigma_1^2}}\left[1-Q_1\left(\frac{\rho r_1}{\sigma_2\sqrt{1-\rho^2}},\frac{r_T}{\sigma_2\sqrt{1-\rho^2}}\right)\right]\left[1-Q_1\left(\frac{\rho r_2}{\sigma_1\sqrt{1-\rho^2}},\frac{r_T}{\sigma_1\sqrt{1-\rho^2}}\right)\right]+$$

$$+P_2\frac{r_1}{\sigma_1^{\,2}}e^{-\frac{r_1^2}{2\sigma_1^2}}\frac{r_2}{\sigma_2^{\,2}}e^{-\frac{r_2^2}{2\sigma_2^2}}\left[1-Q_1\left(\frac{\rho r_1}{\sigma_1\sqrt{1-\rho^2}},\frac{r_T}{\sigma_1\sqrt{1-\rho^2}}\right)\right]\left[1-Q_1\left(\frac{\rho r_2}{\sigma_2\sqrt{1-\rho^2}},\frac{r_T}{\sigma_2\sqrt{1-\rho^2}}\right)\right]$$

Za $r_1\geq r_T$, $r_2<r_T$

$$p_{r_1r_2}(r_1,r_2)=P_1\frac{r_1}{\sigma_1^{\,2}}e^{-\frac{r_1^2}{2\sigma_1^2}}\frac{r_2}{\sigma_2^{\,2}}e^{-\frac{r_2^2}{2\sigma_2^2}}\left[1-Q_1\left(\frac{\rho r_1}{\sigma_1\sqrt{1-\rho^2}},\frac{r_T}{\sigma_1\sqrt{1-\rho^2}}\right)\right]+$$

$$+P_1\frac{r_1}{\sigma_2^{\,2}}e^{-\frac{r_1^2}{2\sigma_2^2}}\frac{r_2}{\sigma_1^{\,2}}e^{-\frac{r_2^2}{2\sigma_1^2}}\left[1-Q_1\left(\frac{\rho r_1}{\sigma_2\sqrt{1-\rho^2}},\frac{r_T}{\sigma_2\sqrt{1-\rho^2}}\right)\right]\left[1-Q_1\left(\frac{\rho r_2}{\sigma_1\sqrt{1-\rho^2}},\frac{r_T}{\sigma_1\sqrt{1-\rho^2}}\right)\right]+$$

$$+P_2\frac{r_1}{\sigma_2^{\,2}}e^{-\frac{r_1^2}{2\sigma_2^2}}\frac{r_2}{\sigma_1^{\,2}}e^{-\frac{r_2^2}{2\sigma_1^2}}\left[1-Q_1\left(\frac{\rho r_1}{\sigma_2\sqrt{1-\rho^2}},r_T\sigma_2\sqrt{1-\rho^2}\right)\right]+$$

$$+P_2\frac{r_1}{\sigma_1^{\,2}}e^{-\frac{r_1^2}{2\sigma_1^2}}\frac{r_2}{\sigma_2^{\,2}}e^{-\frac{r_2^2}{2\sigma_2^2}}\left[1-Q_1\left(\frac{\rho r_1}{\sigma_1\sqrt{1-\rho^2}},\frac{r_T}{\sigma_1\sqrt{1-\rho^2}}\right)\right]\left[1-Q_1\left(\frac{\rho r_2}{\sigma_2\sqrt{1-\rho^2}},\frac{r_T}{\sigma_2\sqrt{1-\rho^2}}\right)\right]$$

Joint PDF of SSC combiner in the presence of Rayleigh fading

Za $r_1<r_T$, $r_2\geq r_T$

$$p_{r_1r_2}(r_1,r_2)=P_1\left(1-e^{-\frac{r_T}{2\sigma_1^2}}\right)\frac{r_1r_2}{\sigma_2^4(1-\rho^2)}e^{-\frac{r_1^2+r_2^2}{2\sigma_2^2(1-\rho^2)}}I_0\left(\frac{\rho r_1r_2}{\sigma_2^2(1-\rho^2)}\right)+$$

$$+P_1\frac{r_1}{\sigma_2^2}e^{-\frac{r_1^2}{2\sigma_2^2}}\frac{r_2}{\sigma_1^2}e^{-\frac{r_2^2}{2\sigma_1^2}}\left[1-Q_1\left(\frac{\rho r_1}{\sigma_2\sqrt{1-\rho^2}},\frac{r_T}{\sigma_2\sqrt{1-\rho^2}}\right)\right]\left[1-Q_1\left(\frac{\rho r_2}{\sigma_1\sqrt{1-\rho^2}},\frac{r_T}{\sigma_1\sqrt{1-\rho^2}}\right)\right]+$$

$$+P_2\left(1-e^{-\frac{r_T}{2\sigma_2^2}}\right)\frac{r_1r_2}{\sigma_1^4(1-\rho^2)}e^{-\frac{r_1^2+r_2^2}{2\sigma_1^2(1-\rho^2)}}I_0\left(\frac{\rho r_1r_2}{\sigma_1^2(1-\rho^2)}\right)+$$

$$+P_2\frac{r_1}{\sigma_1^2}e^{-\frac{r_1^2}{2\sigma_1^2}}\frac{r_2}{\sigma_2^2}e^{-\frac{r_2^2}{2\sigma_2^2}}\left[1-Q_1\left(\frac{\rho r_1}{\sigma_1\sqrt{1-\rho^2}},\frac{r_T}{\sigma_1\sqrt{1-\rho^2}}\right)\right]\left[1-Q_1\left(\frac{\rho r_2}{\sigma_2\sqrt{1-\rho^2}},\frac{r_T}{\sigma_2\sqrt{1-\rho^2}}\right)\right]$$

Joint PDF of SSC combiner in the presence of Rayleigh fading

Za $r_1 \geq r_T$, $r_2 \geq r_T$

$$
\begin{aligned}
p_{r_1 r_2}(r_1, r_2) = {} & P_1 \frac{r_1 r_2}{\sigma_1^{\,4}(1-\rho^2)} e^{-\frac{r_1^2 + r_2^2}{2\sigma_1^{\,2}(1-\rho^2)}} I_0\left(\frac{\rho r_1 r_2}{\sigma_1^{\,2}(1-\rho^2)}\right) + \\
& + P_1 \frac{r_1}{\sigma_1^{\,2}} e^{-\frac{r_1^2}{2\sigma_1^2}} \frac{r_2}{\sigma_2^{\,2}} e^{-\frac{r_2^2}{2\sigma_2^2}} \left[1 - Q_1\left(\frac{\rho r_1}{\sigma_1\sqrt{1-\rho^2}}, \frac{r_T}{\sigma_1\sqrt{1-\rho^2}}\right)\right] + \\
& + P_1 \left(1 - e^{-\frac{r_T}{2\sigma_1^2}}\right) \frac{r_1 r_2}{\sigma_2^{\,4}(1-\rho^2)} e^{-\frac{r_1^2 + r_2^2}{2\sigma_2^{\,2}(1-\rho^2)}} I_0\left(\frac{\rho r_1 r_2}{\sigma_2^{\,2}(1-\rho^2)}\right) + \\
& + P_1 \frac{r_1}{\sigma_2^{\,2}} e^{-\frac{r_1^2}{2\sigma_2^2}} \frac{r_2}{\sigma_1^{\,2}} e^{-\frac{r_2^2}{2\sigma_1^2}} \left[1 - Q_1\left(\frac{\rho r_1}{\sigma_2\sqrt{1-\rho^2}}, \frac{r_T}{\sigma_2\sqrt{1-\rho^2}}\right)\right]\left[1 - Q_1\left(\frac{\rho r_2}{\sigma_1\sqrt{1-\rho^2}}, \frac{r_T}{\sigma_1\sqrt{1-\rho^2}}\right)\right] + \\
& + P_2 \frac{r_1 r_2}{\sigma_2^{\,4}(1-\rho^2)} e^{-\frac{r_1^2 + r_2^2}{2\sigma_2^{\,2}(1-\rho^2)}} I_0\left(\frac{\rho r_1 r_2}{\sigma_2^{\,2}(1-\rho^2)}\right) + \\
& + P_2 \frac{r_1}{\sigma_2^{\,2}} e^{-\frac{r_1^2}{2\sigma_2^2}} \frac{r_2}{\sigma_1^{\,2}} e^{-\frac{r_2^2}{2\sigma_1^2}} \left[1 - Q_1\left(\frac{\rho r_1}{\sigma_2\sqrt{1-\rho^2}}, r_T \sigma_2 \sqrt{1-\rho^2}\right)\right] + \\
& + P_2 \left(1 - e^{-\frac{r_T}{2\sigma_2^2}}\right) \frac{r_1 r_2}{\sigma_1^{\,4}(1-\rho^2)} e^{-\frac{r_1^2 + r_2^2}{2\sigma_1^{\,2}(1-\rho^2)}} I_0\left(\frac{\rho r_1 r_2}{\sigma_1^{\,2}(1-\rho^2)}\right) + \\
& + P_2 \frac{r_1}{\sigma_1^{\,2}} e^{-\frac{r_1^2}{2\sigma_1^2}} \frac{r_2}{\sigma_2^{\,2}} e^{-\frac{r_2^2}{2\sigma_2^2}} \left[1 - Q_1\left(\frac{\rho r_1}{\sigma_1\sqrt{1-\rho^2}}, \frac{r_T}{\sigma_1\sqrt{1-\rho^2}}\right)\right]\left[1 - Q_1\left(\frac{\rho r_2}{\sigma_2\sqrt{1-\rho^2}}, \frac{r_T}{\sigma_2\sqrt{1-\rho^2}}\right)\right]
\end{aligned}
$$

PDF of Derivatives at the output ofSSC combiner in the presence of Rayleigh fading at two timeinstants

(2)

$$p_{\dot{r}_1}(\dot{r}_1) = P_1 \frac{1}{\sqrt{2\pi}\dot{\sigma}_1} e^{-\frac{\dot{r}_1^2}{2\dot{\sigma}_1^2}} + P_2 \frac{1}{\sqrt{2\pi}\dot{\sigma}_2} e^{-\frac{\dot{r}_1^2}{2\dot{\sigma}_2^2}} + \left(P_2 \left(1 - e^{-\frac{r_T^2}{2\sigma_2^2}} \right) - P_1 \left(1 - e^{-\frac{r_T^2}{2\sigma_1^2}} \right) \right) \frac{1}{\sqrt{2\pi}\dot{\sigma}_1} e^{-\frac{\dot{r}_1^2}{2\dot{\sigma}_1^2}} +$$
$$+ \left(P_1 \left(1 - e^{-\frac{r_T^2}{2\sigma_1^2}} \right) - P_2 \left(1 - e^{-\frac{r_T^2}{2\sigma_2^2}} \right) \right) \frac{1}{\sqrt{2\pi}\dot{\sigma}_2} e^{-\frac{\dot{r}_1^2}{2\dot{\sigma}_2^2}}$$

$$p_{\dot{r}_2}(\dot{r}_2) = P_1 \left(1 - e^{-\frac{r_T^2}{2\sigma_1^2}} \right) \left(1 - e^{-\frac{r_T^2}{2\sigma_2^2}} \right) \frac{1}{\sqrt{2\pi}\dot{\sigma}_1} e^{-\frac{\dot{r}_2^2}{2\dot{\sigma}_1^2}} + P_2 \left(1 - e^{-\frac{r_T^2}{2\sigma_1^2}} \right) \left(1 - e^{-\frac{r_T^2}{2\sigma_2^2}} \right) \frac{1}{\sqrt{2\pi}\dot{\sigma}_2} e^{-\frac{\dot{r}_2^2}{2\dot{\sigma}_2^2}} +$$
$$+ P_1 B_1(r_T) \frac{1}{\sqrt{2\pi}\dot{\sigma}_2} e^{-\frac{\dot{r}_2^2}{2\dot{\sigma}_2^2}} + P_2 B_2(r_T) \frac{1}{\sqrt{2\pi}\dot{\sigma}_1} e^{-\frac{\dot{r}_2^2}{2\dot{\sigma}_1^2}} + P_1 \left(1 - e^{-\frac{r_T^2}{2\sigma_1^2}} \right) \left(1 - \left(1 - e^{-\frac{r_T^2}{2\sigma_2^2}} \right) \right) \frac{1}{\sqrt{2\pi}\dot{\sigma}_2} e^{-\frac{\dot{r}_2^2}{2\dot{\sigma}_2^2}} +$$
$$+ P_2 \left(1 - e^{-\frac{r_T^2}{2\sigma_2^2}} \right) \left(1 - \left(1 - e^{-\frac{r_T^2}{2\sigma_1^2}} \right) \right) \frac{1}{\sqrt{2\pi}\dot{\sigma}_1} e^{-\frac{\dot{r}_2^2}{2\dot{\sigma}_1^2}} + P_1 C_1(r_T) \frac{1}{\sqrt{2\pi}\dot{\sigma}_1} e^{-\frac{\dot{r}_2^2}{2\dot{\sigma}_1^2}} + P_2 C_2(r_T) \frac{1}{\sqrt{2\pi}\dot{\sigma}_2} e^{-\frac{\dot{r}_2^2}{2\dot{\sigma}_2^2}}$$

$$B_i(r_T) = -e^{-\frac{r_T^2}{2\sigma_i^2}} \left[1 - Q_1\left(\frac{r_T}{\sigma_i} \sqrt{\frac{1}{(1-\rho_i^2)}}, \frac{\rho_i r_T}{\sigma_i \sqrt{1-\rho_i^2}} \right) \right] +$$
$$+ e^{-\frac{r_T^2}{2\sigma_i^2}} \left[1 - Q_1\left(\frac{\rho_i r_T}{\sigma_i \sqrt{1-\rho_i^2}}, \frac{r_T}{\sigma_i \sqrt{1-\rho_i^2}} \right) \right]$$

$$C_i(r_T) = e^{-\frac{r_T^2}{2\sigma_i^2}} \left[1 - Q_1\left(\frac{r_T}{\sigma_i} \sqrt{\frac{1}{(1-\rho_i^2)}}, \frac{\rho_i r_T}{\sigma_i \sqrt{1-\rho_i^2}} \right) \right] +$$
$$+ e^{-\frac{r_T^2}{2\sigma_i^2}} Q_1\left(\frac{\rho_i r_T}{\sigma_i \sqrt{1-\rho_i^2}}, \frac{r_T}{\sigma_i \sqrt{1-\rho_i^2}} \right)$$

Rice fading is present:

for $r_1 < r_T$, $r_2 < r_T$ it is:

$$p_{r_1 r_2}(r_1, r_2) = P_1 C_1(r_1, \sigma_2, A_2) C_1(r_2, \sigma_1, A_1) +$$

$$\cdot$$

$$+ P_2 C_1(r_1, \sigma_1, A_1) C_1(r_2, \sigma_2, A_2)$$

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

$$p_{r_1 r_2}(r_1, r_2) = P_1 C_1(r_1, \sigma_1, A_1) \frac{r_2}{\sigma_2^{\ 2}} e^{-\frac{r_2^{\ 2} + A_2^{\ 2}}{2\sigma_2^{\ 2}}} I_0\left(\frac{r_2 A_2}{\sigma_2^{\ 2}}\right) +$$

$$+ P_1 C_1(r_1, \sigma_2, A_2) C_1(r_2, \sigma_1, A_1) +$$

$$+ P_2 C_1(r_1, \sigma_2, A_2) \frac{r_2}{\sigma_1^{\ 2}} e^{-\frac{r_2^{\ 2} + A_1^{\ 2}}{2\sigma_1^{\ 2}}} I_0\left(\frac{r_2 A_1}{\sigma_1^{\ 2}}\right) +$$

$$+ P_2 C_1(r_1, \sigma_1, A_1) C_1(r_2, \sigma_2, A_2)$$

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

$$p_{r_1 r_2}(r_1, r_2) = P_1\left(1 - Q_1\left(A/\sigma_1, r_t/\sigma_1\right)\right) C_2(r_1, r_2, \sigma_2, A_2) +$$

$$+ P_2\left(1 - Q_1\left(A/\sigma_2, r_t/\sigma_2\right)\right) C_2(r_1, r_2, \sigma_1, A_1) +$$

$$+ P_1 C_1(r_1, \sigma_2, A_2) C_1(r_2, \sigma_1, A_1) +$$

$$+ P_2 C_1(r_1, \sigma_1, A_1) C_1(r_2, \sigma_2, A_2)$$

For $r_1 \geq r_T$, $r_2 \geq r_T$

$$p_{r_1 r_2}(r_1, r_2) = P_1 C_2(r_1, r_2, \sigma_1, A_1) +$$

$$+ P_1 C_1(r_1, \sigma_1, A_1) \frac{r_2}{\sigma_2^{\ 2}} e^{-\frac{r_2^{\ 2} + A_2^{\ 2}}{2\sigma_2^{\ 2}}} I_0\left(\frac{r_2 A_2}{\sigma_2^{\ 2}}\right) +$$

$$+ P_1 C_1(r_1, \sigma_2, A_2) C_1(r_2, \sigma_1, A_1) +$$

$$+ P_1\left(1 - Q_1\left(A/\sigma_1, r_t/\sigma_1\right)\right) C_2(r_1, r_2, \sigma_2, A_2) +$$

$$+ P_2 C_1(r_1, \sigma_2, A_2) \frac{r_2}{\sigma_1^{\ 2}} e^{-\frac{r_2^{\ 2} + A_1^{\ 2}}{2\sigma_1^{\ 2}}} I_0\left(\frac{r_2 A_1}{\sigma_1^{\ 2}}\right) +$$

$$+ P_2 C_2(r_1, r_2, \sigma_2, A_2) +$$

$$+ P_2 C_1(r_1, \sigma_1, A_1) C_1(r_2, \sigma_2, A_2) +$$

$$+ P_2\left(1 - Q_1\left(A/\sigma_2, r_t/\sigma_2\right)\right) C_2(r_1, r_2, \sigma_1, A_1)$$

- The expressions for probability density functions and joint probability density functions for SSC combiner output signals at two time instants in the presence of different fading distributions are determined and then, these expressions are used for calculation of system performances, such as the bit error rate and the outage probability

- The level crossing rate and the average fade duration are also very often used in designing of wireless communication systems as measures for their quality.
- To obtain second order system characteristics the expressions for signal derivatives are need
- Because of this, the probability density functions of derivatives in two time instants for SSC combiner in fading channels have to be determined

Outage probability for the complex combiner

- Outage probability is defined as the probability that the combiner output signal value falls below a given threshold r_{th}

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

Amount of fading for the SSC/MRC combiner

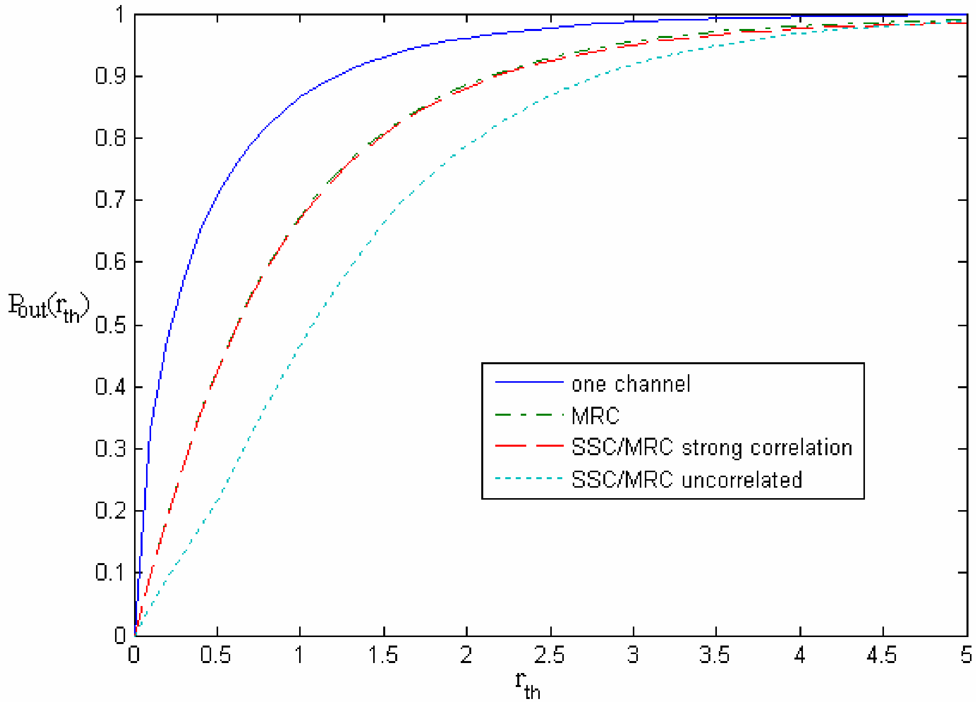
- Amount of fading (AF) is a unified measure of the severity of fading for particular channel model

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

The bit error rate (BER)

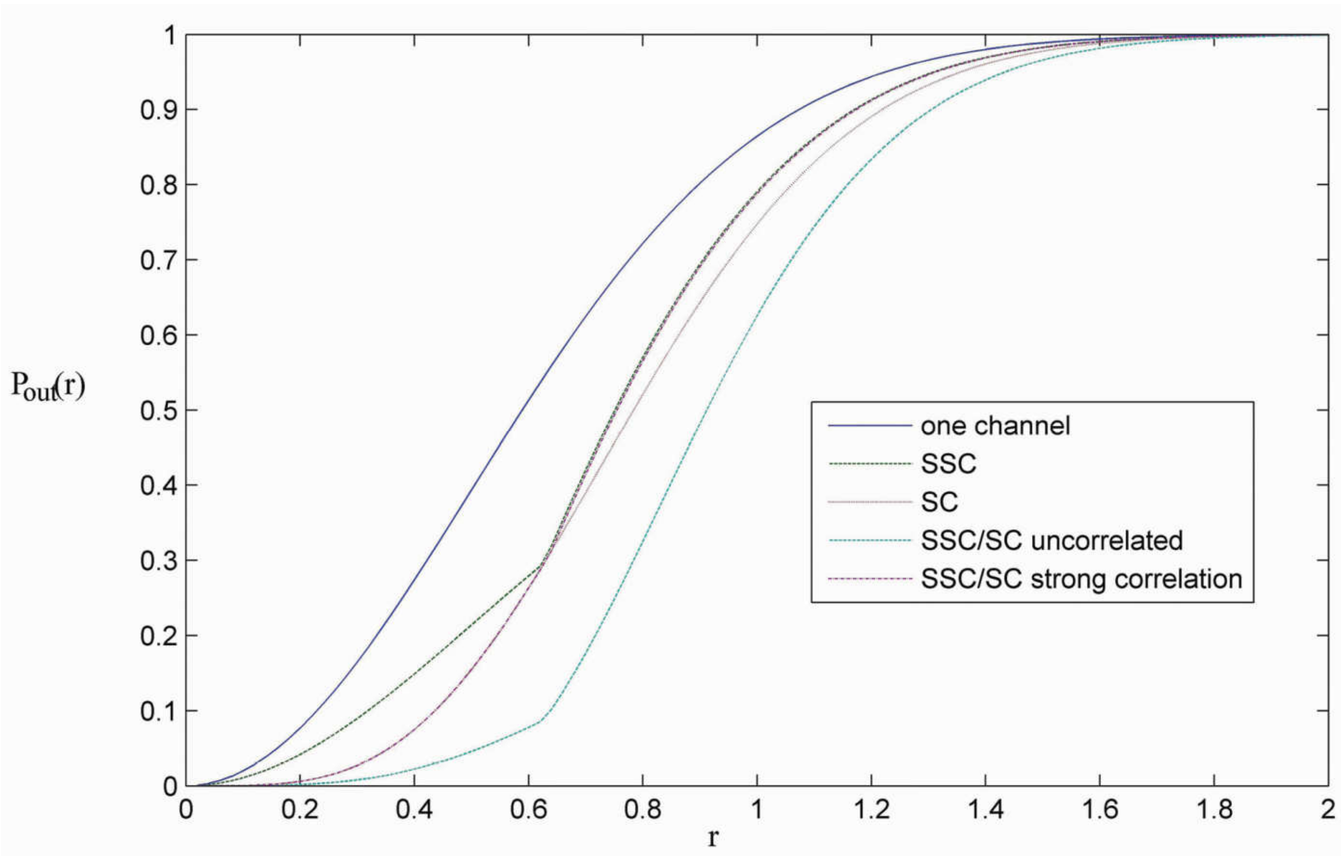
$$P_b(e) = \underbrace{\int_0^{\infty}\int_0^{\infty}\cdots\int_0^{\infty}}_{L} P_b\left(\{r_l\}_{l=1}^{L}\right)\prod_{l=1}^{L} p_{r_1,r_2,\ldots r_L}(r_1, r_2, \ldots r_L)\,dr_1 dr_2 \ldots dr_L$$

Outage probability for the SSC/MRC combiner – Weibull

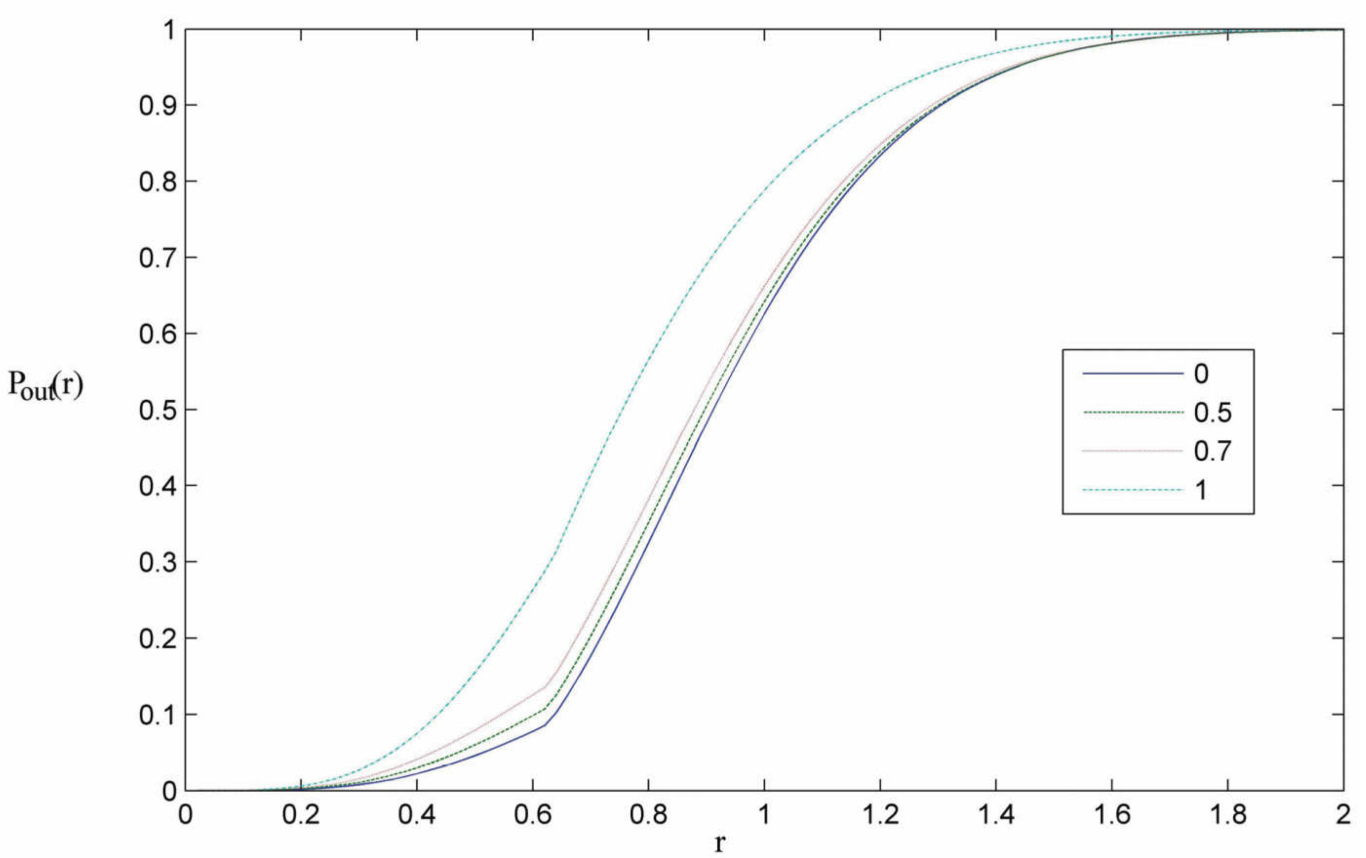


Outage probability for different types of combiners for parameters β=0.7 and Ω=0.5

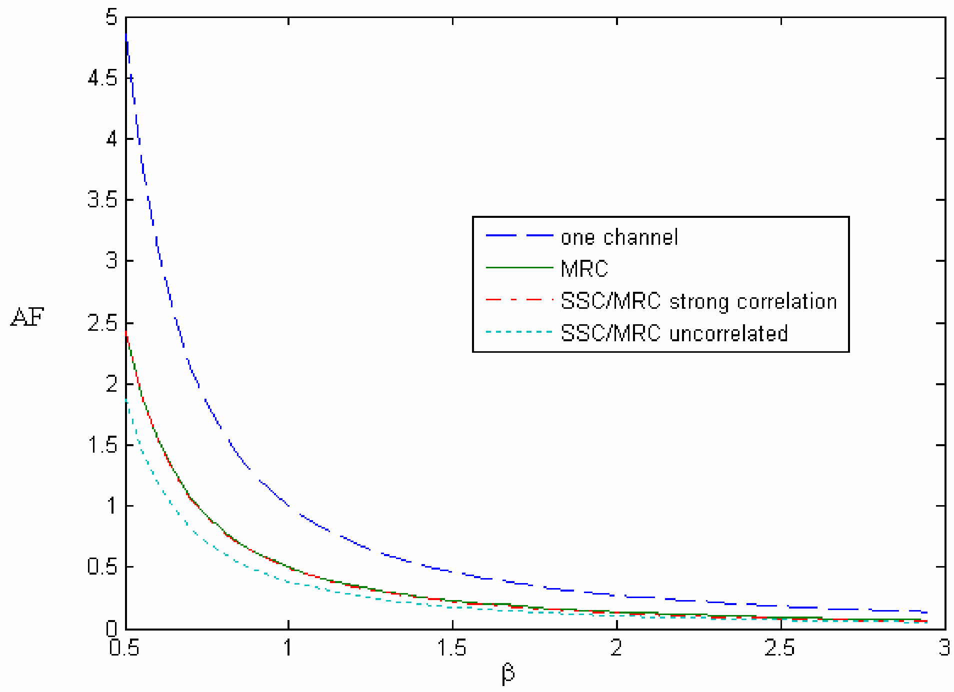
Outage probability for the different combiners – Rayleigh



Outage probability for the different combiners – Rayleigh

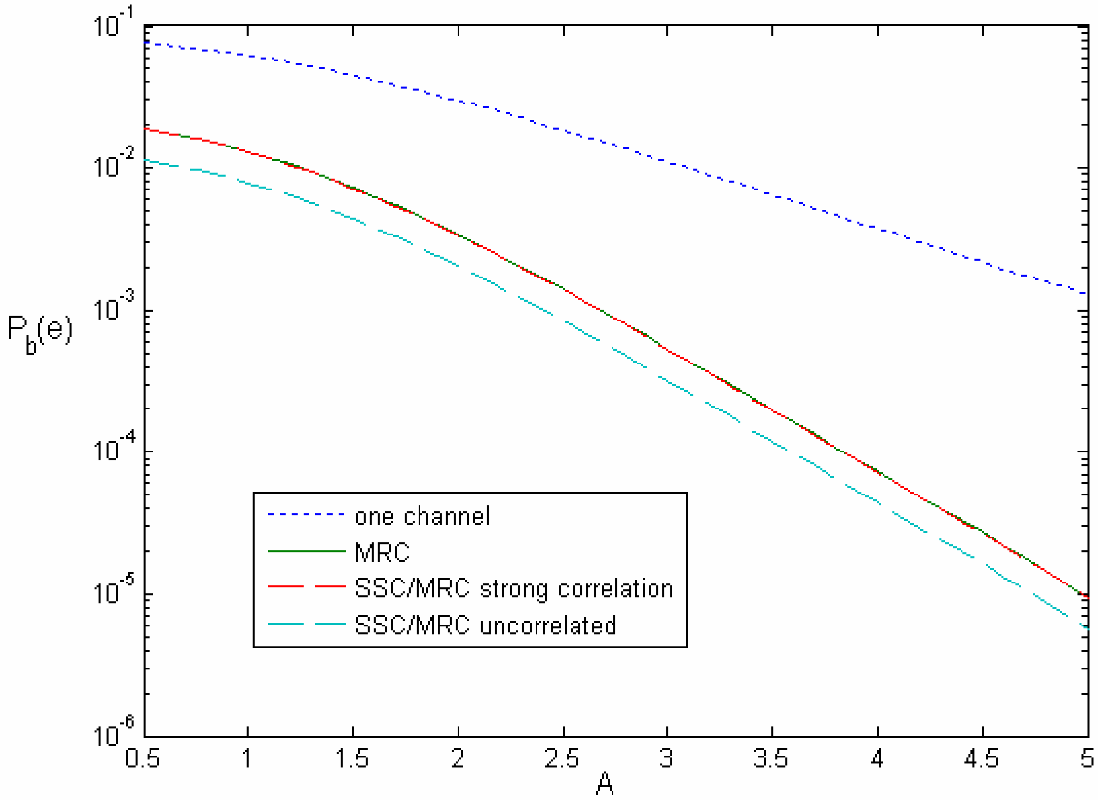


Amount of fading for the SSC/MRC combiner- Weibull



Amount of fading for different types of combiners for Ω=0.5

Bit error rate for different types of combiners – Rice fading



Conclusion 1

- The combining techniques like SSC and MRC are simple and frequently used for signals combining in diversity systems for reducing fading effects
- The joint probability density function of the complex dual SSC/MRC combiner output signal at two time instants, in the presence of different fading distributions are determined

Conclusion

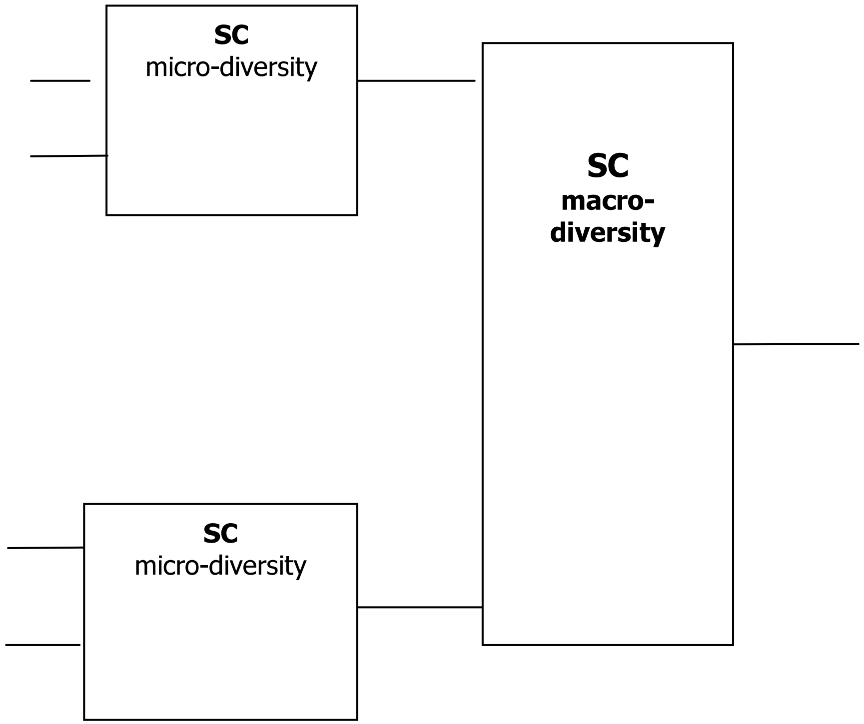
- It is presented the improvement of characteristics of complex SSC/SC(MRC) combiner at two time instants comparing with classical SSC and MRC combiners

Conclusion

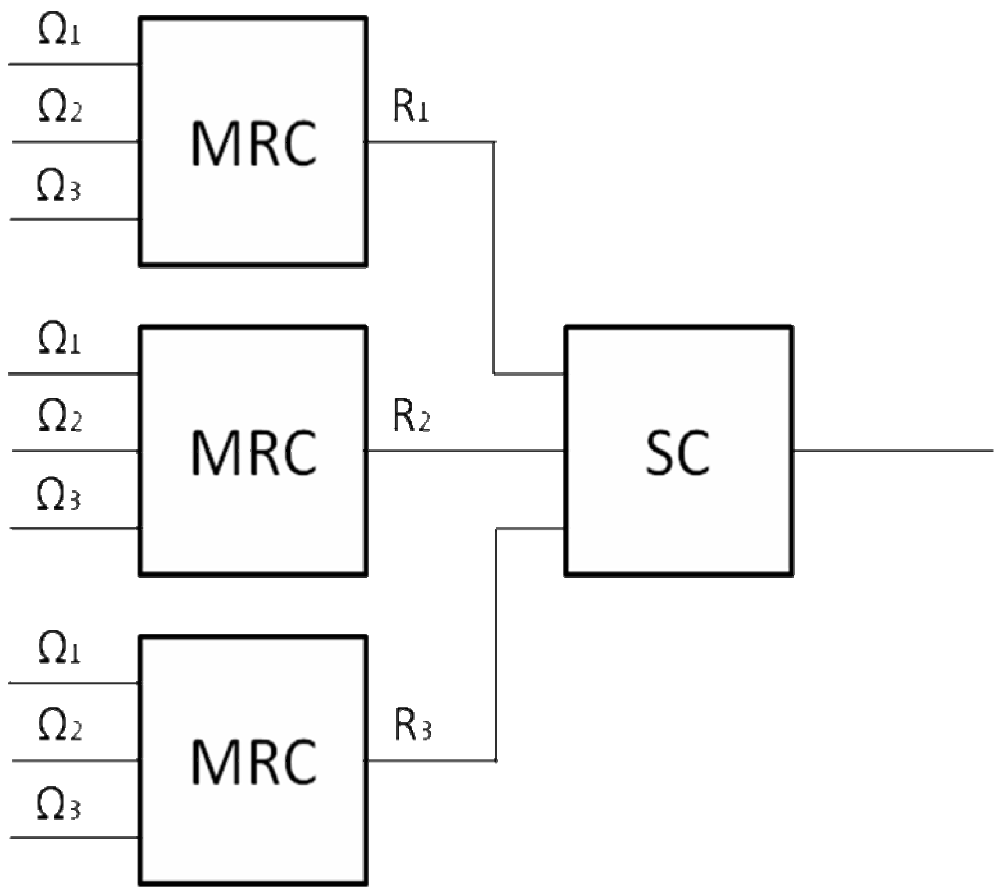
- Complex SSC/MRC combiner is not economical in the case of strongly correlated signals because it does not give better performance than MRC combiner

Macrodiversity and
N- Branches Microdiversity
Reception

System model



System model



- The wireless communication system following microdiversity to mitigate the effects of short-term fading and macrodiversity processing to reduce shadowing effects

- N-branch maximal-ratio combining (MRC) or selection combining (SC) is implemented at the micro level (single base station)
- Selection combining (SC) with two or more base stations (dual diversity) is implemented at the macro level

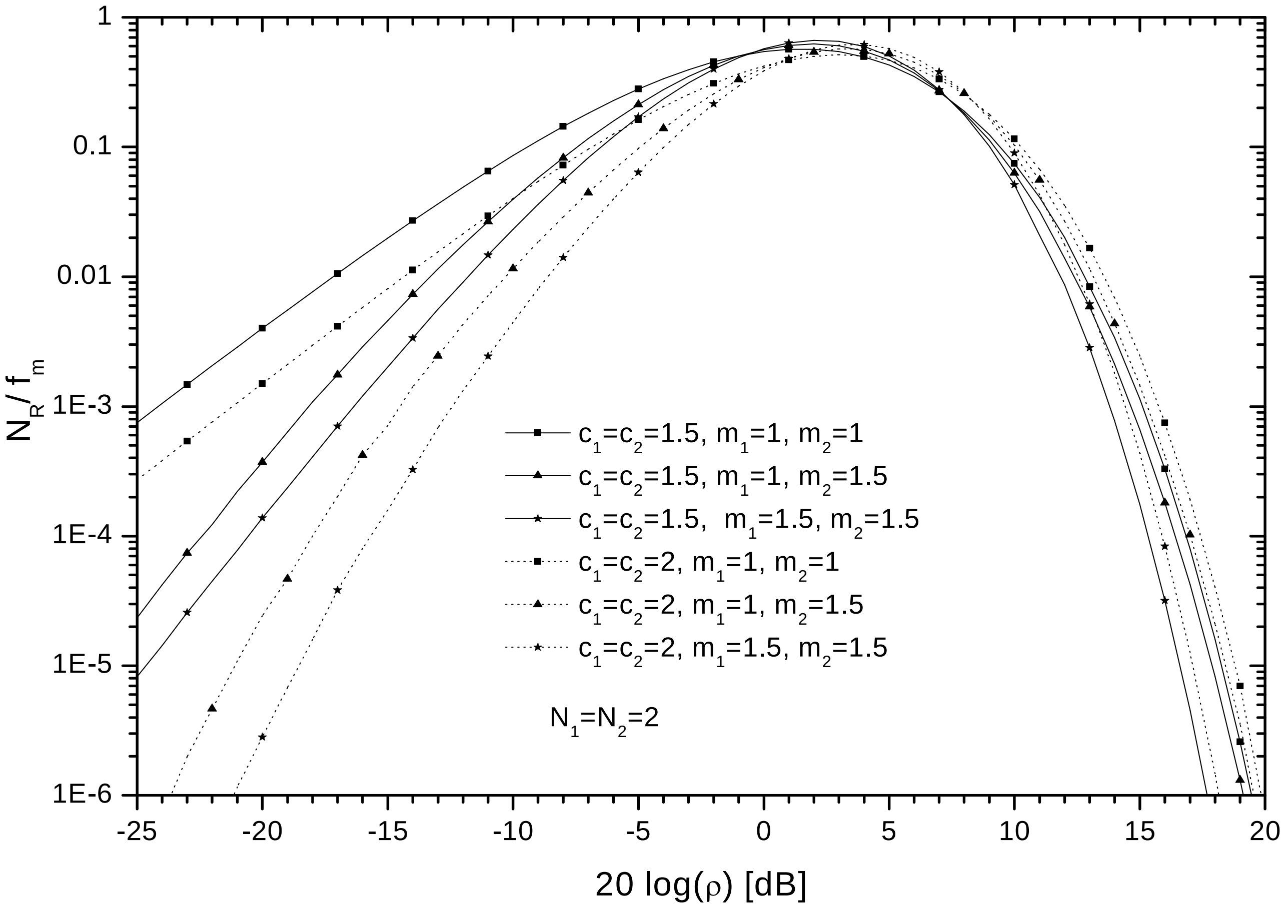
- Model assumes a Rice, Nakagami-*m* or other density function for the envelope of the received signal and a log-normal or gamma distribution to model the average power to account for shadowing

- Analytical expressions for the probability density function (PDF), cumulative distribution function (CDF) and moments of signal after micro- and macrodiversity processing are derived.

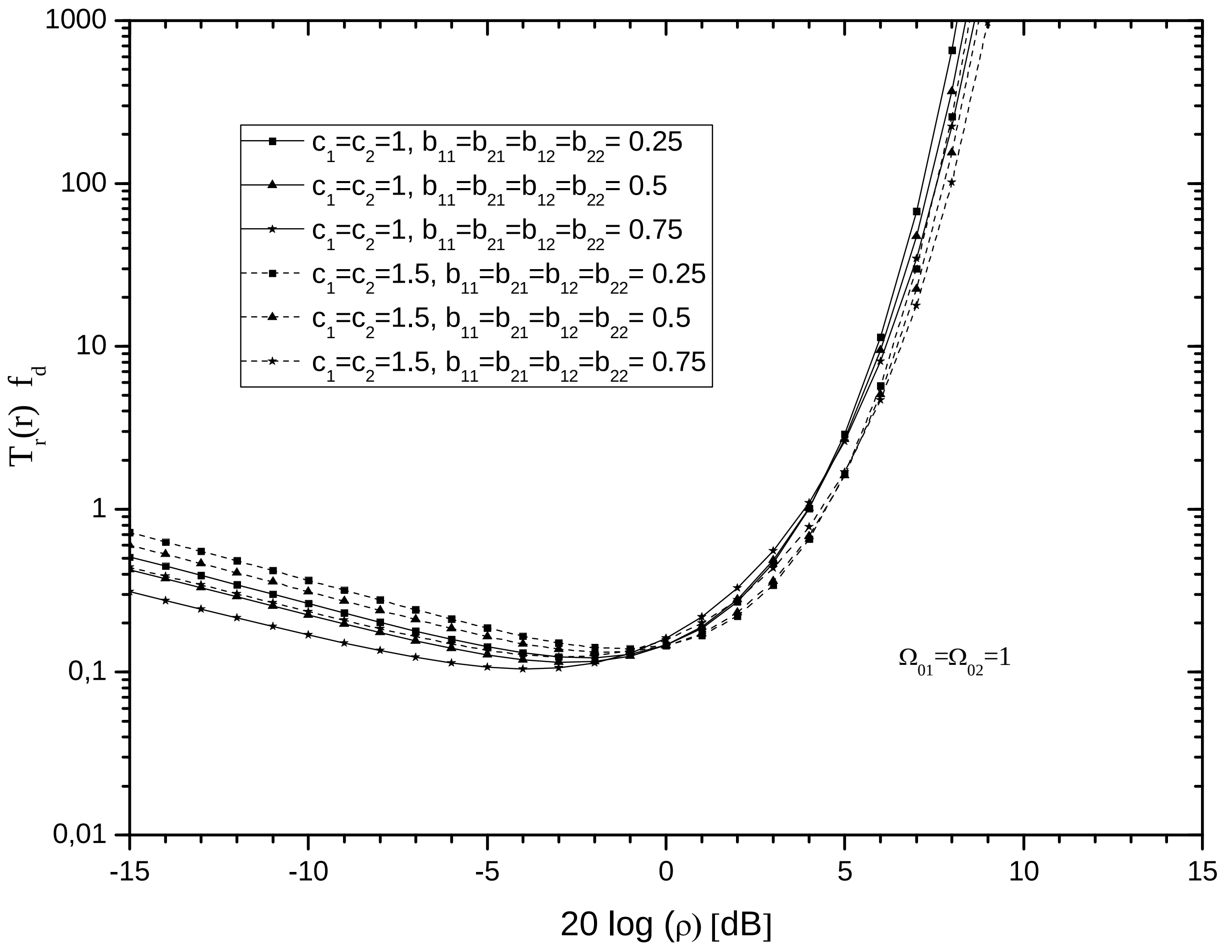
- These expressions are used to study important system performance criteria such as the outage probability, average bit error probability (ABEP), average output signal value and amount of fading (AoF).

- Then, various numerical results are graphically presented to illustrate the proposed mathematical analysis and to show the effects of various system parameters to the system performance, as well as enhancement due to use of the combination of micro- and macrodiversity

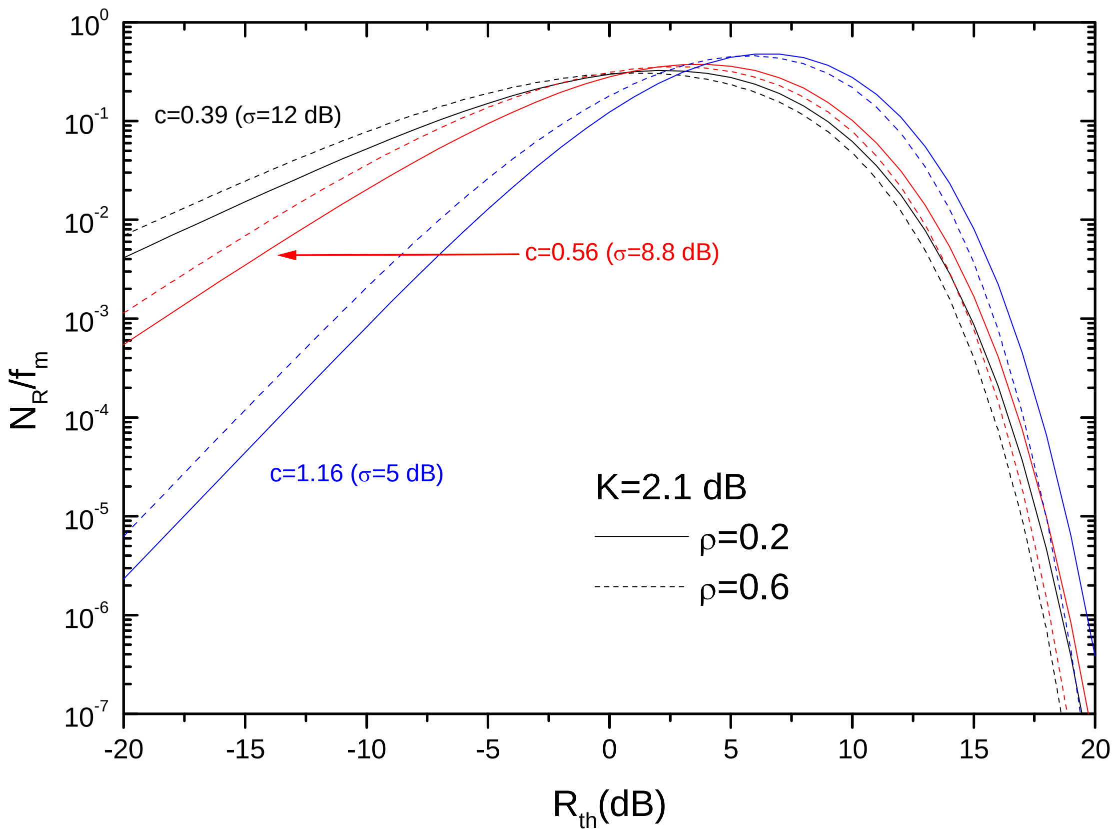
Normalized average LCR of macrodiversity structure versus normalized signal level for various values of Nakagami-*m* fading parameters



Normalized AFD as a function of normalized signal level for various values of system's parameters in the presence of Hoyt Fading



Normalized average LCR for different values of shadowing severity and correlation coefficient with macrodiversity and three branches microdiversity reception



- The average LCR and AFD were presented graphically in order to illustrate the effects of
  -number of diversity branches,

  -severity of fading and shadowing and

  -correlation between base stations

  on the system performance

Obtained results can be used for the system parameter optimization in different propagation conditions