Research Article

Performance Analysis of SSC Diversity Receivers over Correlated Ricean Fading Satellite Channels

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This paper studies the performance of switch and stay combining (SSC) diversity receivers operating over correlated Ricean fading satellite channels. Using an infinite series representation for the bivariate Ricean probability density function (PDF), the PDF of the SSC output signal-to-noise ratio (SNR) is derived. Capitalizing on this PDF, analytical expressions for the corresponding cumulative distribution function (CDF), the moments of the output SNR, the moments generating function (MGF), and the average channel capacity (CC) are derived. Furthermore, by considering several families of modulated signals, analytical expressions for the average symbol error probability (ASEP) for the diversity receivers under consideration are obtained. The theoretical analysis is accompanied by representative performance evaluation results, including average output SNR (ASNR), amount of fading (AoF), outage probability ($P_{out}$), average bit error probability (ABEP), and average CC, which have been obtained by numerical techniques. The validity of some of these performance evaluation results has been verified by comparing them with previously known results obtained for uncorrelated Ricean fading channels.

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1. INTRODUCTION

The mobile terrestrial and satellite communication channel is particularly dynamic due to multipath fading propagation, having a strong negative impact on the average bit error probability (ABEP) of any modulation scheme [1]. Diversity is a powerful communication receiver technique used to compensate for fading channel impairments. The most important and widely used diversity reception methods employed in digital communication receivers are maximal-ratio combining (MRC), equal-gain combining (EGC), selection combining (SC), and switch and stay combining (SSC) [2]. For SSC diversity considered in this paper, 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. Hence, among the above-mentioned diversity schemes, SSC is the least complex and can be used in conjunction with coherent, noncoherent, and differentially coherent modulation schemes. It is also well known that in many real life communication scenarios the combined signals are correlated [2, 3]. A typical example for such signal correlation exists in relatively small-size mobile terminals where typically the distance between the diversity antennas is short. Due to this correlation between the signals received at the diversity branches there is a degradation in the achievable diversity gain.

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 [2]. In particular for mobile satellite communications the Ricean distribution is used to accurately model the mobile satellite channel for single- [4] and clear-state [5] channel conditions. Furthermore, in [6] it was depicted that the Ricean $K$-factor characterizes the land mobile satellite channel during unshadowed periods.

The technical literature concerning diversity receivers operating over correlated fading channels is quite rich, for example, see [7–13]. In [7] expressions for the outage probability ($P_{out}$) and the ABEP of dual SC with correlated Rayleigh fading were derived either in closed form or in terms of
single integrals. In [8] the cumulative distribution functions (CDF) of SC, in correlated Rayleigh, Ricean, and Nakagami-
m fading channels were derived in terms of single-fold inte-
grals and infinite series expressions. In [9] the ABEP of dual-branch EGC and MRC receivers operating over corre-
lated Weibull fading channels was obtained. In [10] the per-
formance of MRC in nonidentical correlated Weibull fad-
ing channels with arbitrary parameters was evaluated. In [11] an analysis for the Shannon channel capacity (CC) of
dual-branch SC diversity receivers operating over correlated
Weibull fading was presented. In [12], infinite series expres-
sions for the capacity of dual-branch MRC, EGC, SC, and
SSC diversity receivers over Nakagami-m fading channels
have been derived.

Past work concerning the performance of SSC operat-
ing over correlated fading channels can be found in [14–
17]. One of the first attempts to investigate the performance
of SSC diversity receivers operating over independent and
correlated identical distributed Ricean fading channels was
made in [14]. However, in this reference only noncoher-
ent frequency shift keying (NCFSK) modulation was con-
sidered and its ABEP has been derived in an integral rep-
resentation form. In [15] the performance of SSC diversity
receivers was investigated for different fading channels, in-
cluding Rayleigh, Nakagami-m and Ricean, and under dif-
ferent channel conditions but dealt mainly with uncorre-
lated fading. For correlated fading in this reference only the
Nakagami-m distribution was studied. In [16] the moments
generating function (MGF) of SSC was presented in terms of
a finite integral representation for the correlated Nakagami-
m fading channel. In [17] expressions for the average output
SNR (ASNR), amount of fading (AoF) and $P_{out}$ for the cor-
related log-normal fading channels have been derived.

All in all, the problem of theoretically analyzing the per-
formance of SSC over correlated Ricean fading channels has
not yet been thoroughly addressed in the open technical lit-
erature. The main difficulty in analyzing the performance of
diversity receivers in correlated Ricean fading channels is the
complicated form of the received signal bivariate probability
density function (PDF), see [14, Equation (17)], and the ab-

ence of an alternative and more convenient expression for
the multivariate distribution. An efficient solution to these
difficulties is to employ an infinite series representation for
the bivariate PDF, such as those that were proposed in [18]
or [19]. Such an approach was used in [20] to analyze the per-
formance of MRC, EGC, and SC in the presence of correlated
Ricean fading. Similarly here the most important statistical
metrics and the capacity of SSC diversity receivers operat-
ing over correlated Ricean fading channels will be studied. In
particular, we derive the PDF, CDF, MGF, moments and the
average CC of such receivers operating over correlated Ricean
fading channels. Furthermore, analytical expressions for the
average symbol error probability (ASEP) of several modula-
tion schemes will be obtained. Capitalizing on these expres-
sions, a detailed performance analysis for the $P_{out}$, ASNR,
AoF, and ASEP/ABEP will be presented.

The remainder of this paper is organized as follows. Af-
ter this introduction, in Section 2 the system model is intro-
duced. In Section 3, the SSC received signal statistics are pre-

Section 4 the capacity is obtained. Section 5 contains the derivation of the most important performance
metrics of the SSC output SNR. In Section 6, various numeri-
cal evaluation results are presented and discussed, while the
conclusions of the paper can be found in Section 7.

2. SYSTEM MODEL

By considering a dual-branch SSC diversity receiver operat-
ing over a correlated Ricean fading channel, the baseband
received signal at the $\ell$th ($\ell = 1$ and 2) input branch can be
mathematically expressed as

$$\zeta_{\ell} = s_{\ell} + n_{\ell}. \quad (1)$$

In the above equation, $s$ is the transmitted complex sym-

mbol, $h_{\ell}$ is the Ricean fading channel complex envelope with

magnitude $R_{\ell} = |h_{\ell}|$, and $n_{\ell}$ is the additive white Gauss-

ian noise (AWGN) having single-sided power spectral den-
sity of $N_0$. The usual assumption for ideal fading phase esti-

mation is made, and hence, only the distributed fading enve-

lope and the AWGN affect the received signal. Moreover, the

AWGN is assumed to be uncorrelated between the two diver-
sity branches. The instantaneous SNR per symbol at the $\ell$th

input branch is

$$\gamma_{\ell} = \frac{R_{\ell}^2 E_s}{2N_0},$$

where $E_s = \mathbb{E}\langle|s|^2\rangle$ is the transmitted average symbol energy, where $\mathbb{E}\langle\cdot\rangle$ denoting expec-
tation and $|\cdot|$ absolute value. The corresponding average

SNR per symbol at both input branches is

$$\gamma = \frac{\Omega^2 E_s}{N_0},$$

where $\Omega = \mathbb{E}\langle R_{\ell}^2 \rangle$. The PDF of the SNR of the Ricean distribution is given by [2, Equation (2.16)]

$$f_{\gamma}(\gamma) = \frac{1 + K}{\bar{\gamma}} \exp \left[ -K - \frac{(1 + K)}{\bar{\gamma}} \gamma \right] \times I_0 \left[ 2 \sqrt{\frac{K(K + 1)}{\bar{\gamma}}} \gamma^{1/2} \right], \quad (2)$$

where $K$ is the Ricean $K$-factor defined as the power ratio

of the specular signal to the scattered signals and $I_0(\cdot)$ is the zeroth-order modified Bessel function of the first kind [21, Equation (8.406)]. The CDF of $\gamma$ is given by [14, Equation (8)]

$$F_{\gamma}(\gamma) = Q_1 \left( \sqrt{2K}, \sqrt{\frac{2(1 + K)}{\bar{\gamma}}} \gamma \right), \quad (3)$$

where $Q_1(\cdot)$ is the first-order Marcum-Q function [2, Equation (4.33)].

The joint PDF of $\gamma_1$ and $\gamma_2$, presented in [14, Equation (17)], can be expressed in terms of infinite series by follow-

ing a similar procedure as for deriving [18, Equation (9)].

Hence, substituting $I_0(\cdot)$ with its infinite series representa-
tion [21, Equation (8.445)], expanding the term $\left[|\gamma_1 + \gamma_2 + 2\sqrt{\gamma_1}\gamma_2 \cos(\theta)\right]^L$ using the multinomial identity [22, Equation (24.1.2)], using [21, Equation (3.389/1)] and after some
mathematical manipulations the joint PDF of $y_1$, $y_2$ can be expressed as
\[
f_{y_1, y_2}(y_1, y_2) = \sum_{i,j=0}^{\infty} A \exp \left[ -\beta_1 (y_1 + y_2) \right] \\
\times (B y_1^{\beta_1-1} y_2^{\beta_2-1} + C y_1^{-1} y_2^{\beta_3-1/2} y_2^{\beta_4-1/2})
\]
(4)
with
\[
A = \frac{2^{\gamma + 2h - 1} (1 + K)^{\gamma + 1} \rho^{2h} K^{\gamma}}{\sqrt{\pi}^{1+\beta_1} (1 - \rho^2)^{(1+2h) v_1! v_2! v_3! ! (1 + \rho)^{2i}}},
\]
\[
B = \frac{[1 + (-1)^{\gamma}] \Gamma [h + (1 + v_3)/2]}{\Gamma [h + 1 + v_3/2] \Gamma [h + 1 + 2h]},
\]
\[
C = \frac{[1 - 1 - (-1)^{\gamma}] 2 \rho (1 + K) \Gamma [h + v_3/2]}{(1 - \rho^2) \Gamma [h + v_3/2]},
\]
\[
\beta_1 = \frac{(1 + K)}{(1 - \rho^2)^{\gamma}}, \quad \beta_2 = v_1 + \frac{v_3}{2} + h + 1,
\]
\[
\beta_3 = v_2 + \frac{v_3}{2} + h + 1, \quad \beta_4 = i + 2h + 1,
\]
(5)
where $\Gamma(\cdot)$ is the Gamma function [21, Equation (8.310/1)] and $\rho$ is the correlation coefficient between $y_1$ and $y_2$. It can be proved that the above infinite series expression always converges [18].

3. RECEIVED SIGNAL STATISTICS

In this section, the most important statistical metrics, namely, the PDF, CDF, MGF, and moments of dual branch SSC output SNR diversity receivers operating over correlated Ricean fading channels will be presented.

3.1. Probability density function (PDF)

Let $y_{\text{sc}}$ be the instantaneous SNR per symbol at the output of the SSC and $y_r$ the predetermined switching threshold. Following [15], the PDF of $y_{\text{sc}}$, $f_{y_{\text{sc}}}(y)$, is given by

\[
f_{y_{\text{sc}}}(y) = \begin{cases} 
  r_{\text{sc}}(y), & y \leq y_r, \\
  r_{\text{sc}}(y) + f_{y}(y), & y > y_r.
\end{cases}
\]
(6)

Moreover, $r_{\text{sc}}(y)$ is given in [23, Equation (21b)] as

\[
r_{\text{sc}}(y) = \int_0^y f_{y_1, y_2}(y_1, y_2) dy_2
\]
\[
= \int_0^\infty f_{y_1, y_2}(y_1, y_2) dy_2 - \int_{y_r}^\infty f_{y_1, y_2}(y_1, y_2) dy_2.
\]
(7)

Hence, by substituting (4) in (7) and using [21, Equation (3.351/2-3)], these integrals can be solved and $r_{\text{sc}}(y)$ can be expressed as

\[
r_{\text{sc}}(y) = \sum_{i,j=0}^{\infty} A \exp \left[ -\beta_1 y \right] \\
\times \left[ B y (\beta_2, \beta_1 y) + C y (\beta_3 + 1/2, \beta_1 y) \right],
\]
(8)
where $y(\cdot, \cdot)$ is the lower incomplete Gamma function [21, Equation (8.350/1)].

3.2. Cumulative distribution function (CDF)

Similar to [23, Equation (20)], the CDF of $y_{\text{sc}}$, $F_{y_{\text{sc}}}(y)$, is given by

\[
F_{y_{\text{sc}}}(y) = \text{Pr} (y_r \leq y_1 \leq y) + \text{Pr} (y_2 < y_r \land y_1 < y)
\]
(9)
which after some manipulations can be expressed in terms of CDFs as

\[
F_{y_{\text{sc}}}(y) = \begin{cases} 
  F_{y_1, y_2}(y, y_r), & y \leq y_r, \\
  F_{y}(y) - F_{y}(y_r) + F_{y_1, y_2}(y, y_r), & y > y_r.
\end{cases}
\]
(10)

Hence, by substituting (4) in $F_{y_1, y_2}(y, y_r)$ in (10) and (11) have been numerically evaluated for the special case of uncorrelated, that is, $\rho = 0$, Ricean fading channels. The resulting CDF was found to be identical to the same CDF presented in [2, Equation 9.273], which was derived using a different mathematical approach as a closed-form expression.

3.3. Moments generating function (MGF)

Based on (6), the MGF of $y_{\text{sc}}$, $M_{y_{\text{sc}}}(s) = \mathbb{E}(\exp(-s y_{\text{sc}}))$, [24, Equation (5.62)], can be expressed in terms of two integrals as

\[
M_{y_{\text{sc}}}(s) = \int_0^\infty \exp(-s y) r_{\text{sc}}(y) dy \\
+ \int_{y_r}^\infty \exp(-s y) f_{y}(y) dy = I_1 + I_2.
\]
(12)
Using [21, Equation (3.381/4)], \( J_1 \) can be expressed in terms of infinite series as

\[
J_1 = \sum_{i,k=0}^{\infty} A_i \left[ \frac{\Gamma(\beta_2)}{\beta_1^i \beta_2^i} \beta_1^i \beta_2^i \gamma(\beta_3, \beta_1 \gamma) \right] + C \beta_1^{1/2} \Gamma(\beta_2 + 1/2) \beta_1^i \beta_2^i \gamma(\beta_3 + 1/2, \beta_1 \gamma).
\]

Setting \( \psi = \sqrt{2}(1 + K) / \gamma + s \) and using [2, Equation (4.33)], \( J_2 \) can be solved as

\[
J_2 = Q_1 \left[ \frac{2K(1 + K)}{1 + \gamma s} \right]^{1/2} y(\gamma) \frac{\Gamma(1 + K)}{\gamma} \frac{1}{1 + \gamma s}.
\]

\[
J_3 = \sum_{i,k=0}^{\infty} A_i \left[ \mathcal{B} y(\beta_3, \beta_1 \gamma) \frac{\Gamma(n + \beta_2)}{\beta_1^i \beta_2^i \gamma^{n+1}} \right] + C \frac{\beta_1^{1/2} \beta_2 + 1/2, \beta_1 \gamma}{\gamma}. \tag{16}
\]

3.4. Moments

Based on (6), the moments for \( \gamma_{sc} \), \( \mu_{\gamma_{sc}}(n) = E(\exp(\gamma_{sc}))) \), [24, Equation (5.38)], can be expressed in terms of two integrals as

\[
\mu_{\gamma_{sc}}(n) = \int_0^{\infty} y^n r_{sc}(y) dy + \int_0^{\infty} y^n f_{\gamma}(y) dy = J_3 + J_4. \tag{15}
\]

Using again [21, Equation (3.381/4)], \( J_3 \) can be expressed in terms of infinite series as

\[
J_3 = \sum_{i,k=0}^{\infty} A_i \left[ \mathcal{B} y(\beta_3, \beta_1 \gamma) \frac{\Gamma(n + \beta_2)}{\beta_1^i \beta_2^i \gamma^{n+1}} \right] + C \frac{\beta_1^{1/2} \beta_2 + 1/2, \beta_1 \gamma}{\gamma}. \tag{16}
\]

Due to the very complicated nature of \( J_5 \), it is very difficult, if not impossible, to derive a closed-form solution for this integral. However, \( J_6 \) can be evaluated via numerical integration using any of the well-known mathematical software packages, such as MATHEMATICA or MATLAB.

5. PERFORMANCE ANALYSIS

In this section a detailed performance analysis, in terms of \( P_{out}, \text{ASEP}, \text{ASNR} \) and \( \text{AOF} \), for SSC diversity receivers operating over correlated Ricean fading channels will be presented.

5.1. Outage probability (\( P_{out} \))

\( P_{out} \) is the probability that the output SNR falls below a predetermined threshold \( \gamma_{th} \), \( P_{out}(\gamma_{th}) \), and can be obtained by replacing \( \gamma \) with \( \gamma_{th} \) in (10) as

\[
P_{out}(\gamma_{th}) = F_{\gamma_{sc}}(\gamma_{th}). \tag{21}
\]

5.2. Average symbol error probability (ASEP)

The ASEP, \( P_{se} \), can be evaluated directly by averaging the conditional symbol error probability, \( P_e(y) \), over the PDF of \( \gamma_{sc} \) [29]

\[
P_{se} = \int_0^{\infty} P_e(y) f_{\gamma_{sc}}(y) dy. \tag{22}
\]

For different families of modulation schemes, \( P_e(y) \) can be obtained as follows.

(i) For binary phase shift keying (BPSK) and square \( M \)-ary quadrature amplitude modulation (QAM) signaling formats and for high-input SNR, \( P_e(y) = D \text{erfc}(\sqrt{Ey}) \), where

4. CHANNEL CAPACITY (CC)

CC is a well-known performance metric providing an upper bound for maximum errorless transmission rate in a Gaussian environment. The average CC, \( \bar{C} \), is defined as [26]

\[
\bar{C} = BW \int_0^{\infty} \log_2(1 + y) f_{\gamma_{sc}}(y) dy, \tag{18}
\]
erf(\cdot) is the complementary error function [21, Equation (8.250/1)] and \( D, E \) are constants the values of which depend on the specific modulation scheme under consideration. Using this expression, by substituting (6) in (22), yields

\[
\mathcal{P}_{sc} = \int_0^\infty D \operatorname{erfc} \left( \sqrt{E \beta} r_{sc}(y) \right) dy + \int_y^\infty D \operatorname{erfc} \left( \sqrt{E \beta} f_r(y) \right) dy = \mathcal{I}_7 + \mathcal{I}_8.
\]

(23)

Expressing \( \operatorname{erfc} (\sqrt{E \beta} f_r(y)) = \sqrt{\pi \beta} \Gamma (\beta + 1/2) \left( \frac{\beta + 3}{\beta + 1} \right) \) and \( \exp(-y) = G_{\beta,0}^0 \left[ y \right] \), one can solve with the aid of [28] and after some straightforward mathematical manipulations, \( \mathcal{I}_7 \) can be expressed as

\[
\mathcal{I}_7 = \sum_{i=0}^{\infty} \frac{\lambda D \Gamma (\beta_2 + 1/2)}{\sqrt{\pi \beta_1^2 E^2}} \left\{ 2F_1 \left( \frac{3}{2}, \frac{\beta_1}{\beta_2}; \frac{1}{2} \beta_1 + 1; \frac{1}{\beta} \right) \right\}
\]

(24)

with \( 2F_1(\cdot, \cdot; \cdot) \) being Gauss Hypergeometric function [21, Equation (9.100)]. Moreover, \( \mathcal{I}_8 = \int_0^\infty D \operatorname{erfc} (\sqrt{E \beta} f_r(y) dy - \int_0^\infty D \operatorname{erfc} (\sqrt{E \beta} f_r(y) dy = \mathcal{I}_{8,a} - \mathcal{I}_{8,b}. \) Hence, substituting again \( \mathcal{I}_8(\cdot) \) with its infinite series representation [21, Equation (8.445)], \( \mathcal{I}_{8,a} \) and \( \mathcal{I}_{8,b} \) can be solved with the aid of [28] and \( \mathcal{I}_{8,b} \) using [27, Equation (06.27.21.0019.01)]. Thus, using these solutions of \( \mathcal{I}_{8,a} \) and \( \mathcal{I}_{8,b} \) and after some mathematical manipulations, \( \mathcal{I}_8 \) can be expressed as in (25):

\[
\mathcal{I}_8 = \frac{D(1 + K) \exp(-K)}{\varphi} \sum_{k=0}^{\infty} \left( k \right)^{-2} \left( \frac{K(K + 1)}{\varphi} \right)^k
\]

\[
\times \left( \frac{\Gamma(k + 1) \Gamma(k + 3/2)}{\sqrt{\pi E x k + 1/2} \Gamma(k + 2)} \right) \times 2F_1 \left[ \frac{k + 1, k + 3}{2}, k + 2; 1 + \frac{1 + K}{\varphi E} \right]
\]

\[
- \frac{2\sqrt{E/\varphi}}{\beta_1 (1 - \rho^2)^{1+3/2}} \sum_{\rho=0}^{\infty} \left( -\frac{(1 + K)/\varphi}{\varphi E} \beta_1 \right)^{2+1} \rho!
\]

\[
\times \left[ \frac{\Gamma(k + 1/2)}{2\beta_1 (1 - \rho^2)^{k + 1}} \right] - \frac{\Gamma(k + 1, (1 + K) y_t/\varphi)}{2\beta_1 (1 - \rho^2)^{k + 1}}.
\]

(25)

In (25), \( \Gamma(\cdot, \cdot) \) is the upper incomplete Gamma function [22, Equation (6.51)].

(ii) For noncoherent binary frequency shift keying (BFSK) and binary differential phase shift keying (BDPSK), \( P_r(y) = D \exp(-Dy) \). Similar to the derivation of (12), that is, using [21, Equation (3.381/4)] and [2, Equation (4.33)], \( \mathcal{P}_{sc} \) can be expressed as

\[
\mathcal{P}_{sc} = \sum_{i=0}^{\infty} \frac{\lambda D}{\sqrt{\pi \beta_1^2 E^2}} \left( \frac{\beta + 3}{\beta + 1} \right) \Gamma (\beta + 1/2) \left( \frac{\beta + 3}{\beta + 1} \right) \times 2F_1 \left( \frac{3}{2}, \frac{\beta + 3}{\beta + 1}; \frac{1}{\beta} \right)
\]

(26)

(iii) For Gray encoded \( M \)-ary PSK and \( M \)-ary DPSK, \( P_r(y) = D \int_0^\infty \exp(-E \theta) y d\theta \), where \( \Lambda \) is constant. Thus, \( \mathcal{P}_{sc} \) can be expressed as

\[
\mathcal{P}_{sc} = \sum_{i=0}^{\infty} \frac{\lambda D}{\sqrt{\pi \beta_1^2 E^2}} \left( \frac{\beta + 3}{\beta + 1} \right) \Gamma (\beta + 1/2) \left( \frac{\beta + 3}{\beta + 1} \right) \times 2F_1 \left( \frac{3}{2}, \frac{\beta + 3}{\beta + 1}; \frac{1}{\beta} \right)
\]

(27)

where \( g(\theta) = 1 + K + \varphi E \theta \). The above finite integrals can be easily evaluated via numerical integration.

5.3. Average output SNR (ASNR) and amount of fading (AoF)

The ASNR, \( \gamma_{sc} \), is a useful performance measure serving as an excellent indicator for the overall system fidelity and can be obtained from the first-order moment of \( \gamma_{sc} \) as

\[
\gamma_{sc} = \mu_{\gamma_{sc}}(1).
\]

(28)
The AoF, defined as $\text{AoF} \triangleq \frac{\text{var}(\gamma_{\text{ssc}})}{\text{var}(\gamma_{\text{ssc}})}$, is a unified measure of the severity of the fading channel [2] and gives an insight to the performance of the entire system. It can be expressed in terms of first- and second-order moments of $\gamma_{\text{ssc}}$ as

$$\text{AoF} = \frac{\mu_{\gamma_{\text{ssc}}}(2)}{\mu_{\gamma_{\text{ssc}}}(1)} - 1.$$  \hspace{1cm} (29)

### 6. PERFORMANCE EVALUATION RESULTS

Using the previous mathematical analysis, various performance evaluation results have been obtained by means of numerical techniques and will be presented in this section. Such results include performances for the ASNR, AoF, $P_{\text{out}}$, ABEP\(^1\), and $\bar{C}$ and will be presented for different Ricean channel conditions, that is, different values for $K$ and $\rho$, as well as for various modulation schemes.

In Figures 1 and 2 the normalized ASNR ($\overline{\gamma}_{\text{ssc}}/\overline{\gamma}$) and AoF are plotted as functions of the Ricean $K$-factor for several values of the correlation coefficient $\rho$. These performance evaluation results have been obtained by numerically evaluating (15)–(17), (28), and (29). The results presented in Figure 1 show that as $K$ increases, that is, the severity of the fading decreases, and/or $\rho$ increases, the normalized ASNR decreases, resulting in a reduced diversity gain. We note that similar observations have been made in [3, 30]. Furthermore, the results presented in Figure 2 indicate that as $K$ increases and/or $\rho$ decreases, AoF is degraded.

Next the ABEP has been obtained using (23)–(27). In Figures 3 and 4 the ABEP is plotted as a function of the average input SNR per bit, that is, $\gamma_0 = P/\log_2 M$, for several values of $K$. Figure 3 considers the performance of DBPSK, BPSK, and $M$-ary PSK signaling formats and $\rho = 0.5$. As expected, when $K$ increases, the ABEP improves and BPSK exhibits the best performance. Figure 4 presents the ABEP of 16-QAM for different values of $\rho$ and $K$. For comparison purposes, the performance of an equivalent single receiver, that is, without diversity, is also included. Similar to the previous cases, it is observed that the ABEP improves as $K$ increases and/or $\rho$ decreases, while significant overall performance improvement, as compared to the no-diversity case, is also noted.

In Figure 5, $P_{\text{out}}$ is plotted as a function of the normalized outage threshold per bit, $\gamma_0/\overline{\gamma}$, for several values of $K$ and $\rho$. These performance results have been obtained by numerically evaluating (10), (11), and (21) and for $\rho = 0$ they are identical to the ones obtained by using [2, Equation 9.273]. It is observed that $P_{\text{out}}$ decreases, that is, the outage performance improves, as $K$ increases and/or $\rho$ decreases.

Finally, the normalized average CC can be obtained as $\overline{C} = \overline{C}/BW$ (in b/s/Hz) by employing (19) and (20). In Figure 6, $\overline{C}$ is plotted as a function of $\overline{\gamma}_b$ for several values

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\(^1\) For the consistency of the presentation from now on instead of the ASEP the ABEP performance will be used. As it is well known [2] for $M$-ary ($M > 2$) modulation schemes, assuming Gray encoding, the ABEP can be simply obtained from the ASEP as $P_{\text{be}} = P_{\text{se}}/\log_2 M$, since $E_b = E_s \log_2 M$, where $E_s$ denotes the transmitted average bit energy.
Average bit error probability (ABEP) versus average input SNR per bit for DBPSK, BPSK, and $M$-PSK ($M = 8$ and 16) signaling formats, for different values of the Ricean $K$-factor.

Figure 3

Outage probability ($P_{\text{out}}$) versus the normalized average input SNR per bit for several values of the Ricean $K$-factor and the correlation coefficient $\rho$.

Figure 5

Normalized average channel capacity ($C/BW$) versus the average input SNR per bit for several values of the correlation coefficient $\rho$.

Figure 6
of $\rho$ and for $K=1$. These results illustrate that as $\rho$ increases, $C_0$ decreases, as expected [12], and the receiver without diversity always has the worst performance.

7. CONCLUSIONS

In this paper, the performance of dual branch SSC diversity receivers operating over correlated Ricean fading channels has been studied. By deriving a convenient expression for the bivariate Ricean PDF, analytical formulae for the most important statistical metrics of the received signals and the capacity of such receivers have been obtained. Capitalizing on these formulas, useful expressions for a number of performance criteria have been obtained, such as ABER, $P_{\text{out}}$, ASNR, AoF, and average CC. Various performance evaluation results for different fading channel conditions have been also presented and compared with equivalent performance results of receivers without diversity.

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