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Outage Analysis of Hybrid Satellite-Terrestrial Cooperative Network with Best Relay Selection

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Abstract—**In this paper, we study the performance of a downlink hybrid satellite-terrestrial cooperative network. The decode-and-forward scheme is used and a selection of the best relay terminal is implemented. In this proposed system, a two time-slot scenario is considered. The first time slot is used by the satellite for broadcasting the information to the terrestrial relays and the destination. In the second time slot, only the best relay which provides the maximal received signal-to-noise (SNR) ratio at the destination is selected for forwarding the information. Then, both signals are combined using the maximum ratio combining (MRC) technique. The analytical expression of the outage probability is evaluated and is then verified with the simulation. The results show that our analytical expression matched well to the simulation results at the high SNR regime.**

I. INTRODUCTION

The satellite communications are used to provide services over a wide coverage area. However, this coverage area is limited by the masking effect caused by obstacles that block the line of sight (LOS) link between the satellite and a terrestrial user. This is the main limitation of mobile satellite communication systems. To overcome this issue, the satellite diversity techniques have been proposed in [1], [2]. The temporal and spatial diversity as the blockage mitigation technique have been studied in [1] while [2] proposed two solutions, the automatic repeat request (ARQ) and packet forwarding.

Recently, a hybrid satellite-terrestrial cooperative network has been proposed as it provides the coverage extension by using terrestrial relays [3], [4]. The delay diversity technique for hybrid satellite terrestrial DVB-SH system has been discussed in [3]. Fixed gap-fillers are used to forward the satellite signal. So, user terminals achieve time diversity by receiving different delayed signals from both the satellite and the relay stations. In [4], space-time codes and rate compatible turbo codes have been implemented to achieve diversity gains and additional coding gains. Another diversity technique is to use a two time-slot scenario. The satellite signal is transmitted first then the ground stations are relaying the satellite signal by using amplify-and-forward (AF) or decode-and-forward (DF) transmission scheme. Recently, a new hybrid satellite-terrestrial cooperative scheme has been proposed in [5]. User terminals help each other to relay the information. The concept of this scenario is that the satellite broadcasts the information to terrestrial users in the first time slot and in the second time slot, non-masked terminals are used to relay the information toward masked terminals.

Although the cooperative diversity techniques can increase the system availability, the additional bandwidth is needed for the relay transmission. To minimize the bandwidth consumption while keeping the maximum diversity order, Bletsas et al. [6] have proposed an opportunistic cooperative protocol in which only one relay is used for forwarding the message to the destination. Two criteria for selecting the best relay have been studied. The first criterion is to choose the relay which maximizes the minimum of the source-relay and the relay-destination channel gain, while the second criterion is based on the maximization of the harmonic mean of both channel gains. It has been illustrated in [7] that the outage performance of both selection techniques are the same in the high-SNR regime. The bandwidth consumption can be further decreased by implementing on-demand cooperation together with the best relay selection [8].

The outage probability is an important performance measure of communication systems operating over fading channels [9]. In particular, the performance in terms of outage probability has been studied for the case of the cooperative communication systems [10], [11]. In [12], the outage and symbol error probability of hybrid satellite-terrestrial cooperative network operating in AF mode has been evaluated.

In this paper, we investigate the performance of a hybrid satellite-terrestrial cooperative network with best relay selection. The relay is operating in DF mode. The closed-form expression of the outage probability is then evaluated by using the land mobile satellite (LMS) channel derived in [13]. The analytical results are confirmed using Monte Carlo simulations.

The rest of this paper is organized as follows. The system model is discussed in Section II. In Section III, we derived the outage probability of the opportunistic selection decode and forward (OPSDF) hybrid satellite-terrestrial cooperative network. The simulation and numerical results are presented in Section IV. The conclusion is finally drawn in Section V.

II. SYSTEM MODEL

The system model is represented in Fig. 1. The system consists of one satellite source denoted by s, M terrestrial relays denoted by r_1, r_2, ..., r_M, and a destination denoted by d. We

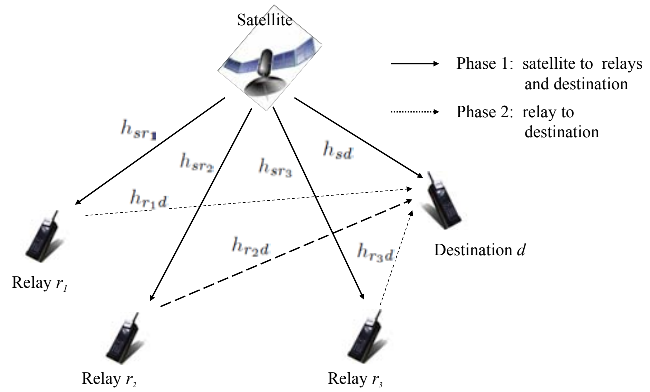

Fig. 1. Hybrid satellite-terrestrial system with 3 relays and one destination.

assume that each terminal is equipped with a single antenna and is able to implement the cooperative functionality.

The set of M relays is divided into two subsets. The first subset of relays gathers the terminals that failed to decode the satellite message. This subset is denoted S_1 with cardinality k, i.e., $|S_1| = k$, where $0 \leq k \leq M$. The second subset of relays gathers the terminals that succeed in decoding the satellite message. This subset is denoted S_2, with cardinality $|S_2| = M - k$.

A. Channel model

We denote the channel gain between the satellite and the destination by h_{sd}, the channel gain between the satellite and the ith relay by h_{sr_i}, and the channel gain between the ith relay and the destination by h_{r_id}. We assume that all channels are independent and flat fading. The statistics of the channel model are defined as follows.

- The satellite-destination link is modeled as the LMS fading channel [13]. The probability density function (PDF), $f_{\gamma_{sd}}(\gamma)$ of the instantaneous received SNR per symbol, γ_{sd} is given in [13] as

$$f_{\gamma_{sd}}(\gamma) = \frac{\Omega_0}{2b_0\overline{\gamma}_{sd}}\left(\frac{2b_0m_0}{2b_0m_0+\Omega_0}\right)^{m_0}\exp\left(-\frac{\Omega_0\gamma}{2b_0\overline{\gamma}_{sd}}\right) \times {}_1F_1\left(m_0, 1, \frac{\Omega_0^2\gamma}{2b_0\overline{\gamma}_{sd}(2b_0m_0+\Omega_0)}\right), \text{for } \gamma > 0 \quad (1)$$

  where Ω_0 is the average power of the LOS component, $2b_0$ is the average power of the multipath component, and m_0 is the Nakagami parameter ranging from 0 to ∞. When $m_0 = 0$, the PDF of γ_{sd} becomes a Rayleigh PDF and when $m_0 = \infty$, it becomes a Rice PDF. The ratio $\overline{\gamma}_{sd} = \frac{P_s}{N_0}\sigma^2_{sd}$ is the average received SNR of the s to d link with variance σ^2_{sd}. P_s and N_0 are the total transmit power of the satellite source and the noise power at the d side respectively. The function ${}_1F_1(a,b,z)$ is the confluent hypergeometric function defined in [14] by

$$ {}_1F_1(a,b,z) = \sum_{n=0}^{\infty}\frac{a^{(n)}}{b^{(n)}n!}z^n$$

  where $x^{(n)} = x(x+1)...(x+n-1)$.
- The satellite-relay link is modeled as the LMS fading channel [13]. The PDF $f_{\gamma_{sr}}(\gamma)$ of the instantaneous received SNR per symbol, γ_{sr} is given in [13] as

$$f_{\gamma_{sr}}(\gamma) = \frac{\Omega_r}{2b_r\overline{\gamma}_{sr}}\left(\frac{2b_rm_r}{2b_rm_r+\Omega_r}\right)^{m_r}\exp\left(-\frac{\Omega_r\gamma}{2b_r\overline{\gamma}_{sr}}\right) \times {}_1F_1\left(m_r, 1, \frac{\Omega_r^2\gamma}{2b_r\overline{\gamma}_{sr}(2b_rm_r+\Omega_r)}\right), \text{for } \gamma > 0 \quad (2)$$

  where Ω_r is the average power of the LOS component, $2b_r$ is the average power of the multipath component, and m_r is the Nakagami parameter ranging from 0 to ∞. When $m_r = 0$, the PDF of γ_{sr} becomes a Rayleigh PDF and, when $m_r = \infty$, it becomes a Rice PDF. The ratio $\overline{\gamma}_{sr} = \frac{P_s}{N_0}\sigma^2_{sr}$ is the average received SNR of the s to r link with variance σ^2_{sr}. P_s and N_0 are the total transmit power of the satellite source and the noise power at the r side respectively.
- The relays-destination link is modeled as a Rayleigh fading channel. The PDF $f_{\gamma_{r_id}}(\gamma)$ of the instantaneous received SNR per symbol, γ_{r_id} is defined in [15] as

$$f_{\gamma_{r_id}}(\gamma) = \frac{1}{\overline{\gamma}_{r_id}} \times \exp\left(-\frac{\gamma}{\overline{\gamma}_{r_id}}\right), \text{for } \gamma > 0 \quad (3)$$

  and the cumulative distribution function (CDF) is given by

$$F_{\gamma_{r_id}}(\gamma) = \left[1 - \exp\left(-\frac{\gamma}{\overline{\gamma}_{r_id}}\right)\right], \quad \text{for } \gamma > 0 \quad (4)$$

  where $\overline{\gamma}_{r_id} = \frac{P_{r_i}}{N_0}\sigma^2_{r_id}$ is the average received SNR of the ith relay to d link with variance $\sigma^2_{r_id}$. P_{r_i} and N_0 are the total transmit power of the ith relay and the noise power at the d side respectively.

B. OPSDF transmission scheme

The transmission scheme is divided into two time slots. In the first time slot, the satellite broadcasts its message to the M terrestrial relays and the destination. The satellite message is assumed to be successfully decoded when the received SNR, γ_{sr_i} at the relay terminal is higher than a threshold SNR. In the second time slot, only one relay is selected from the subset S_2 for forwarding the information. Actually, the relay selection takes place between the two time slots. The selection can be achieved using the same approach as in [6]. The selected relay is the one that provides the best link quality between a relay and the destination. Then, both signals from the two phases are combined using the MRC technique.

III. OUTAGE ANALYSIS

In this section, we analyze the outage probability of the OPSDF hybrid satellite-terrestrial cooperative network in the high SNR regime. First, we evaluate the outage probability of the direct link.

A. Outage probability of the direct link

The instantaneous mutual information I_{sd} of the direct link is given by

$$I_{sd} = \frac{1}{2}\log_2\left(1+\frac{P_s}{N_0}|h_{sd}|^2\right) = \frac{1}{2}\log_2\left(1+\gamma_{sd}\right) \tag{5}$$

The outage probability P_{sd}^{out} of the direct link is defined as

$$\begin{aligned} P_{sd}^{out} &= \Pr\left[I_{sd} < R\right] = \Pr\left[\gamma_{sd} < 2^{2R}-1\right] \\ &= \Pr\left[\gamma_{sd} < \gamma_{th}\right] = F_{\gamma_{sd}}(\gamma_{th}) \end{aligned} \tag{6}$$

where R denotes the target spectral efficiency (in bits/s/Hz), $\gamma_{th} = 2^{2R}-1$ and $F_{\gamma_{sd}}(\gamma)$ denotes the CDF of γ_{sd}. We have that

$$F_{\gamma_{sd}}(\gamma) = \int_0^{\gamma} f_{\gamma_{sd}}(\tau)d\tau \tag{7}$$

For the high-SNR regime, $\exp(-x) \sim (1-x)$ as $x \to 0$ for $\overline{\gamma}_{sd} \to \infty$. Using the table of integrals in [14], we obtain

$$\begin{aligned} F_{\gamma_{sd}}(\gamma) &= A_0\left(\frac{\gamma}{\overline{\gamma}_{sd}}\right) {}_1F_1\left(m_0, 2, B_0\frac{\gamma}{\overline{\gamma}_{sd}}\right) \\ &\quad - \frac{A_0\Omega_0}{4b_0}\left(\frac{\gamma}{\overline{\gamma}_{sd}}\right)^2 {}_2F_2\left(2, m_0; 3, 1; B_0\frac{\gamma}{\overline{\gamma}_{sd}}\right) \end{aligned} \tag{8}$$

where

$$A_0 = \frac{\Omega_0}{2b_0}\left(\frac{2b_0m_0}{2b_0m_0+\Omega_0}\right)^{m_0}, B_0 = \frac{\Omega_0^2}{2b_0(2b_0m_0+\Omega_0)},$$

and

$${}_pF_q(a_1,...,a_p;b_1,...,b_q;z) = \sum_{n=0}^{\infty}\frac{a_1^{(n)}...a_p^{(n)}}{b_1^{(n)}...b_q^{(n)}n!}z^n$$

is the general hypergeometric function defined in [14]. Hence, using (8) in (9) the outage probability of the direct link is

$$\begin{aligned} P_{sd}^{out} &= A_0\left(\frac{\gamma_{th}}{\overline{\gamma}_{sd}}\right) {}_1F_1\left(m_0, 2, B_0\frac{\gamma_{th}}{\overline{\gamma}_{sd}}\right) \\ &\quad - \frac{A_0\Omega_0}{4b_0}\left(\frac{\gamma_{th}}{\overline{\gamma}_{sd}}\right)^2 {}_2F_2\left(2, m_0; 3, 1; B_0\frac{\gamma_{th}}{\overline{\gamma}_{sd}}\right) \end{aligned} \tag{9}$$

B. Outage probability of the OPSDF transmission scheme

As described in Section II-B, only one relay which provides the maximal received SNR at the destination is selected for forwarding the information. Hence, at the output of the MRC, the instantaneous received SNR is given by

$$\gamma_{OPSDF|k} = \begin{cases} \gamma_{sd} + \gamma_{rd|k}, & \text{if } 0 \le k < M \\ \gamma_{sd}, & \text{if } k = M \end{cases} \tag{10}$$

where $\gamma_{rd|k} = \max\{\gamma_{r_1d}, \gamma_{r_2d}, ..., \gamma_{r_{M-k}d}\}$.

The instantaneous mutual information of the OPSDF transmission scheme for a given k value is defined by

$$I_{OPSDF|k} = \begin{cases} \frac{1}{2}\log_2\left(1+\gamma_{sd}+\gamma_{rd|k}\right), & \text{if } 0 \le k < M \\ \frac{1}{2}\log_2\left(1+\gamma_{sd}\right), & \text{if } k = M \end{cases} \tag{11}$$

So, the outage probability for a given k value is calculated as

$$P_{OPSDF|k}^{out} = \Pr\left[I_{OPSDF|k} < R\right] \tag{12}$$

$$P_{OPSDF|k}^{out} = \begin{cases} \Pr\left[\gamma_{sd}+\gamma_{rd|k} < \gamma_{th}\right]\Pr\left[|S_1| = k\right] \\ \Pr\left[\gamma_{sd} < \gamma_{th}\right]\Pr\left[|S_1| = M\right] \end{cases} \tag{13}$$

$$P_{OPSDF|k}^{out} = \begin{cases} F_{\gamma_{OPSDF|k\neq M}}(\gamma_{th})\Pr\left[|S_1| = k\right] \\ F_{\gamma_{OPSDF|k=M}}(\gamma_{th})\Pr\left[|S_1| = M\right] \end{cases} \tag{14}$$

where $\Pr\left[|S_1| = k\right]$ is the probability that k relays failed to decode and $\Pr\left[|S_1| = M\right]$ is the probability that M relay failed to decode. $F_{\gamma_{OPSDF|k}}(\gamma)$ is the CDF of $\gamma_{OPSDF|k}$.

The total outage probability of the OPSDF transmission scheme, P_{OPSDF}^{out} is the summation of the $P_{OPSDF|k}^{out}$ for all the values of k from 0 to M.

$$P_{OPSDF}^{out} = \sum_{k=0}^{M} P_{OPSDF|k}^{out} \tag{15}$$

It is well known that the PDF of the sum of two independent random variables is the convolution product of these two variables. Therefore, the PDF of $\gamma_{OPSDF|k}$ is given as

$$f_{\gamma_{OPSDF|k}}(\gamma) = \begin{cases} \int_{-\infty}^{+\infty} f_{\gamma_{rd|k}}(\gamma-\tau)f_{\gamma_{sd}}(\tau)d\tau, & \text{if } 0 \le k < M \\ f_{\gamma_{sd}}(\gamma), & \text{if } k = M \end{cases} \tag{16}$$

After some mathematical manipulations, the CDF of $\gamma_{OPSDF|k}$ can be expressed as

$$F_{\gamma_{OPSDF|k}}(\gamma) = \begin{cases} \int_{0}^{\gamma} F_{\gamma_{rd|k}}(\gamma-\tau)f_{\gamma_{sd}}(\tau)d\tau, & \text{if } 0 \le k < M \\ F_{\gamma_{sd}}(\gamma), & \text{if } k = M \end{cases} \tag{17}$$

By applying the order statistic theory described in [16], the CDF of $\gamma_{rd|k}$ can be calculated as

$$F_{\gamma_{rd|k}}(\gamma) = F_{\gamma_{rd}}^{M-k}(\gamma) = \left[1-\exp\left(-\frac{\gamma}{\overline{\gamma}_{rd}}\right)\right]^{M-k} \tag{18}$$

For the high-SNR regime, $\exp(-x) \sim (1-x)$ as $x \to 0$ for $\overline{\gamma}_{sd}$ and $\overline{\gamma}_{rd} \to \infty$. By using the table of integrals in [14], $F_{\gamma_{OPSDF|k\neq M}}(\gamma)$ can be expressed as equation (19). Let P_{sr} denote the probability of a decoding failure at the relay.

$$\begin{aligned} P_{sr} &= \Pr\left[\gamma_{sr} < \gamma_{th}\right] = F_{\gamma_{sr}}(\gamma_{th}) \\ &= A_r\left(\frac{\gamma_{th}}{\overline{\gamma}_{sr}}\right) {}_1F_1\left(m_r, 2, B_r\frac{\gamma_{th}}{\overline{\gamma}_{sr}}\right) \\ &\quad - \frac{A_r\Omega_r}{4b_r}\left(\frac{\gamma_{th}}{\overline{\gamma}_{sr}}\right)^2 {}_2F_2\left(2, m_r; 3, 1; B_r\frac{\gamma_{th}}{\overline{\gamma}_{sr}}\right) \end{aligned} \tag{20}$$

$$F_{\gamma_{OPSDF|k\neq M}}(\gamma) = \frac{A_0}{(M-k+1)}\left(\frac{\gamma}{\overline{\gamma}_{sd}}\right)\left(\frac{\gamma}{\overline{\gamma}_{rd}}\right)^{M-k} {}_1F_1\left(m_0, M-k+2, B_0\frac{\gamma}{\overline{\gamma}_{sd}}\right) - \frac{A_0\Omega_0}{2b_0(M-k+1)(M-k+2)}\left(\frac{\gamma}{\overline{\gamma}_{sd}}\right)^2\left(\frac{\gamma}{\overline{\gamma}_{rd}}\right)^{M-k} {}_2F_2\left(2, m_0; M-k+3, 1; B_0\frac{\gamma}{\overline{\gamma}_{sd}}\right) \quad (19)$$

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where

$$A_r = \frac{\Omega_r}{2b_r}\left(\frac{2b_rm_r}{2b_rm_r+\Omega_r}\right)^{m_r}, B_r = \frac{\Omega_r^2}{2b_r(2b_rm_r+\Omega_r)}$$

The probability that k relays failed to decode is given as

$$\Pr\left[|S_1| = k\right] = \binom{M}{k}(1-P_{sr})^{M-k}P_{sr}^k \quad (21)$$

and the probability that M relays failed to decode is given as

$$\Pr\left[|S_1| = M\right] = P_{sr}^M \quad (22)$$

So, the total outage probability of OPSDF can be written as

$$P_{OPSDF}^{out} = \sum_{k=0}^{M}\binom{M}{k}(1-P_{sr})^{M-k}P_{sr}^kF_{\gamma_{OPSDF|k}}(\gamma_{th}) \quad (23)$$

IV. Simulation Results

In this section, we present the numerical results of the outage probability of OPSDF hybrid satellite-terrestrial cooperative network versus the average transmitted SNR, $\frac{P_s}{N_0}$. Simulation curves (denoted by Sim) are compared to theoretical curves (denoted by Theo). The numerical values for the LMS channel are shown in Table I. First, we compare the analytical outage probability and the simulated outage probability at the high SNR regime. In order to see the diversity order we assume that the transmitted signal power at the source and at the relay are the same i,e. $\frac{P_s}{N_0} = \frac{P_r}{N_0}$. Figs. 2 and 3 plot the outage probability of the OPSDF hybrid satellite-terrestrial cooperative network for $M = 1, 2, 3$. In Fig. 2, the direct link and the satellite-relay link both experience the deep shadowing. In Fig. 3, the direct link experiences the deep shadowing while the satellite-relay link experiences moderate shadowing. The results show that the analytical outage probabilities and the simulated ones are very close when the SNR is large. They show that our analytical expressions provide good predictions of the outage probability of OPSDF hybrid satellite-terrestrial cooperative network at the high SNR regime.

In practice, transmitted signal power at the source and at the relay are not the same. Figs. 4 and 5 plot the outage probabilities of OPSDF cooperative hybrid satellite-terrestrial system versus the average transmitted satellite SNR, $\frac{P_s}{N_0}$ and the average transmitted relay SNR, $\frac{P_r}{N_0}$ is set to be constant, 15 dB. Fig. 4 shows that for the outage probability of 10^{-3}, the required $\frac{P_s}{N_0}$ is 35 dB for the direct link, 24 dB for OPSDF with single relay, and only 17 dB when there are two relays. So, with cooperation, 11 dB of diversity gain is achieved when using one relay.

TABLE I
LMS CHANNEL PARAMETERS [13]

	Parameter		
	b	m	Ω
Deep Shadowing	0.0158	2.56	0.123
Moderate Shadowing	0.0129	7.64	0.372
Infrequent Light Shadowing	0.158	19.4	1.29

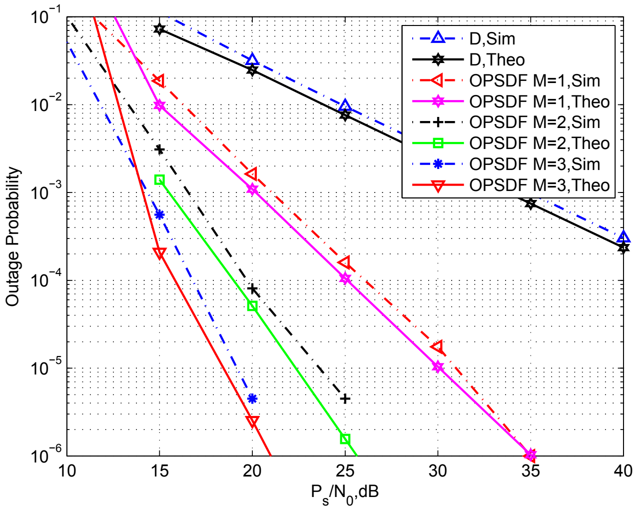

Fig. 2. Outage probability versus transmitted SNR, $\frac{P_s}{N_0}$, when the direct link (D) and the satellite-relay link both experience a deep shadowing, $m_0 = m_r = 2.56$, the relay-destination link experience Rayleigh fading with variance 0.25, $\frac{P_r}{N_0} = \frac{P_s}{N_0}$, and $\gamma_{th} = 0$ dB.

V. Conclusion

In this paper, the transmission scheme of a hybrid satellite-terrestrial cooperative network with relay selection has been presented. Only the best relay which provides the maximal received SNR at the destination is selected for forwarding the message. The performance in terms of outage probability is evaluated. The results show that our analytical outage probability matched well to the simulation results at the high SNR regime.

References

[1] J. Schodorf and P. Wu, "Diversity reception for blockage mitigation in ehf land mobile satellite communications systems," in *IEEE Vehicular Technology Conference*, vol. 1, 2001, pp. 126 – 130.

[2] W. Phoel, "Concepts for reliable satellite communications over blockage channels," in *IEEE Military Communications Conference*, vol. 4, oct. 2005, pp. 2132 –2137.

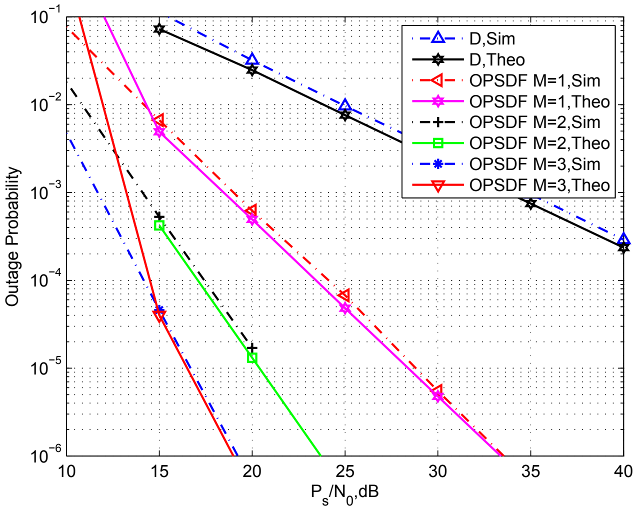

Fig. 3. Outage probability versus transmitted SNR, $\frac{P_s}{N_0}$, when the direct link (D) experiences the deep shadowing, $m_0 = 2.56$, the satellite-relay link experience moderate shadowing, $m_r = 7.64$, the relay-destination link experience Rayleigh fading with variance 0.25, $\frac{P_r}{N_0} = \frac{P_s}{N_0}$, and $\gamma_{th} = 0$ dB.

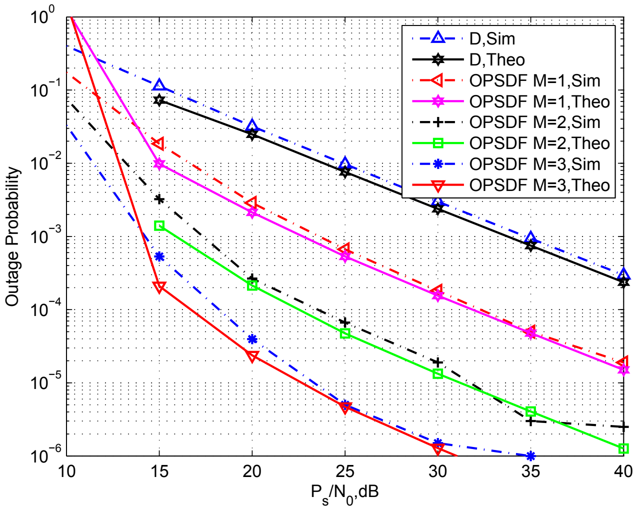

Fig. 4. Outage probability versus transmitted satellite SNR, $\frac{P_s}{N_0}$, when the direct link (D) and the satellite-relay link both experience the deep shadowing, $m_0 = m_r = 2.56$, the relay-destination link experience Rayleigh fading with variance 0.25, $\frac{P_r}{N_0} = 15$ dB, and $\gamma_{th} = 0$ dB.

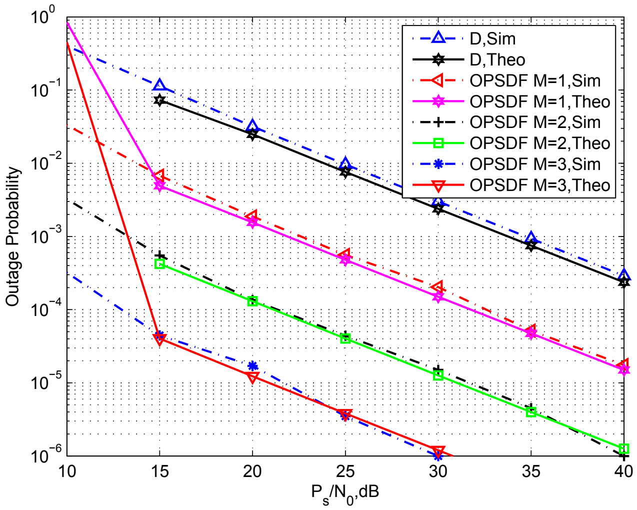

Fig. 5. Outage probability versus transmitted satellite SNR, $\frac{P_s}{N_0}$, when the direct link (D) experiences the deep shadowing, $m_0 = 2.56$, the satellite-relay link experience moderate shadowing, $m_r = 7.64$, the relay-destination link experience Rayleigh fading with variance 0.25, $\frac{P_r}{N_0} = 15$ dB, and $\gamma_{th} = 0$ dB.

[3] S. Morosi, S. Jayousi, and E. Del Re, "Cooperative delay diversity in hybrid satellite/terrestrial dvb-sh system," in *IEEE International Conference on Communications*, may 2010, pp. 1 –5.

[4] D.-S. Ahn, S. Kim, H. W. Kim, and D.-C. Park, "A cooperative transmit diversity scheme for mobile satellite broadcasting systems." *Int. J. Satellite Communications Networking*, vol. 28, pp. 352–368, 2010.

[5] B. Paillassa, B. Escrig, R. Dhaou, M.-L. Boucheret, and C. Bes, "Improving satellite services with cooperative communications," *Int. J. Satellite Communications Networking*, vol. 29, p. 479 500, 2011.

[6] A. Bletsas, A. Khisti, D. P. Reed, and A. Lippman, "A simple cooperative diversity method based on network path selection," *IEEE Journal on selected areas in communications*, vol. 24, no. 3, pp. 659–672, 2006.

[7] X. Chen, T. wai Siu, Q. Zhou, and F. Lau, "High-snr analysis of opportunistic relaying based on the maximum harmonic mean selection criterion," *IEEE Signal Processing Letters*, vol. 17, no. 8, pp. 719 –722, aug. 2010.

[8] B. Escrig, "On-demand cooperation mac protocols with optimal diversity-multiplexing tradeoff," in *IEEE Wireless Communications and Networking Conference (WCNC)*, april 2010, pp. 1 –6.

[9] Y.-C. Ko, M.-S. Alouini, and M. Simon, "Outage probability of diversity systems over generalized fading channels," *IEEE Transactions on Communications*, vol. 48, no. 11, pp. 1783 – 1787, nov 2000.

[10] J. Laneman and G. Wornell, "Distributed space-time-coded protocols for exploiting cooperative diversity in wireless networks," *IEEE Transactions on Information Theory*, vol. 49, no. 10, pp. 2415 – 2425, oct. 2003.

[11] J. Laneman, D. Tse, and G. Wornell, "Cooperative diversity in wireless networks: Efficient protocols and outage behavior," *IEEE Transactions on Information Theory*, vol. 50, no. 12, pp. 3062 – 3080, dec. 2004.

[12] A. Iqbal and K. M. Ahmed, "A hybrid satellite-terrestrial cooperative network over non identically distributed fading channels," *Journal of communications*, vol. 7, pp. 581–589, 2011.

[13] A. Abdi, W. Lau, M.-S. Alouini, and M. Kaveh, "A new simple model for land mobile satellite channels: first- and second-order statistics," *IEEE Transactions on Wireless Communications*, vol. 2, no. 3, pp. 519 – 528, may 2003.

[14] I. S. Gradshteyn and I. M. Ryzhik, *Table of Integrals, Series, and Products*. New York: Academic Press, 2007.

[15] M. K. Simon and M.-S. Alouini, *Digital Communication over Fading Channels*. Wiley, 2005.

[16] H. A. David and H. N. Nagaraja, *Order Statistics, Third Edition*. New York: Wiley, 2003.