Optimized Power Allocation Scheme for Land Mobile Satellite Cooperative Diversity Communications

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***Abstract*—In this paper, an optimized transmitting power allocation scheme between the source and its cooperator is presented, minimizing the derived closed-form approximated outage probability expressions for the separately adopted maximum ratio combining (MRC) algorithm and selective diversity combining (SDC) algorithm at the satellite. The circumstance considered is the uplink of a dual-hop land mobile satellite cooperative diversity communication system with decode-and-forward (DF) protocol. Simulation results illustrate that the optimized power allocation scheme excellently outperforms the conventional uniform power allocation scheme on outage probability. The preferable choice of the combing algorithm between MRC and SDC in terms of the minimal outage probabilities changes with the variation of the maximum power allowed to consuming for transmitting a packet.**

Keywords-cooperative diversity; decode-and-forward protocol; land mobile satellite system; power allocation; maximum ratio combining ; selective diversity combining ; outage probability

I. INTRODUCTION

Multiple Input Multiple Output (MIMO) technology is of great importance among those technologies applied in the third and fourth generation of terrestrial wireless systems, providing higher spectral efficiency at no extra cost of transmitting power or bandwidth[1]. The success of MIMO technology in terrestrial systems enormously stimulates the intensive research on its application in satellite communications. In the new generation satellite systems where available spectrum and power are strictly restricted, high transmit speed and spectral efficiency are demanded, therefore, giving rise to more room to the utilization of MIMO technology. However, due to the limit of communication terminals, such as size, power and hardware complexity, it is difficult to employ multiple antennas on both ends, especially at the user terminal. The installation of only one antenna at each user terminal tremendously hampers the MIMO technology.

Recently, cooperative diversity technique, which is based on user cooperation and relay cooperation, has emerged as a promising technique and received considerable interests [2] [3].The spirit of this technique lies in that single-antenna terminals in a multi-user scenario are allowed to share their antennas and other resources through distributed transmission and processing, so that a virtual multi-antenna transmitter is achieved, hence obtaining the spatial diversity benefits of the virtual MIMO system.

In a land mobile satellite (LMS) communication system, we consider the uplink scenario where severe channel condition might happen due to the relative movement of the user terminal and the satellite, resulting in line-of-sight (LOS) path from one user terminal to satellite completely blocked. In such situation, cooperative relay of other user terminals under better channel condition may offer an effective way to combat channel fading, enabling better reliability of communication, as well as reducing the terminal burden [4].

The outage probability has been widely used as a performance measure in evaluating wireless systems. Lower outage probability indicates better performance of the system. There have been papers focusing on the power allocation problem to improve the outage probabilities of the wireless cooperative relay systems under terrestrial Rayleigh fading model environments with decode-and-forward (DF) protocol, (e.g., [5][6]), but to the best of our knowledge up to now, there has been no work on the land mobile satellite communication in the literature.

In the paper, the power allocation scheme aiming at optimizing outage performance of the LMS DF cooperative diversity system is provided when the uplink is undergoing different degree of shadowing. We use the Optimization Toolbox in MATLAB to get the minimum values of the closed-form outage probability approximation expressions with MRC algorithm and SDC algorithm, respectively. The optimized scheme is compared with the uniform power allocation scheme.

The remainder of this paper is organized as follows. Section II presents the system model and the channel fading model. In section III we optimize the closed-form approximated expressions for the outage probabilities. The numerical results of comparison between optimized power allocation and the uniform power allocation are presented in section IV. Finally, conclusion remarks are made in section V.

II. SYSTEM AND MODEL AND CHANNEL FADING MODEL

A. System Model

We examine a simple frequency nonselective fading system consisting of a source terminal, a cooperative terminal, a GEO satellite, each equipped with one single antenna. A gateway station communicates with the ground terminals via the satellite, as shown in Fig.1. The source terminal and the cooperative relay terminal operate in the same frequency band and cannot

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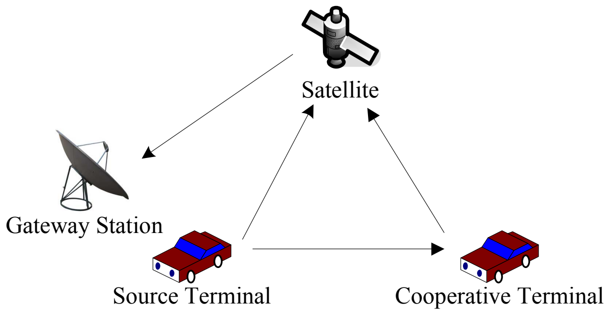

Figure 1. A three node LMS cooperative diversity system.

transmit and receive signal at the same time, so the half duplex mode is adopted. The time scheduling consists of two time slots. In the first time slot, the source transmits its signal both to the satellite and the cooperator. The received signals at the satellite and the cooperator during the first time slot can be written as

$$y_{sd} = \sqrt{p_1} h_{sd} x + n_d \tag{1}$$

$$y_{sr} = \sqrt{p_1} h_{sc} x + n_c \tag{2}$$

where p_1 is the source transmitted power , x is the transmitted signal. h_{sd} and h_{sc} are the respective channel coefficients of the source to satellite path and the source to cooperator path. n_d and n_c are the noise at the satellite and the cooperator, respectively.

During the second time slot, the regenerated signal at the cooperator is transmitted to the satellite. The received signal at the satellite during this time slot is

$$y_{rd} = \sqrt{p_2} h_{cd} x + n_d \tag{3}$$

where p_2 is the cooperator transmitted power, h_{cd} denotes the channel coefficients from the cooperator to the satellite.

Furthermore, n_d and n_c can be modeled as mutually independent, circularly symmetric, complex additive white Gaussian noise (AWGN) with zero-mean and variance N_0.

To make the following presentation clearer, the instantaneous and the average signal to noise ratio (SNR) of the first and the second hop are defined as

$$\Gamma_1 = |h_{sc}|^2 p_1 / N_0 \,,\ \Gamma_2 = |h_{cd}|^2 p_2 / N_0 \tag{4}$$

$$\overline{\Gamma}_1 = \sigma_{sc}^2 p_1 / N_0 \quad ,\ \overline{\Gamma}_2 = \sigma_{cd}^2 p_2 / N_0 \tag{5}$$

where Γ_1 and $\overline{\Gamma}_1$ are the instantaneous and average SNR of first hop, while Γ_2 and $\overline{\Gamma}_2$ are the instantaneous and average SNR of the second hop . σ_{sc}^2 is the variance of $\overline{\Gamma}_1$,while σ_{cd}^2 is the variance of the variance of $\overline{\Gamma}_2$.

The instantaneous and average SNR of the direct link are defined as

$$\Gamma_0 = |h_{sd}|^2 p_1 / N_0 \ ,\ \overline{\Gamma}_0 = \sigma_{sd}^2 p_1 / N_0 \tag{6}$$

where Γ_0 and $\overline{\Gamma}_0$ are instantaneous and the average SNR of the direct link. σ_{sd}^2 is the variance of the variance of $\overline{\Gamma}_0$.

B. Fading Model

Assume that channel coefficients h_{sd} and h_{cd} are mutually independent nonidentical Rician fading coefficients, the power of which are distributed according to noncentral-χ^2 distribution with two degree of freedom. Each of the resulting signal-to-noise ratio (SNR), i.e., Γ_0 and Γ_2 is of the same distribution. The probability distribution function (PDF) of the instantaneous SNR per symbol is expressed as

$$\begin{aligned} p^i(\Gamma) &= [(1+K_i)/\overline{\Gamma}_i]\exp[-K_i - (1+K_i)\Gamma/\overline{\Gamma}_i] \\ &\times I_0(2\sqrt{K_i(1+K_i)\Gamma/\overline{\Gamma}_i}) \end{aligned} \tag{7}$$

where, $p^i(\bullet)$ (i=0, 2) is the PDF of instantaneous SNR Γ_0 and Γ_2. $\overline{\Gamma}_i$ (i=0, 2) is the average SNR per symbol. K_0 is the source to satellite Rician K-factor defined as the ratio of the power in the LOS component to the power in the other (non-LOS) multipath components, and K_2 is the cooperator to satellite Rician K-factor. $I_0(\bullet)$ is the zero-order modified Bessel function of the first kind. The cumulative distribution function (CDF) of the instantaneous SNR is given by

$$P^i(\Gamma) = 1 - Q(\sqrt{2K_i}, \sqrt{2(1+K_i)\Gamma/\overline{\Gamma}_i}) \tag{8}$$

where $P^i(\bullet)$ (i=0, 2) is the CDF of instantaneous SNR Γ_0 and Γ_2, and $Q(\bullet,\bullet)$ is the first-order Marcum Q function.

Assume that h_{sc} is Rayleigh fading coefficient independent of h_{sd} and h_{cd} .The PDF of Γ_1 per symbol is given as

$$p_{rayeigh}(\Gamma) = \exp(-\Gamma/\overline{\Gamma}_1)/\overline{\Gamma}_1 \tag{9}$$

where $\overline{\Gamma}_1$ is the average SNR per symbol. The CDF of the instantaneous SNR is

$$P_{rayeigh}(\Gamma) = 1 - \exp(-\Gamma/\overline{\Gamma}_1) \tag{10}$$

III. OPTIMIZED POWER ALLOCATION SCHEME

At the satellite, the received signals come from two links, i.e., the direct link and the cooperative relay link. The signals from the two links are combined through two kinds of rules, maximum ratio combining (MRC) algorithm and selective diversity combining (SDC) algorithm. It is assumed that the channel state information (CSI) is fully available at the satellite. For DF protocol, we examine a repetition-coded structure [2] at the cooperator. When data rate is set to a fixed value R, the whole communication system is in outage state when the maximum average mutual information I_D<R.

$$P_{out1} = 1-\exp(-\gamma_{th}/\overline{\Gamma}_1)+\exp(-\gamma_{th}/\overline{\Gamma}_1)$$
$$\times\{\{1-\exp(-[(1+K_2)\gamma_{th}/\overline{\Gamma}_2+K_2])\sum_{k=0}^{20}[K_2\overline{\Gamma}_2/(1+K_2)\gamma_{th}]^{k/2}I_k(2[K_2(1+K_2)\gamma_{th}/\overline{\Gamma}_2]^{k/2})\}$$
$$*\{(1+K_0)I_0(2\sqrt{K_0(1+K_0)\gamma_{th}/\overline{\Gamma}_0})\exp[-K_0-(1+K_0)\gamma_{th}/\overline{\Gamma}_0]/\overline{\Gamma}_0\}\} \quad (17)$$

$$P_{out2} = \{1-\exp(-[(1+K_0)\gamma_{th}/\overline{\Gamma}_2+K_0])\sum_{k=0}^{20}[K_0\overline{\Gamma}_2/(1+K_0)\gamma_{th}]^{k/2}I_k(2[K_0(1+K_0)\gamma_{th}/\overline{\Gamma}_2]^{k/2})\}$$
$$\times\{1-\exp(-\gamma_{th}/\overline{\Gamma}_1)$$
$$\times\{1-\exp(-[(1+K_2)\gamma_{th}/\overline{\Gamma}_2+K_2])\sum_{k=0}^{20}[K_2\overline{\Gamma}_2/(1+K_2)\gamma_{th}]^{k/2}I_k(2[K_2(1+K_2)\gamma_{th}/\overline{\Gamma}_2]^{k/2})\}\} \quad (18)$$

From the perspective of information theory, I_D depends on the SNR of the received signal. Therefore, the values of Γ_0, Γ_1 and Γ_2 decide the outage probability of the whole system. From (4) and (6), we can see that how to allocate transmit power between the source and the relay to achieve the minimum outage probability is an important issue.

For MRC, $I_D < R$ is equivalent to the event [2][8]

$$\min\{\Gamma_1, \Gamma_0+\Gamma_2\} < \gamma_{th} \quad (11)$$

where min(•) returns the minimum value , and γ_{th} is the predetermined threshold.

So the outage probability is

$$P_{out1} = \Pr\{\min\{\Gamma_1, \Gamma_0+\Gamma_2\} < \gamma_{th}\} \quad (12)$$

For SDC, $I_D < R$ is equivalent to the event

$$\Gamma_0 < \gamma_{th}, \min(\Gamma_1, \Gamma_2) < \gamma_{th} \quad (13)$$

The outage probability is

$$P_{out2} = \Pr\{\Gamma_0 < \gamma_{th}, \min(\Gamma_1, \Gamma_2) < \gamma_{th}\} \quad (14)$$

Based on [7], the first-order Marcum Q function is defined as

$$Q(\alpha,\beta) = \int_{\beta}^{\infty} x\exp(-(x^2+\alpha^2)/2)I_0(\alpha x)dx \quad (15)$$

It has the series form as follows:

$$Q(\alpha,\beta) = \exp(-(x^2+\alpha^2)/2)\sum_{k=0}^{\infty}(\alpha/\beta)^k I_k(\alpha\beta) \quad (16)$$

where $I_k(\bullet)$ is the k-order modified Bessel function of the first kind. With the first-order Marcum Q function shown in (16), it is difficult to express the closed-form of the outage probability function with infinite upper bound of the cumulative calculation. For the sake of cumulative calculation simplicity, the closed-form approximation for the CDF of the outage probability is derived when the upper bound is limited, e.g., to 20, with little loss of calculation accuracy. The closed-form approximation for P_{out1} and P_{out2} are presented in (17) and (18), respectively.

We are interested in performing optimized power allocation to minimize the outage probability subject to two constraints of the total power budget p_{tot}, and the maximum power $p_{\max}$ per hop. While the total power constraint corresponds to the maximum power that a given packet is allowed to consume throughout its propagation from source to satellite, the maximum power per hop corresponds to the power that each user terminal can provide. We should note that $p_{\max} < p_{tot} \le 2p_{\max}$.

Consequently, the problem is formulated as

$$\begin{aligned} &\min && P_{outi}, \quad i=1,2 \\ &\text{subject to} && p_1+p_2 \le p_{tot} \\ & && 0 \le p_n \le p_{\max}, \quad n=1,2 \end{aligned} \quad (19)$$

The problem formulated in (19) is a convex problem, which means that it has a single global solution. When drawn in a linear scale, the objective function is convex. Also, since all the constraints are linear, they form a convex set, which leads to a convex problem and, therefore, a unique optimal solution.

In this paper, the optimized power allocation result is determined utilizing the Optimization Toolbox given in MATLAB.

IV. Simulation Results and Analysis

The numerical results of the optimized power allocation scheme are presented. Simulation results are generated using Monte Carlo methods. The outage probability of the cooperative diversity system is plotted versus the maximum total SNR budget, defined by p_{tot}/N_0. Set $p_{\max}/p_{tot} = 0.8$. In order to characterize different fluctuations of the signal envelope caused by different shadowing and multipath situations, different K_i values should be taken. In a LMS system, typical K_i value ranges from 7 to 15 dB [10]. In this paper is assumed that $K_2 = 14dB$. K_0 takes the value of 7 and 12, denoting heavy shadowing and light shadowing, respectively. Set the spectral efficiency R to $1\mathrm{b/s/Hz}$. Assuming that $\sigma_{sd}^2 = 0.5$, $\sigma_{sc}^2 = 5$ and $\sigma_{cd}^2 = 5$. We also have $\gamma_{th} = 2^{2R}-1$

Fig.2 and Fig.3 show the outage performances of the optimized power allocation and those of traditional uniform

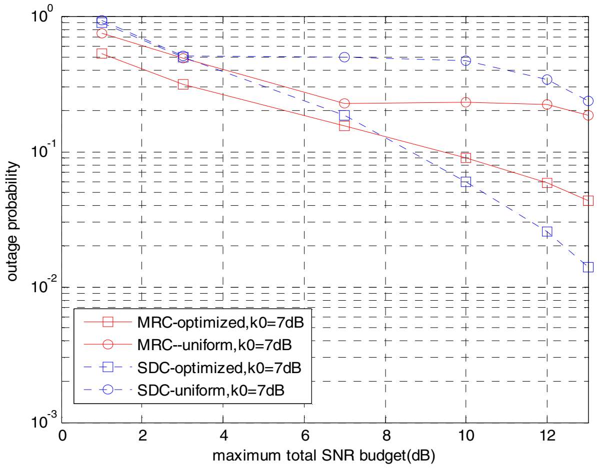

Figure 2. System outage performances with optimized power allocation , uniform power allocation and with no cooperative diversity, $K_0 = 7dB$.

power allocation. Propagation channel in Fig.2 is heavy shadowing channel with $K_0 = 7dB$. The propagation channel in Fig.3 is light shadowing channel with $K_0 = 12dB$.

Within the same signal combing algorithm, for the same K_0 values, it can be seen from Fig.2 and Fig.3 that, the outage probability of systems with the optimized power allocation are smaller than that of cases using uniform allocation method, with the differences getting much more obvious as the maximum total SNR budget increases. As the outage performance results are compared between Fig.2 and Fig.3, i.e., between different K_0 values, we can see that, more LOS components contribute little to improving the optimized outage performance with MRC algorithm, while much improvement is made with SDC algorithm.

When comparisons are made between the two signal combing algorithms by the optimized outage performances, it is shown that, for the same k_0 value, outage performances

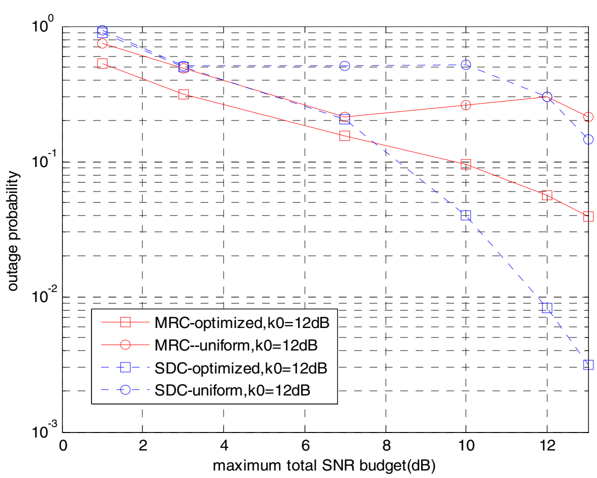

Figure 3. System outage performances with optimized power allocation , uniform power allocation and with no cooperative diversity, $K_0 = 12dB$.

with MRC algorithm outperform those with SDC algorithm at low maximum total SNR budgets, while for the relatively high maximum total SNR budget scenarios, the situation turns to the opposite. And for different k_0 values, each p_{tot} / N_0 in two figures at which the outage probabilities are equal for the two algorithms has almost the same value.

V. CONCLUSIONS

The scheme of optimized power allocation for dual-hop LMS cooperative diversity system was proposed. Both MRC and SDC combining algorithms at the are considered. As the channel shadowing condition of the source to satellite path gets better, optimized power allocation scheme provides more significant advantages over the uniform power allocation scheme for two combining algorithms. When the maximum total power budget is set to a relatively high value, compared with MRC algorithm, SDC algorithm tends to be a better choice of signal combining strategy, reaching much lower outage probabilities. On the contrary, MRC algorithm performs better when the maximum total SNR budget is relatively low.

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REFERENCES

[1] P. Arapoglou, K. Liolis, M. Bertinelli, A. Panagopoulos, Panayotis Cottis and Riccardo De Gaudenzi, "MIMO over satellite: a review," IEEE on Communication Surveys and Tutorials, vol. 13, no. 1, pp. 27-51, 2011.

[2] J. Laneman, D. N. C. Tse and G. W. Wornell, "Cooperative diversity in wireless networks: efficient protocols and outage behavior, " IEEE Trans. Inf. Theory, vol.50, no.12, pp.3062–3080, December 2004.

[3] Gao Zhiwei, Wang Ping and Liu Fuqiang, "Multiuser diversity performance evaluation of 4G cooperative relay cellular network, " Proc. the 15th APCC, pp. 322–325, October 2009.

[4] Ariflqbal and Kazi Mohiuddin Ahmed," Outage probability analysis of multi-hop cooperative satellite-terrestrial network," 2011 Conf. the 8th ECTI., pp. 256 – 259, May 2011.

[5] J. Luo, R. S. Blum, L. J. Cimini, L. J. Greenstein and A. M. Haimovich, "Decode-and–forward cooperative diversity with power allocation in wireless networks," IEEE Trans. Wireless Commun., vol. 6, no. 3, pp. 793-799, March 2007.

[6] Qiu Lin, Song Meina, Liu Lianrui and Song Junde, "Relay selection and power allocation scheme for cellular network using cooperative diversity", 2010 International Workshop on DBTA., pp.1-5, November 2010.

[7] M. K. Simon, M. S. Alouini, "Digital communication over fading channels," 2 ed. New York: Wiley, 2005, pp.74-75.

[8] X. J. Zhang, Y. Gong, "Joint power allocation and relay positioningin multi-relay cooperative systems," IET Commun., vol. 3, pp. 1683–1692, 2008.

[9] R. L. Rardin, Optimization in Operations Research. Englewood Cliffs, NJ: Prentice-Hall, 1998.

[10] J. Xu, J. H. Jong and C. Ravishankar, "Channel modeling for a land mobile satellite system," IEEE Conf. Globecom Telecommunication, pp. 4596-4600, 2007.