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Performance analysis of Adaptive Power Technique for Cooperative Diversity Communications

Abdurrahman Alfitouri, and Khairi Ashour Hamdi
School of Electrical and Electronic Engineering,
The University of Manchester, Manchester, M13 9PL, UK
Emails: {Abdurrahman.alfitouri, k.hamdi}@manchester.ac.uk

Abstract—Cooperative diversity is a promising technique for use in wireless networks because it can provide diversity gain without the need to install multiple antennas at the source or destination. This paper is concerned with the performance analysis of a dual-hop random access network employed adaptive power technique (APT) relay in cooperative diversity networks. The network considered uses amplify-and-forward relaying, and is the only mean to connect source to its destination. This scheme is compared with such popular schemes as the orthogonal scheme, best relay selection, maximal ratio transmission (MRT) and the optimum combining scheme. A new unified mathematical method is developed, which leads to the derivation of new analytical expressions for the overall spectral-efficiency of the dual-hop random access network over Rayleigh fading channels. Numerical results show that the APT can benefit from an increase in the number of relays and reduction of the noise power at the relay and destination. The results also show that the performance of the APT is comparable to the other cooperative schemes, except the MRT. Furthermore, the new mathematical results obtained for APT have been confirmed by Monte Carlo simulation.

Index Terms—Cooperative diversity, adaptive power technique, moment generating function, relay.

I. INTRODUCTION

Cooperative diversity network technology, see [1]–[3], is known to be an effective means of high data-rate coverage and a way of coping with the fading of wireless channels, both of which are required for future cellular and ad-hoc wireless communication systems. The multiple antennas have been considered as one of cooperative diversity protocols, where it used to increase diversity to combat channel fading [4]. Multiple copies of the data symbols, which lead to improve the system performance, can be obtained at the receiver node, when each antenna at the transmitter sending the same signal information to another antenna at the receiver.

The performance of cooperative diversity using equal gain combinations over Nakagami-m fading channels is proposed in [5]. The single and multiple relay selection schemes and their achievable diversity orders are reported in [6]. The end-to-end performance of a two-hop system with non-regenerative relays over flat Rayleigh-fading channels is proposed in [7]. The average symbol error rate analysis for the distributed spatial diversity wireless system with amplifying relays is presented in [8] for a Rayleigh-fading environment.

Most previous work assumes that the destination has perfect knowledge of the channel for all links. This assumption is not a practical assumption, because the destination cannot

obtain the ($S \rightarrow \text{Relay}$) channel information perfectly without noise amplification. Moreover, the complexity overhead for the system will increase with the number of relay nodes [9].

In this paper, we analyse the performance of cooperative diversity networks, where number of relay nodes using to enhance the source signal at the destination. There is one source, one destination, and M relays can see and communicate to both nodes (source and destination). Each one of these nodes is equipped with single antenna, which can be used for both transmission and reception. There is no direct link between the source and destination nodes. We analyse the performance of adaptive power technique (APT) cooperative diversity networks over Rayleigh fading channels. Each relay needs to know ($S \rightarrow \text{Relays} \rightarrow D$) only for its own channels, which makes the complexity of this system less than for the other systems, such as maximal ratio transmission (MRT). The idea is to adaptive the transmitted power for each relay, which leads to optimize the system performance. To the best of the our knowledge, the performance of APT has not previously been addressed in the literature. We derive explicit expressions for the spectral efficiency (SE) of the APT scheme of this model, which can be used to estimate the throughput of the cooperative diversity, and to study the impact of the different system parameters on their efficiency, where the new results expressed in terms of the weights and abscissas of a Laguerre orthogonal polynomial.

The signal-to-noise ratio (SNR) in this model is a ratio of a large number of random variables. However, the direct approach to find the overall SE may require at least $(4M)$ -fold numerical integrations, which is difficult to obtain in general. As result, we investigate the use of a simple and useful *Lemma 1* to evaluate this averaging, where the result includes a simple mathematical equation that can be easily evaluated. We compare our scheme with some popular schemes, such as the orthogonal scheme (OS), best relay selection (BRS), MRT, and the optimum combining scheme (OCS). Furthermore, simulation results are provided to validate our analysis. We found that the APT can benefit from increase in the number of relays, and the reduction of the noise power at the relay and destination. Also, our results show that the performance of the APT is comparable to the other cooperative schemes performance, except the MRT, whose performance was better.

The remainder of this paper is organized as follows. Section II introduces the system model under investigation for the

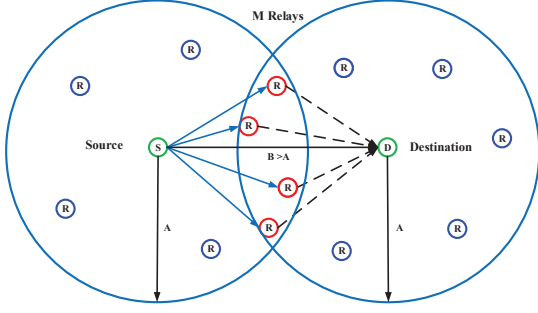


Fig. 1: System Model

EGT, and the other schemes that we are planning to compare with APT. The SE analysis for APT is presented in section III. Results are presented and discussed in Section IV. Finally, concluding remarks are given in Section V.

Notations: $E[\cdot]$ denotes the expectation operator, B^* denotes the conjugates of channel B , $|\cdot|$ denotes the absolute value, $\text{Re}(B)$ denotes the real of B , $\max(B)$ denotes to the maximum of B . Also, we use $\sim CN(0,1)$ to stand for a circularly symmetric complex Gaussian distribution with zero mean and variance 1.

II. SYSTEM MODEL

The system model under consideration is shown in Fig. 1. There is one source, one destination, and each one of these nodes is equipped with single antenna, which can be used for both transmission and reception. There are number of relays distributed uniformly in the service area around the source and the destination, and the service area is around each node (source and destination) considered as a circle with radius A . The source and destination are hidden from each other, which means no direct link between them. Only M relays in the overlapping area between the source and destination can see and communicate with both the source and destination. The communication between the source and the destination is divided into two phases. During the first phase, which known also as the Broadcast Channel (BC) phase, the source sends its signal to the relays simultaneously. In the second phase, called also as the Multiple Access Channel (MAC) phase, the M relays forward the amplified signal to the destination. The channel from the source to the i^{th} relay is denoted as h_i and the channel from the i^{th} relay to the destination as g_i . All channels are assumed to be subject to independent and identically distributed complex Gaussian fading with zero mean and unit variance, e.g., $h_i, g_i \sim CN(0,1)$. All the additive white Gaussian noise (AWGN) terms related to all links ($S \rightarrow Relays \rightarrow D$), assumed to have zero mean and variance (σ_r^2 , and σ_d^2 , respectively.). Without loss of generality, In the first phase, the received signal at the i^{th} relay is given by

$$y_i = h_i l_i^{-\frac{\alpha}{2}} x + n_i \quad (1)$$

where x is the transmitted symbol with unit power, h_i is the complex channel gain between the source and relay i , l_i is the distance between the source and relay i , α is the path loss exponent, and n_i is AWGN at the i^{th} relay. During the second phase, each relay amplifies y_i by multiplying it with w_i , which is the weight of relay i , and broadcasts it to the destination. The received composite signal at the destination in the BC phase is given by

$$y_D = \sum_{i=1}^M g_i w_i r_i^{-\frac{\alpha}{2}} \left(h_i l_i^{-\frac{\alpha}{2}} x + n_i \right) + n_d \quad (2)$$

where g_i is the complex channel gain between the destination and relay i , r_i is the distance between the relay i and destination, and n_d is AWGN at the destination.

A. Adaptive Power Technique

In cooperative network, MRT is considered as the optimum technique to combine the multiple relays signal, to achieve maximum data rate. However, the complexity of the MRT is higher than any other technique, where each relay in the network needs to know all the channels between the relays, source, and destination. On the other hand, the BRS is considered as one of cooperation schemes that attracts many interests. It usually achieves full diversity with less synchronization or feedback requirements. However, the achievable rate of BRS will be less than the MRT, where only one relay relaying the data between the source and destination. In this regard, APT is introduced as effective scheme to achieve cooperative diversity. Its trade-off between the complexity and system performance, where the performance of the APT cooperative diversity system is significantly better than the BRS, but less than the MRT. On the other hand, the APT has less complexity at both the relays and the destination since the relay needs to know only its own channels [10], [11]. With out loss of generality, at each relay, the channel state information (CSI) is available, which mean that the relay knows the channels between ($S \rightarrow Relays \rightarrow D$). Therefore, the weight of the relay i can be expressed as

$$w_i = \frac{1}{\sqrt{M}} \frac{h_i^* g_i^*}{|h_i| |g_i|}. \quad (3)$$

Therefore, the received signal at the destination can be written as

$$y_D = \frac{1}{\sqrt{M}} \sum_{i=1}^M \left(|h_i| |g_i| r_i^{-\frac{\alpha}{2}} l_i^{-\frac{\alpha}{2}} x + |g_i| \frac{h_i^*}{|h_i|} r_i^{-\frac{\alpha}{2}} n_i \right) + n_d. \quad (4)$$

Thus, the SNR at the destination node is given by

$$\text{SNR} = \frac{\left(\sum_{i=1}^M |h_i| l_i^{-\frac{\alpha}{2}} |g_i| r_i^{-\frac{\alpha}{2}} \right)^2}{\sigma_r^2 \sum_{i=1}^M |g_i|^2 r_i^{-\alpha} + M \sigma_d^2}. \quad (5)$$

B. Orthogonal Scheme

To compare the performance of cooperative diversity of multi relays using APT, we also consider an OS that employs orthogonal channel access [12]. Each link ($S \rightarrow R_i \rightarrow D$), where $i = 1, \dots, M$ uses $\frac{1}{2M}$ channel resources for communication. Without loss of generality, the relay i will receive y_i , and amplify it with gain ω_i . According to CSI assisted amplify and forward (AF) relaying, to satisfy the peak power concentration, the gain of the relay i is given as

$$\omega_i = \sqrt{\frac{1}{|h_i|^2 + \sigma_r^2}}. \quad (6)$$

In the second hop, the relay forwards the signal received from the source. Therefore, the SNR can be written as

$$\text{SNR}_i = \frac{|h_i|^2 l_i^{-\alpha} |g_i|^2 r_i^{-\alpha} \omega_i^2}{\omega_i^2 \sigma_r^2 |g_i|^2 r_i^{-\alpha} + \sigma_d^2}. \quad (7)$$

This can be written as

$$\text{SNR}_{ri} = \frac{\frac{|h_i|^2 l_i^{-\alpha}}{\sigma_r^2} \frac{|g_i|^2 r_i^{-\alpha}}{\sigma_d^2}}{\frac{|g_i|^2 r_i^{-\alpha}}{\sigma_r^2} + \frac{|h_i|^2 l_i^{-\alpha}}{\sigma_d^2} + 1}. \quad (8)$$

The form of the SNR with all relays participating is

$$\text{SNR} = \sum_{i=1}^M \frac{\frac{|h_i|^2 l_i^{-\alpha}}{\sigma_r^2} \frac{|g_i|^2 r_i^{-\alpha}}{\sigma_d^2}}{\frac{|g_i|^2 r_i^{-\alpha}}{\sigma_r^2} + \frac{|h_i|^2 l_i^{-\alpha}}{\sigma_d^2} + 1}. \quad (9)$$

C. Best Relay Selection

In the above scheme, the performance of the system is degraded because of inefficient use of channel resources. This can be eliminated using the BRS scheme. In this scheme, the relay node which achieves the highest end-to-end SNR at the destination is selected to retransmit the signal from the source to destination. As result, only two channels are required, regardless of the number of relays. Without loss of generality, the end-to-end SNR of i relay can be written as

$$\text{SNR}_i = \frac{\gamma_{1i} \gamma_{2i}}{\gamma_{1i} + \gamma_{2i} + 1} \quad (10)$$

where $\gamma_{1i} = \frac{|h_i|^2 l_i^{-\alpha}}{\sigma_r^2}$ is the instantaneous SNR of the source signal at relay i , and $\gamma_{2i} = \frac{|g_i|^2 r_i^{-\alpha}}{\sigma_d^2}$ is the instantaneous SNR of the relayed signal (by relay i) at the destination. Because the relay used is the one that achieves the highest end-to-end SNR [13], the SNR at the destination node can be written as

$$\text{SNR}_{\text{Best}} = \max_i \left(\frac{\gamma_{1i} \gamma_{2i}}{\gamma_{1i} + \gamma_{2i} + 1} \right). \quad (11)$$

D. Maximal Ratio Transmission

The other way to achieve cooperative diversity at the relay nodes is MRT, which combats severe fading effects and achieves the maximum SNR [14]. Thus, the weight of the relay i is w_i [15], where

$$w_i = \frac{g_i^*}{\sqrt{\sum_{i=1}^M |g_i|^2}}. \quad (12)$$

From (12), the weight of each relay depends on the channel between the relay and destination. Moreover, each relay needs to know all the channels between each relay and destination. This means that the complexity of this scheme will be greater than APT, where each relay needs to know only its own channels. The destination will then constructively combine the received signals from all relays, to obtain the desired information more reliably. Therefore, the received signal at the destination can be written as

$$y_D = \sum_{i=1}^M \left(\frac{|g_i|^2}{\sqrt{\sum_{i=1}^M |g_i|^2}} h_i r_i^{-\frac{\alpha}{2}} l_i^{-\frac{\alpha}{2}} x + \frac{|g_i|^2}{\sqrt{\sum_{i=1}^M |g_i|^2}} r_i^{-\frac{\alpha}{2}} n_i \right) + n_d. \quad (13)$$

Therefore, the SNR at the destination node is given by

$$\text{SNR} = \frac{\left(\sum_{i=1}^M \frac{|h_i| |g_i|^2}{\sqrt{\sum_{i=1}^M |g_i|^2}} r_i^{-\frac{\alpha}{2}} l_i^{-\frac{\alpha}{2}} \right)^2}{\sigma_r^2 \sum_{i=1}^M \frac{|g_i|^4}{\sum_{i=1}^M |g_i|^2} r_i^{-\alpha} + \sigma_d^2}. \quad (14)$$

E. Optimum Combining Scheme

In this section, we obtain the performance of the cooperative diversity based on the optimum combining weights in terms of received SNR at the destination [16], [17]. To achieve the optimum combination of the received signals at the destination, the optimum combining weights w_i are given by

$$w_i = \frac{\sigma_r^2 + |h_i|^2 l_i^{-\alpha}}{\sigma_r^2 \sigma_d^2 + |g_i|^2 r_i^{-\alpha} \sigma_d^2 + |h_i|^2 l_i^{-\alpha} \sigma_r^2}. \quad (15)$$

Applying the optimum combining weights given in (15), the instantaneous SNR at the destination node is given by

$$\text{SNR} = \sum_{i=1}^M \frac{\frac{|h_i|^2 l_i^{-\alpha}}{\sigma_r^2} \frac{|g_i|^2 r_i^{-\alpha}}{\sigma_d^2}}{\frac{|g_i|^2 r_i^{-\alpha}}{\sigma_r^2} + \frac{|h_i|^2 l_i^{-\alpha}}{\sigma_d^2} + 1}. \quad (16)$$

III. SPECTRAL EFFICIENCY ANALYSIS OF EGT

In communication systems, the SE describes the data rate that can be sent over specific bandwidth. In this section, we derive the achievable SE of the two phase relay system, which can be expressed as

$$\mathfrak{R} = \frac{1}{2} \mathbb{E}[\log_2(1 + \text{SNR})]. \quad (17)$$

The factor $\frac{1}{2}$ comes from the fact that the communications between the source and destination is performed in two phases. The achievable SE of the two phase relay system with the EGT scheme can be written as

$$\mathfrak{R} = \frac{1}{2} \mathbb{E} \left\{ \log_2 \left(1 + \frac{\left(\sum_{i=1}^M |h_i| |g_i| r_i^{-\frac{\alpha}{2}} l_i^{-\frac{\alpha}{2}} \right)^2}{\sigma_r^2 \sum_{i=1}^M |g_i|^2 r_i^{-\alpha} + M \sigma_d^2} \right) \right\}. \quad (18)$$

The expectation in (17) is with respect to random variable SNR, where its a ratio of a large number of random variables, and it seems to be difficult to derive a closed-form expression for its distribution. The overall SE of our proposed model can be found from (18), where we need to find the expectation of this equation with respect to the following set of $(4M)$ random variables: $\mathbf{h} = \{h_1, h_2, \dots, h_M\}$, $\mathbf{r} = \{r_1^{-\alpha}, r_2^{-\alpha}, \dots, r_M^{-\alpha}\}$, $\mathbf{g} = \{g_1, g_2, \dots, g_M\}$, and $\mathbf{l} = \{l_1^{-\alpha}, l_2^{-\alpha}, \dots, l_M^{-\alpha}\}$. The direct approach to compute this expectation is difficult to obtain in general, as it may require the computation of a $(4M)$ -fold convolution integrals. As result, in this paper we use a useful *Lemma 1* to evaluate the averaging in (18), where can be easily evaluated.

Lemma 1. [18, Eq. (5)] Let $x_1, \dots, x_N, y_1, \dots, y_M$ be arbitrary random variables > 0 . Then

$$\ln \left(1 + \frac{\sum_{n=1}^N x_n}{\sum_{m=1}^M y_m + 1} \right) = \int_0^\infty \frac{1}{z} \left(1 - e^{-z \sum_{n=1}^N x_n} \right) e^{-z (\sum_{m=1}^M y_m + 1)} dz. \quad (19)$$

Thus, we can rearrange (18) to obtain the exact analytical expression for SE as follows:

$$\Re = \frac{1}{2} \mathbb{E}[(\log_2 e) \times \int_0^\infty \frac{1}{z} \left(1 - e^{-z \left(\sum_{i=1}^M |h_i| |g_i| r_i^{-\frac{\alpha}{2}} l_i^{-\frac{\alpha}{2}} \right)^2} \right) \times e^{-z \sigma_r^2 \sum_{i=1}^M |g_i|^2 r_i^{-\alpha}} e^{-z M \sigma_d^2} dz]. \quad (20)$$

The expectation in (20) is not easy to obtain, where the square in the exponent includes all the summation. In this regard, we use *corollary 2* to simplify the evaluation of the required average, which make the random variables appear only in a liner combination at the exponent.

Corollary 2. [19, Eq. (6)] Recalling firstly the well-known identity

$$\frac{1}{\sqrt{\pi}} \int_{-\infty}^{\infty} e^{-\omega^2} d\omega = 1. \quad (21)$$

which is also equivalent to

$$1 = \frac{1}{\sqrt{\pi}} \int_{-\infty}^{\infty} e^{-(\omega + ju)^2} d\omega \quad \forall u. \quad (22)$$

Equation (22) implies that

$$e^{-zu^2} = \frac{1}{\sqrt{\pi}} \int_{-\infty}^{\infty} e^{-\omega^2} e^{-j2\omega\sqrt{z}u} d\omega. \quad (23)$$

Because the left hand side of (23) is real, it follows that the right hand side should also be real. Thus, (23) can be written as:

$$e^{-zu^2} = \frac{1}{\sqrt{\pi}} \int_{-\infty}^{\infty} e^{-\omega^2} \operatorname{Re} \left(e^{-j2\omega\sqrt{z}u} \right) d\omega. \quad (24)$$

According to [20], this means (20) can be written as

$$\Re = \frac{1}{2} (\log_2 e) \int_0^\infty \frac{e^{-zM\sigma_d^2}}{z} \left(1 - \frac{1}{\sqrt{\pi}} \int_{-\infty}^{\infty} e^{-\omega^2} \times \operatorname{Re} \left(\prod_{i=1}^M \mathbb{E} \left[e^{-j2\omega\sqrt{z}|h_i||g_i|r_i^{-\frac{\alpha}{2}} l_i^{-\frac{\alpha}{2}}} \right] \right) d\omega \right) \times \prod_{i=1}^M \mathbb{E} \left[e^{-z\sigma_r^2|g_i|^2 r_i^{-\alpha}} \right] dz. \quad (25)$$

which can be expressed as

$$\Re = \frac{1}{2} (\log_2 e) \int_0^\infty \frac{e^{-zM\sigma_d^2}}{z} (1 - \mathcal{M}_v(z)) \mathcal{M}_u(z) dz \quad (26)$$

where $\mathcal{M}_v(z) = \frac{1}{\sqrt{\pi}} \int_{-\infty}^{\infty} e^{-\omega^2} \operatorname{Re} \Phi(2\sqrt{z}\omega) d\omega$, and $\Phi(\omega) = \mathbb{E} \left[e^{-j2\omega\sqrt{z} \sum_{i=1}^M |h_i||g_i|r_i^{-\frac{\alpha}{2}} l_i^{-\frac{\alpha}{2}}} \right]$ is the characteristic function (CHF) of the sum, and $\mathcal{M}_u(z) = \prod_{i=1}^M \mathbb{E} [e^{-zu}]$ is the MGF of u , where $u = \sigma_r^2 |g_i|^2 r_i^{-\alpha}$. Hence, $|g_i|^2$ is the power of the channel gain, which is represented by random variable with exponential distribution. Therefore, $\mathcal{M}_u(z)$ can be simplified to

$$\mathcal{M}_u(z) = \prod_{i=1}^M \mathbb{E} \left[e^{-z\sigma_r^2 |g_i|^2 r_i^{-\alpha}} \right] = \prod_{i=1}^M \left(\frac{1}{1 + z\sigma_r^2 r_i^{-\alpha}} \right). \quad (27)$$

The term $r_i^{-\alpha}$ stands for the random distance between the relay r_i and the destination, as far as the distribution of r_i is concerned, it can be shown that their probability density function (PDF) is $f(r) = 2r/A^2, r \leq A$. Therefore, (27) can be expressed as

$$\mathcal{M}_u(z) = \prod_{i=1}^M \int_0^A \frac{1}{1 + z\sigma_r^2 r_i^{-\alpha}} \frac{2r_i}{A^2} dr_i = \left(1 - {}_2F_1 \left(1; \frac{2}{\alpha}; 2 + \frac{2+\alpha}{\alpha}; -\frac{A^\alpha}{z\sigma_d^2} \right) \right)^M \quad (28)$$

where ${}_2F_1(a; b; u)$ is the confluent hypergeometric function. Also, $\mathcal{M}_v(z)$ can be simplified as (29), which is shown at the top of next page. Equation (29) gives the MGF of v at arbitrary distances r , and l , which can be obtained by averaging out $\mathcal{M}_v(z)$ in (29) with respect to the distribution of r and l , as shown in (28). It is worth mentioning that (29) can also be

Table I: Simulation Parameters

Parameter	Value
Path loss exponent (α)	3
Number of relays (M)	10
Radius area (A)	1km
Noise power at relay (σ_r^2)	1 watt/Hz
Noise power at destination (σ_d^2)	1 watt/Hz

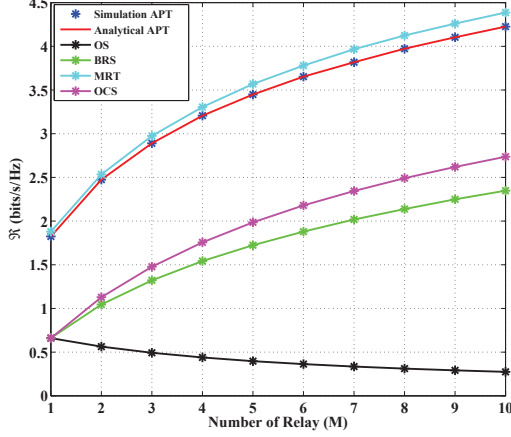


Figure 2: SE as function of M .

expressed in terms of the weights and abscissas of a Laguerre orthogonal polynomial, therefore (29) can be expressed as (30), which is shown at the top of next page, where λ_e and Ψ_e are the sample points and the weights factors of the Laguerre polynomial, respectively, tabulated in [21, Eq. (25.4.46)]. The remainder R_E is small for $E \geq 15$. Substituting (27) and (30) into (26) gives the final expression of overall SE.

Equation (26) can also be expressed in terms of the weights and abscissas of a Laguerre orthogonal polynomial

$$\mathfrak{R} = \frac{1}{2}(\log_2 e) \sum_{n=1}^N \frac{\xi_n}{\beta_n} (1 - \mathcal{M}_v(\mu_n)) \mathcal{M}_u(\mu_n) + R_N \quad (31)$$

where $\mu_n = \frac{\beta_n}{M\sigma_d^2}$, β_n and ξ_n are the sample points and the weights factors of the Laguerre polynomial, respectively, tabulated in [21, Eq. (25.4.45)]. The remainder R_N is sufficiently small for $N \geq 15$; therefore, (31) provides an efficient numerical evaluation method for the required SE.

IV. NUMERICAL AND SIMULATION RESULTS

In this section, we provide the numerical and simulation results for the performance of SE as a function of the number of relays, noise power at the relays, and destination. Our analytical results for APT are compared with Monte-Carlo simulation results for verification. We compare cooperative diversity networks which apply different schemes at the relays and the destination nodes.

Fig. 2, shows SE of five different schemes as function of the number of relays, M , when $\sigma_r^2 = \sigma_d^2 = 1 \text{ watt/Hz}$. We can see that the theoretical APT curve is a good match to the simulated APT performance. We also see that an

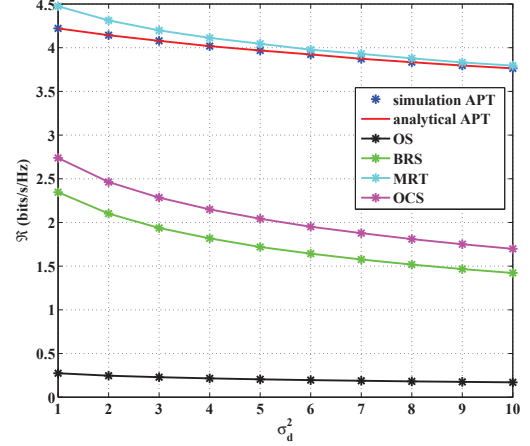


Figure 3: SE as function of σ_d^2 .

increase in the number of cooperating relay nodes (M) has a beneficial impact on enhancement of the SE performance, and the achieved diversity order for the different schemes, except for OS, where the system performance worsens as M increases. In addition, it is evident that the performance of the APT cooperative diversity system is significantly better than the others, except for the APT. However, the APT needs to know the channels of all the relays, which leads to an increase in the complexity of the system. The APT has less complexity at both the relays and the destination since the relay needs to know only its own channels.

Fig. 3, illustrates the SE as function of the noise power at the destination, when $M = 10$, and $\sigma_r^2 = 1 \text{ watt/Hz}$. The effect of this noise on the schemes varies. OCS was the most affected by an increase the σ_d^2 , followed by the BRS, which also decreased with increase in σ_d^2 . The degradation of the remaining schemes (MRT and APT) was less than for OCS and BRS. In (18), the term $M\sigma_d^2$ appears in the denominator so as either M or σ_d^2 increases, SE will decrease. In addition, any increase in σ_d^2 is multiplied by M , which enhances the effect on system performance. The effect of this noise on OS scheme is very small, and it can be negligible.

Fig. 4, compares the performance of the SE for the same five schemes as a function of noise power at the relays, σ_r^2 , when $M = 10$, and $\sigma_d^2 = 1 \text{ watt/Hz}$. It is clear that SE decreases with increase in σ_r^2 for all the schemes. We also notice that, as expected, at high relay noise power, the performance of the systems dropped dramatically. For instance, at $\sigma_r^2 = 10 \text{ watt/Hz}$, it can be seen that SE is dropped approximately by 1, 1.5, and 1.25 bits/s/Hz for the BRS, OCS, APT, and MRT, respectively. The effect of this noise on OS scheme is very small, and it can be negligible.

V. CONCLUSION

We have analysed the performance of the APT cooperative diversity network using AF relays over independent, and identically distributed Rayleigh fading channels. We also

$$\mathcal{M}_v(z) = \frac{1}{\sqrt{\pi}} \int_{-\infty}^{\infty} e^{-\omega^2} \operatorname{Re} \prod_{i=1}^M \left(\frac{(l_i r_i)^\alpha \sqrt{1 + 4\omega^2 z (l_i r_i)^{-\alpha}} - j\omega (l_i r_i)^{\frac{\alpha}{2}} \sqrt{z} \left(\pi - j2 \operatorname{Arcsinh} \left(2\omega (l_i r_i)^{-\frac{\alpha}{2}} \sqrt{z} \right) \right)}{((l_i r_i)^\alpha + 4\omega^2 z) \sqrt{1 + 4\omega^2 z (l_i r_i)^{-\alpha}}} \right) d\omega. \quad (29)$$

$$\mathcal{M}_v(z) = \frac{1}{\sqrt{\pi}} \sum_{e=1}^E \Psi_e \operatorname{Re} \prod_{i=1}^M \left(\frac{(l_i r_i)^\alpha \sqrt{1 + 4\lambda_e^2 z (l_i r_i)^{-\alpha}} - j\lambda_e (l_i r_i)^{\frac{\alpha}{2}} \sqrt{z} \left(\pi - j2 \operatorname{Arcsinh} \left(2\lambda_e (l_i r_i)^{-\frac{\alpha}{2}} \sqrt{z} \right) \right)}{((l_i r_i)^\alpha + 4\lambda_e^2 z) \sqrt{1 + 4\lambda_e^2 z (l_i r_i)^{-\alpha}}} \right) + R_E. \quad (30)$$

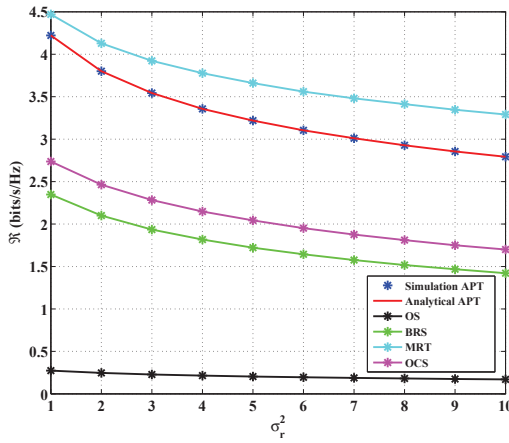


Figure 4: SE as function of σ_r^2 .

compared the performance of the APT cooperative diversity system with OS, BRS, MRT, and OCS. Using the MGF, an exact-form expression for SE was obtained. The accuracy of the new mathematical results has been confirmed by Monte Carlo simulation. These results show that APT scheme can provide better performance compared with the other schemes, except the MRT. However, the APT benefits from greater simplicity, each relay needs to know only its channels, and the CSI is not required at the destination. Finally, we have shown the effect of variation of important factors such as number of relays, noise power at the relays and noise power at the destination, on predicted system performance.

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