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Cooperative MRC diversity over Hoyt fading channels

Abstract. *Performance analysis of cooperative non-regenerative transmission system operating over Nakagami-q (Hoyt) fading channels will be presented in this paper. Usage of Maximal Ratio Combining (MRC) space diversity technique at the reception will be considered. Closed form expression will be provided for the moment generating function (MGF) of the received signal-to-noise ratio (SNR). Capitalizing on this, standard performance measure, average symbol error probability (ASEP) over various modulation formats will be efficiently evaluated. Obtained numerical results will be graphically presented in order to show the influence of system parameters, like fading severity and reception diversity order on overall system performances.*

Streszczenie. *Przeanalizowano kooperacyjny system transmisji wykorzystujący kanałNagakami-q (Hoyt). Rozważono użycie techniki Maximal Ratio Combining (MRC). Przedstawiono przykład ilustrujący wpływ parametrów transmisji, takich jak zróżnicowanie zaniku (fading severity) czy różnorodność porządku odczytu (reception diversity order) na możliwości systemu. (**Transmisja kooperacyjna MRC w kanałach Hoyt**).*

Keywords: Non-regenerative cooperative transmission, Amplify-and-Forward, Maximal Ratio Combining, Hoyt fading channels
Słowa kluczowe: transmisja kooperacyjna, kanały z zanikami

Introduction

Wireless systems in the future will be envisaged to offer ubiquitous high data-rate coverage in large areas [1]. A promising solution for providing broader and more efficient coverage in both modern (ad-hoc, WLAN) and traditional (bent pipe satellites) communications networks, are multihop relaying technology communications. Multihop transmission is a communication technique that arises in many applications: to attain broader coverage without the need to use large power at the transmitter; to communicate via ad hoc networks where nodes are communicating without the aid of central control/infrastructure; to combat the impairments (multipath fading, shadowing and co-channel interference) of the wireless channel through spatial/multiuser diversity. With cooperative transmission, communication is achieved by relaying the information from the source to the destination thought a number of intermediate terminals, when the direct link between the source and destination is in deep fade, so the signals to the destination propagate through two or more hops/links in series [2].

Cooperative transmission can be classified into two main categories, namely regenerative and non-regenerative transmission, depending on the complexity and relay type used. The most popular signal processing methods at relays are decode-and-forward (DF) for regenerative and amplify-and-forward (AF) for nonregenerative cooperative transmission.

With DF, cooperative relays first try to decode the received information and then regenerate a new version to transmit to the destination. Non-regenerative relays just amplify and retransmit the information signal, as opposed to regenerative relaying nodes. Additionally, relays of non-regenerative systems are classified in two main subcategories, as channel state information (CSI) assisted relays, where they use the CSI from the previous hop to produce their gain leading to a power control of the retransmitted signal, and fixed-gain relays with lower complexity compared with CSI assisted ones, and which introduce a fixed gain and thus a variable signal power at the output.

With AF, the relays retransmit scaled versions of the received information to the destination without decoding them. Therefore, AF needs no sophisticated processing at the relays or the destination. To limit the transmit power at the relays, the received signal at each relay can be amplified with a varying or fixed gain. The varying gain relaying scheme maintains the constant transmit power at the relays at all times, but it requires knowledge of the instantaneous channel gains of all the source-relay links. To reduce the complexity at the relays, the fixed-gain relaying scheme has been proposed, which maintains the long-term average transmit power at each relay.

Multipath fading seriously degrades the performance of the system when signal components that are received over different propagation paths add destructively. Temporal, frequency and spatial diversity are the basic diversity techniques to overcome the effects of fading. In addition to these traditional diversity techniques, mobiles can also relay each other's information and the signals coming from the source and the relays can be used to provide additional diversity. The spatial diversity obtained through this virtual array is also referred to as "user cooperation diversity" or "cooperative diversity. The main idea of cooperative diversity networks is that (in addition to the direct signal from the source to the destination) some neighboring nodes can relay the signal of the source node to the destination node. As a result, the destination node can receive multiple independent copies of the same signal and can achieve diversity without the need to install multiple antennas at the source node or the destination node.

There are several principal types of combining techniques and division can be generally performed by their dependence on complexity restriction put on the communication system and amount of channel state information available at the receiver. The optimal combining technique is maximum ratio combining (MRC) [3]. This combining technique involves co-phasing of the useful signal in all branches, multiplication of the received signal in each branch by the estimated envelope of that particular signal and summing of the received signals from all antennas.

The most frequently used statistical models to describe fading in wireless communications systems analysis distributions are Nakagami-*m*, Rice, Hoyt, Rayleigh, α-μ and Weibull. Several studies have shown that the Hoyt fading model provides a very accurate fit to experimental channel measurements in a various communication applications, like mobile satellite propagation channels and spans the range of the fading figure from the one-sided Gaussian to the Rayleigh distribution. Similarly, the Hoyt distribution can be considered as an accurate fading model for satellite links with strong ionospheric scintillation.

Performances of non-regenerative transmission systems are discussed in the literature [4],[5],[6]. Outage probability of non-regenerative transmission over α-μ fading channels was discussed in [4]. Outage probability is derived for both nonregenerative relays: channel state information (CSI) and fixed gain relay. Similar analysis over Nakagami-*m* fading channels is presented in [5]. In [6], the moment generating function (MGF) based approach has been used extensively to calculate the average SER of M-ary modulation schemes for MRC diversity systems over Nakagami-m fading channels.

System model

Let us consider cooperative transmission from a a source node (*S*) to a destination node (*D*) communicate over a channel with a flat Hoyt fading coefficient (*f*), as shown at Fig.1.

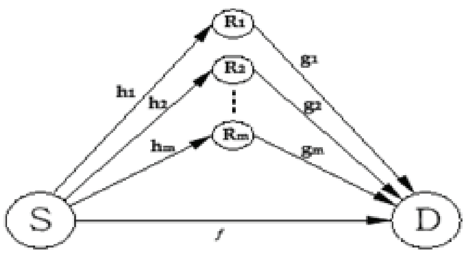

Fig. 1. Cooperative diversity wireless network.

A number of cooperating nodes (R_i, i = 1, 2, .. . ,*M*) relay the signal to provide the destination with multiple copies of the original signal. The channel coefficients between the source *S* and R_i (h_i) and between R_i and *D* (g_i) are also flat Hoyt fading coefficients. In addition, *f*, h_i and g_i are mutually-independent and non-identical. We also assume here without any loss of generality that all additive white Gaussian noise (AWGN) terms have zero mean and equal variance N0. Assuming MRC at the destination node, the total SNR at the destination node can be written as:

(1) $$y_{equ}=y_f+\sum_{i=1}^{M}\frac{y_{h_i}y_{g_i}}{y_{h_i}+y_{g_i}+1}$$

where y_{h_i} = $h_i^2E_s/N_o$ denotes the instantaneous SNR between *S* and R_i, y_{g_i} = $g_i^2E_s/N_o$ denotes the instantaneous SNR between R_i and *D*, while $y_f = f^2E_s/N_o$ is the instantaneous SNR between *S* and *D*. Es stands for the signal transmitted energy. Communication is obtained over a Hoyt fading channel with a following probability density function (PDF) of SNR [7]:

(2) $$p_r(r)=\frac{1+q^2}{2q\bar{r}}\exp\left(-\frac{(1-q^2)^2r}{4q^2\bar{r}}\right)I_0\left(\frac{(1-q^4)r}{4q^2\bar{r}}\right)$$

In previous expression $\overline{r}=E|r|^2P_2/N_0$ denotes the channel average SNR value, $I_0(x)$ is the zero-th order modified Bessel function of the first kind and $0\leq q\leq 1$ is the desired signal Hoyt fading parameter. Hoyt distribution spans the range from one-sided Gaussian fading ($q=0$) to Rayleigh fading ($q=1$). It is typically observed on satellite links subject to strong ionosphere scintillation.

Performance analysis

Assuming the statistical independence of *f*, h_i and g_i the MGF of the destination node SNR value can be written considering [6] as:

(3) $$M_{equ}(s)=M_{y_f}(s)\prod_{i=1}^{M}M_{y_i}(s)$$

where $M_{y_f}(s)$ i $M_{y_i}(s)$ are the MGF of y_f and $y_i = min(y_{g_i},y_{h_i})$, respectively.

Using the well-known fact that MGF can be determined from the relation $M_X(s)=E(e^{sX})$ (with E being the statistical average operator), with respect to (2), easily can be shown:

(4) $$M_{y_f}(s)=\frac{1+q_f^2}{2q_f\bar{y_f}}\sum_{m=0}^{\infty}\frac{\left(\frac{(1-q_f^4)}{8q_f^2\bar{y_f}}\right)^{2m}\Gamma(2m+1)}{\left(s+\frac{(1-q_f^2)}{4q_f^2\bar{y_f}}\right)^{2m+1}\Gamma(m+1)m!}$$

with q_f being fading amplitude *f* severity parameter, while $\overline{y_f}=E[f^2]E_s/N_o$ denotes the average SNR value in the link between S and D.$\Gamma(a,x)$ denotes incomplete Gamma function [8]. In order to determine MGF function of y_i, it is necessary first to determine cumulative distribution function (CDF) of y_i by using:

(5) $$\begin{aligned}&F_{y_i}(y)=1-P(y_{h_i}>y)-P(y_{g_i}>y)=\\&1-\sum_{k=0}^{\infty}\frac{1+q_{h_i}^2}{2q_{h_i}\bar{y_{h_i}}}\left(\frac{(1-q_{h_i}^4)}{8q_{h_i}^2\bar{y_{h_i}}}\right)^{2k}\left(\frac{(4q_{h_i}^2\bar{y_{h_i}})}{(1+q_{h_i}^2)^2}\right)^{2k+1}\\&\times\frac{\Gamma\left(2k+1,\frac{(1+q_{h_i}^2)^2}{4q_{h_i}^2\bar{y_{h_i}}}y\right)}{\Gamma(k+1)k!}\times\sum_{l=0}^{\infty}\frac{1+q_{g_i}^2}{2q_{g_i}\bar{y_{g_i}}}\left(\frac{(1-q_{g_i}^4)}{8q_{g_i}^2\bar{y_{g_i}}}\right)^{2l}\\&\times\left(\frac{(4q_{g_i}^2\bar{y_{g_i}})}{(1+q_{g_i}^2)^2}\right)^{2l+1}\frac{\Gamma\left(2l+1,\frac{(1+q_{g_i}^2)^2}{4q_{g_i}^2\bar{y_{g_i}}}y\right)}{\Gamma(l+1)l!}\end{aligned}$$

with q_{h_i} and q_{g_i} being severity parameters of fading amplitudes h_i and g_i, respectively, while $\overline{y_{h_i}}=E[h_i^2]E_s/N_o$ and $\overline{y_{g_i}}=E[g_i^2]E_s/N_o$ denote the average SNR value of the corresponding links. By differenting probability density function (PDF) of y_i can be obtained in the form of:

(6)
$$\begin{aligned}&p_{y_i}(y)=\sum_{k=0}^{\infty}\left\{\frac{1+q_{h_i}^2}{2q_{h_i}\bar{y_{h_i}}}\left(\frac{(1-q_{h_i}^4)}{8q_{h_i}^2\bar{y_{h_i}}}\right)^{2k}\left(\frac{(4q_{h_i}^2\bar{y_{h_i}})}{(1+q_{h_i}^2)^2}\right)^{2k+1}\right.\\&\left.\times\left(\frac{(1+q_{h_i}^2)^2}{(4q_{h_i}^2\bar{y_{h_i}}}\right)^{2k+1}\frac{y^{2k}}{\Gamma(k+1)k!}\exp\left(-\frac{(1+q_{h_i}^2)^2}{4q_{h_i}^2\bar{y_{h_i}}}y\right)\right\}\\&\times\sum_{l=0}^{\infty}\left\{\frac{1+q_{g_i}^2}{2q_{g_i}\bar{y_{g_i}}}\left(\frac{(1-q_{g_i}^4)}{8q_{g_i}^2\bar{y_{g_i}}}\right)^{2l}\left(\frac{(4q_{g_i}^2\bar{y_{g_i}}}{(1-q_{g_i}^2)^2}\right)^{2l+1}\right.\\&\left.\times\frac{\Gamma\left(2l+1,\frac{(1+q_{g_i}^2)^2}{4q_{g_i}^2\bar{y_{g_i}}}y\right)}{\Gamma(l+1)l!}\right\}+\sum_{k=0}^{\infty}\left\{\frac{1+q_{h_i}^2}{2q_{h_i}\bar{y_{h_i}}}\left(\frac{(1-q_{h_i}^4)}{4q_{h_i}^2\bar{y_{h_i}}}\right)^{2k}\right.\\&\left.\times\left(\frac{(4q_{h_i}^2\bar{y_{h_i}}}{(1+q_{h_i}^2)^2}\right)^{2k+1}\frac{\Gamma\left(2k+1,\frac{(1+q_{h_i}^2)^2}{4q_{h_i}^2\bar{y_{h_i}}}y\right)}{\Gamma(k+1)k!}\right\}\times\sum_{l=0}^{\infty}\\&\left\{\frac{1+q_{g_i}^2}{2q_{g_i}\bar{y_{g_i}}}\left(\frac{(1-q_{g_i}^4)}{8q_{g_i}^2\bar{y_{g_i}}}\right)^{2l}\left(\frac{(4q_{g_i}^2\bar{y_{g_i}}}{(1-q_{g_i}^2)^2}\right)^{2l+1}\right.\\&\left.\times\left(\frac{(1+q_{g_i}^2)^2}{(4q_{g_i}^2\bar{y_{g_i}}}\right)^{2l+1}\frac{y^{2l}}{\Gamma(l+1)l!}\exp\left(-\frac{(1+q_{g_i}^2)^2}{4q_{g_i}^2\bar{y_{g_i}}}y\right)\right\}\end{aligned}$$

Considering [8], $M_{y_i}(s)$ can be presented as (7), with ${}_2F_1(a,b;c;x)$ denoting Gauss hypergeometric function.

After substituting (4) and (7) into (3), we can obtain closed form expression for the MGF of the destination node

SNR $M_{y_{eq}}(s)$.

(7)

$$M_{y_i}(s)=\sum_{k=0}^{\infty}\sum_{l=0}^{\infty}\frac{1+q_{h_i}^2}{2q_{h_i}\bar{y_{h_i}}}\frac{1+q_{g_i}^2}{2q_{g_i}\bar{y_{g_i}}}\left(\frac{(1-q_{h_i}^4)}{8q_{h_i}^2\bar{y_{h_i}}}\right)^{2k}\left(\frac{(1-q_{g_i}^4)}{8q_{g_i}^2\bar{y_{g_i}}}\right)^{2l}\frac{\Gamma(l+k+2)}{\Gamma(k+1)\Gamma(l+1)k!l!\left(s+\frac{(1+q_{h_i}^2)^2}{4q_{h_i}^2\bar{y_{h_i}}}+\frac{(1+q_{g_i}^2)^2}{4q_{g_i}^2\bar{y_{g_i}}}\right)^{2k+2l+2}}$$
$$\left\{{}_2F_1\left(1,2k+2l+2;2k+2;\frac{s+\frac{(1+q_{h_i}^2)^2}{4q_{h_i}^2\bar{y_{h_i}}}}{s+\frac{(1+q_{h_i}^2)^2}{4q_{h_i}^2\bar{y_{h_i}}}+\frac{(1+q_{g_i}^2)^2}{4q_{g_i}^2\bar{y_{g_i}}}}\right)\frac{1}{2k+1}+{}_2F_1\left(1,2k+2l+2;2l+2;\frac{s+\frac{(1+q_{g_i}^2)^2}{4q_{g_i}^2\bar{y_{g_i}}}}{s+\frac{(1+q_{h_i}^2)^2}{4q_{h_i}^2\bar{y_{h_i}}}+\frac{(1+q_{g_i}^2)^2}{4q_{g_i}^2\bar{y_{g_i}}}}\right)\frac{1}{2l+1}\right\}$$

Capitalizing on this expression, standard system performance measure, average symbol error probability (ASEP) can be derived over various digital modulation formats [9]. *M*-ary modulations are increasingly being used in wireless mobile channels as the need for high data rates and spectral efficiency in such environments increases. Therefore, the computation of the achievable symbol-error rate (SER) of these modulation schemes in fading environments has been an important topic in digital communication theory. For example, ASEP values for the cases when Binary Frequency-Shift Keying (BFSK) modulation and *M*-ary Differential Phase Shift Keying (MDPSK) modulation are applied can be efficiently evaluated by applying (8) and (9) , respectively:

(8) $$P_s=\frac{1}{2\pi}\int_0^{\pi}M_y\left(\frac{1}{2-4\cos(\theta)}\right)d\theta$$

(9) $$P_s=\frac{1}{2\pi}\int_0^{\pi-\pi/M}M_y\left(\frac{\sin(\frac{\pi}{M})}{1+\cos(\frac{\pi}{M})\cos(\theta)}\right)d\theta$$

Numerical results

In order to determine various system parameters effects on the total link performances, numerically obtained results for the ASEP over MDPSK and BFSK modulation schemes are graphically presented.

It can be seen from Fig.2 and Fig.3 that ASEP values deteriorate for the higher number of cooperating nodes R_i. Also we can derive the conclusion that better performances are achieved in the area of higher values of Hoyt fading severity parameters q_{h_i}, q_{g_i}, q_h, since increase of these values lead to ASEP values decrease.

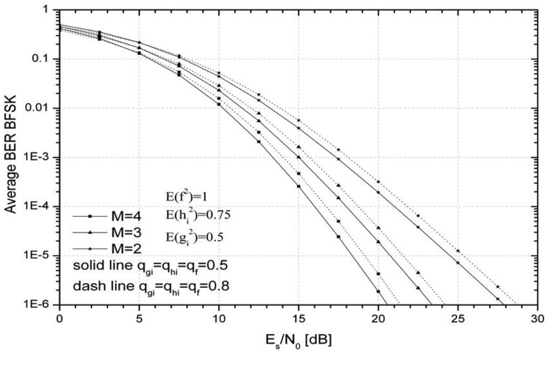

Fig. 2. ABEP over BFSK modulation scheme for various values of fading severity and number of cooperating nodes R_i.

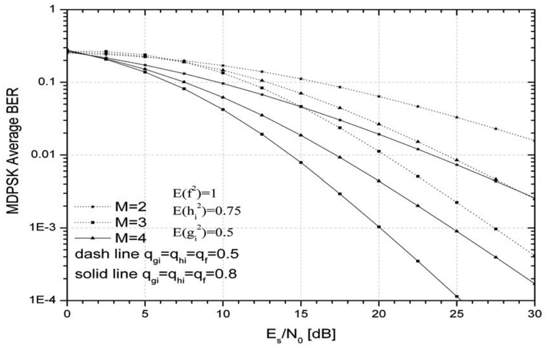

Fig. 3. ABEP over MDPSK modulation scheme for various values of fading severity and number of cooperating nodes R_i.

Conclusions

In this paper, we have outlined a simple, unified approach for deriving closed-form ASEP for AF cooperative MRC reception over Hoyt fading channels. The main contribution is closed form expression for MGF of destination node SNR. Capitalizing on this ASEP values are efficiently evaluated over MDPSK and BFSK modulation schemes. In order to discuss effects of various system parameters on the total link performances, numericaly obtained results for the are graphicaly presented..

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