The Effect of Co-channel Interference in DF Based MARC System with Relay Selection

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Abstract

Network coding has recently received significant attention as an innovative approach to improve the throughput of wireless communication systems. The multiple access relay channel (MARC), in which multiple users communicate with a common destination via relays, is one of the important network coding applications for wireless cooperative communications. In this paper, the effect of co-channel interference in decode-and-forward (DF) based MARC model with relay selection is investigated by obtaining the average bit error rate (BER) results of the proposed system for cascaded Rayleigh fading channels. The simulation results obtained by using binary phase shift keying (BPSK) modulation have shown that the proposed system overcome diversity gain reduction due to error propagation, and detrimental effects of the co-channel interference.

Keywords—co-channel interference; multiple access relay channel; network coding; binary phase shift keying; relay selection.

1. Introduction

The main factors that determine the performance of cooperative communications systems include the total number of collaborating terminals and the relaying techniques that are generally classified as analog (amplify-and-forward, AF) and digital (decode-and-forward, DF) according to the signal processing approach performed in relay terminals. The received signals are scaled and retransmitted to the destination in analog relaying whereas they are detected and then retransmitted in structures using digital relaying. The superior aspects of digital relaying techniques to the analog relaying include that digital relaying approaches are very suitable to use with coding techniques and network protocols and they do not require expensive RF chains in practice [1].

The most important problem encountered in DF based cooperative communication systems is the decrease in effective signal-to-noise ratio (SNR) at the destination terminals, which occurs as a result of detection errors at the relays. This situation, which is termed error propagation, causes significant decreases in the diversity degree of the system. The Cyclic Redundancy Check (CRC) based approaches where only the data blocks that are detected correctly are forwarded constitute one of the ways to overcome performance decreases stemming from error propagation. Furthermore, the relaying procedure cannot be performed in CRC based protocols even if there is an only one-bit error. Link Adaptive Relaying (LAR) and Selective Relaying (SR) techniques are among the important approaches in combating performance decreases caused by error propagation without employing CRC approach. LAR approach [2-4] is based on the idea that the power of the relay is scaled with a coefficient that is dependent on the channel gains of the source-relay and relay-destination links in a cooperative communication system. On the other hand, SR technique is an application of the LAR approach where the relay terminals either forward the detected source information or remain silent depending on the SNRs of the links in the system.

Important contributions of this study can be listed as follows.

- The effect of cascaded channels which is more convenient for vehicular networks is examined.
- The effect of co-channel interference in the proposed system is investigated.
- The spectral efficiency of the proposed system is increased by selection of the best relay in multiple relays.
- We tried to improve the proposed MARC system model with the LAR technique.
- In order to obtain best results maximum likelihood (ML) decision rule is considered at the destination.

The rest of paper follows as: Section II presents the related works. Section III presents the system model. Section IV gives the ML decision rule. The numerical results are presented in Section V. Finally, the concluding remarks are provided in Section VI.

2. Related Work

Network coding concept is one of the effective approaches proposed to overcome bandwidth bottleneck where relay nodes combine the detected signals, create new data streams and transmit them to the destination [6]. By performing such operations on incoming data at information routing nodes, not only the achievable throughput of the network is improved but also the delay in the system, total transmission power and the amount of required buffer memory are decreased. The Multiple Access Relay Channel (MARC) in which several users transmit to a single destination via one or more relays is one of the prominent applications of network coding. In [7], authors consider the system outage behavior and closed-form expressions for the exact outage probability over Nakagami-m fading channels. The performance of the link adaptive relaying technique is investigated in MARC system in [8]. In [9], the authors are thinking of the Multiple Relative Analog Network Coding (ANC) and they provide calculating Maximum Likelihood (ML), Zero Forcing (ZF) and Minimum Mean Square Error (MMSE) Symbol Error Rate (SER). The possibility of an outage of the signal schemes is theoretically derived for the orthogonal multiple access transition channel (MARC) system in [10]. In [11] the exact average bit error probability performance of DF cooperative systems with multiple relays for binary phase-shift keying (BPSK) signals in Rayleigh fading channels is investigated.

One of the major problems of wireless communication is the channel estimation error and co-channel interference, which causes degradation in the performance of the system. Co-channel interference is mostly dominated by AWGN and decreases the performance of cooperative communication system. In [12] the performance analysis of DF (Decode-And-Forward) based cooperative system using cooperative MRC (C-MRC) at the destination with co-channel interference in Rayleigh fading channels are investigated.

The error performance of cooperative communication system can be increased by using multiple relays. In order to decrease the complexity of the cooperative system with multiple relays, relay selection algorithm can be used. In literature, there are lots of studies [12], [13] that focused on relay selection algorithm. In [14], the effect of co-channel interference in DF based cooperative systems with best relay selection has been studied.

In the literature, the channels between the terminals are usually modeled as Rayleigh and Nakagami-*m* distribution. However, when terminals are in motion, all these classical distributions are inadequate. For this case, experimental studies show that a new model which is named as multiplicative channel model or cascaded channel model is used instead of these classical distributions [15]-[19]. The effect of co-channel interference in DF based cooperative vehicular systems is examined in [20].

3. System Model

In this paper, the best relay selection based MARC system model shown in Fig.1 is analyzed where the source terminals $S_1, S_2, \ldots, S_N$ transmit their modulated symbol $x_{S_i}\,(i=1,2,\ldots,N)$ to a common destination (D) with help of relay terminals $R_1, R_2, \ldots, R_M$. We assumed that BPSK modulation is used and all terminals in the system have a single antenna and communicate in half-duplex mode. The transmission protocol is divided into $N+1$ equal time slots. The source terminals transmit their data during the first N time slots and $(N+1)$th slot is allocated to the broadcast of the best relay terminal.

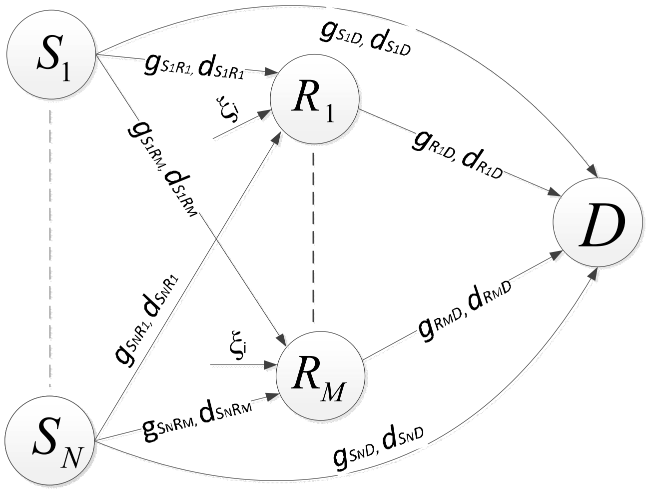

Fig. 1. MARC system model.

In Fig.1, g_{ij} and d_{ij} $i \in \{S_1, S_2, \ldots, S_N, R_1, R_2, \ldots, R_M\}$, $j \in \{R_1, R_2, \ldots, R_M, D\}, i \neq j$ are the complex fading coefficient and the distance between node i and j respectively. The magnitude of $h_{ij} = |g_{ij}|$ is assumed to be cascaded (Q Rayleigh) Rayleigh fading which is the multiplicative of the independent and identically distributed Rayleigh fading coefficients and can be shown as

$$h_{ij} = \prod_{a=1}^{Q} h_{ij}^{a} . \tag{1}$$

Here, Q is the degree of cascading and h_{ij}^{a} shows the Rayleigh distribution. Thus, the probability density function (pdf) of h_{ij} can be given as

$$f(h) = \frac{2}{\sqrt{2^Q \sigma^2}} G_{0,Q}^{Q,0}\left[\frac{h^2}{2^Q \sigma^2} \middle|_{\frac{1}{2},\ldots,\frac{1}{2}}^{-} \right]. \tag{2}$$

Here, the corresponding subscripts and upper scripts are dropped for convenience and $G_{\cdot\cdot}^{\cdot\cdot}[.]$ is the Meijer G-function [7]. Notice that the density depends only on the parameter $\sigma^2 = \prod_{i=1}^{Q} \sigma_i^2$. This implies that, in theory, the Q clusters interacting in cascade effect the Q-Rayleigh distribution only through the production of their "size" parameters, the σ_i^2's. The received signals at the k_{th} relay terminal and the destination terminal during the i_{th} time slot for BPSK signaling can be written as

$$y_D^i(n) = h_{S_i D}\sqrt{E_S}\, x_{S_i}(n) + z_D^i(n), \tag{3}$$

$$y_R^i(n) = h_{S_i R}\sqrt{E_S}\, x_{S_i}(n) + \sqrt{E_i}\, x_i(n)\xi_i + z_{R_k}^i(n). \tag{4}$$

Here, $z_D^i(n)$ and $z_{R_k}^i(n)$ express the AWGN modeled as independent zero-mean complex Gaussian random variables with variance $N_0/2$ per dimension, $x_{S_i}(n)$ is the symbol of S_i, $x_i(n)$ is the symbol of co-channel interference and given by $x_{S_i}(n) = -(-1)^{u_{S_i}(n)}$ and $x_i(n) = -(-1)^{u_i(n)}$, respectively. Here, $u_i(n)$ is co-channel interferer's binary sequence. In (3) and (4), E_S is the energy of transmitted symbol, E_i is the energy of co-channel interference transmitted symbol, $\gamma_{ij} = E_S |h_{ij}|^2 / N_0$ is the instantaneous value of the signal-to-noise ratio (SNR), ξ_i denotes the complex fading distribution whose magnitude represents the Rayleigh distribution.

The received signals at the relay are demodulated by decision rule given by

$$sign\left[\operatorname{Re}\left\{h_{S_i R_k}(n)^* y_{S_i R_k}(n)\right\}\right] \underset{\hat{u}_{S_i}(n)=0}{\overset{\hat{u}_{S_i}(n)=1}{\gtrless}} 0 \tag{5}$$

where $\hat{u}_{S_i}(n)$ indicates the binary decision of the user S_i. The k_{th} relay terminal obtains the network encoded data with an operation given by $u_{R_k}(n) = \hat{u}_{S_1}(n) \oplus \ldots \oplus \hat{u}_{S_N}(n)$. Here, $\oplus$ indicates the exclusive OR (XOR) operation. BPSK modulation symbol $x_{R_k}(n) = -(-1)^{u_{R_k}(n)}$. In order to increase the performance of the system, we use the best relay selection criteria where the selected relay (R_{best}) has the minimum average BER of the proposed system. The received signals at the destination at $(N+1)$th time slot can be expressed as

$$y_D^{N+1}(n) = h_{R_{best}D}\sqrt{\alpha E_S}\, x_{R_{best}}(n) + z_D^{N+1}(n) \tag{6}$$

where α is the link adaptive power coefficient which controls the transmit power of the relay. It is determined by [5]

$$\alpha = \frac{\min(\gamma_{S_1 R_{best}}, \gamma_{S_2 R_{best}}, \ldots, \gamma_{S_N R_{best}}, \gamma_{R_{best}D})}{\gamma_{R_{best}D}}.$$

4. ML Decision Rule

Maximum likelihood (ML) decision rule can be written as

$$\begin{aligned} &\bar{u}_{S_1}(n), \bar{u}_{S_2}(n), \ldots, \bar{u}_{S_N}(n) = \\ &\underset{u_{S_1}(n), u_{S_2}(n), \ldots, u_{S_N}(n), u_{R_{best}}(n) \in \{0,1\}}{\arg\max} P[u_{S_1}(n), u_{S_2}(n), \ldots, u_{S_N}(n), u_{R_{best}}(n)]. \end{aligned} \tag{7}$$

where $P[u_{S_1}(n), u_{S_2}(n), \ldots, u_{S_N}(n), u_{R_{best}}(n)]$ is the joint probability of data bits which are transmitted by source terminals and the selected relay terminal. It can be computed as

$$\begin{aligned} P[u_{S_1}(n), u_{S_2}(n), \ldots, u_{S_N}(n), u_{R_{best}}(n)] &= P[u_{S_1}(n)] \times \ldots \times P[u_{S_N}(n)] \times \\ &P[u_{R_{best}}(n) \mid u_{S_1}(n), u_{S_2}(n), \ldots, u_{S_N}(n)], \end{aligned} \tag{8}$$

$$P[u_{R_{best}}(n) \mid u_{S_1}(n), u_{S_2}(n), \ldots, u_{S_N}(n)] = \begin{cases} 1-\varepsilon_{R_{best}}, & u_{R_{best}}(n) = \hat{u}_{R_{best}}(n) \\ \varepsilon_{R_{best}}, & u_{R_{best}}(n) \neq \hat{u}_{R_{best}}(n) \end{cases} \tag{9}$$

where $\hat{u}_{R_{best}}(n)$ indicates the network encoded data given by $\hat{u}_{R_{best}}(n) = u_{S_1}(n) \oplus \ldots \oplus u_{S_N}(n)$. The probability expressions given above can be given as

$$P[u_{S_i}(n) = 0] \approx \left(1 + e^{L_{S_i}(n)}\right)^{-1}, \tag{10}$$

$$P[u_{S_i}(n) = 1] \approx 1 - \left(1 + e^{L_{S_i}(n)}\right)^{-1}, \tag{11}$$

$$P[u_{R_{best}}(n) = 0] \approx \left(1 + e^{L_{R_{best}}(n)}\right)^{-1}, \tag{12}$$

$$P[u_{R_{best}}(n) = 1] \approx 1 - \left(1 + e^{L_{R_{best}}(n)}\right)^{-1}. \tag{13}$$

In case of BPSK modulation, the log-likelihood ratio (LLR) terms are expressed by

$$L_{S_i}(n) = \frac{4\sqrt{E_S}\operatorname{Re}\left\{h_{S_i D}(n)^* y_{S_i D}^i(n)\right\}}{N_0}, \tag{14}$$

$$L_{R_{best}}(n) = \frac{4\sqrt{E_S}\operatorname{Re}\left\{h_{R_{best}D}(n)^* y_{R_{best}D}^i(n)\right\}}{N_0}. \tag{15}$$

The term $\varepsilon_{R_{best}}$ given in (9) is the probability of erroneous transmission from the relay which can be written as [7]

$$\varepsilon_{R_{best}} = \sum_{m=1}^{N'} \sum_{\mathbf{b} \in \mathbf{B}_{N,2m-1}} (\varepsilon_1)^{b_1} \times \ldots \times (\varepsilon_N)^{b_N} \times (1-\varepsilon_1)^{1-b_1} \times \ldots \times (1-\varepsilon_N)^{1-b_N}. \quad (16)$$

where $N' = \lfloor (N+1)/2 \rfloor$ with $\lfloor . \rfloor$ is floor function, $\mathbf{B}_{T,2t-1}$ indicates a cluster of all binary vectors with T length and $2t-1$ contains non-zero elements. And also it is in the form of $\mathbf{b} = [b_1 \quad b_2 \quad \ldots \quad b_T]$. In (16), ε_i which is probability of error in $S_i \rightarrow R_{best}$ link that can be given by

$$\varepsilon_i = Q(\sqrt{2\gamma_{S_i R_{best}}}). \quad (17)$$

5. Simulation Results

In this section, numerical results for error performance of the relay selection based MARC system model with co-channel interference at the relay terminal is presented for BPSK modulation over cascaded fast Rayleigh fading channels. Following similar simulation conditions as in [4], we assume that source terminals which are very close to each other, relays and destination terminals are located in a straight line where the distance from the i_{th} source to the k_{th} relay ($d_{S_i R_k}$, $i = 1, 2, ..., N$; $k = 1, 2, ..., M$), the distance from the k_{th} relay to the destination ($d_{R_k D}$) are normalized by distance between the i_{th} source and the destination, and hence $d_{S_i R_j} + d_{RD} = 1$, $d_{S_1 R_k} \approx d_{S_2 R_k} \approx \ldots \approx d_{S_N R_k}$. The variance of the channel fading coefficient between node i and node j is modeled as $\sigma_{ij}^2 = d_{ij}^{-v}$ where d_{ij} is the distance and v denotes the path loss coefficient chosen to be 4 for the case of lossy environments and specular reflection from the earth surface [4]. Signal-to-interference ratio (SIR) $\gamma_{g_i} = E_i / N_0$ is assumed to be 20 dB. The energy of co-channel interference is considered $E_i = 1$. The SNR comparisons are done at a BER of 10^{-3}. In figures the numerical results are obtained by using the best relay (R_{best}).

In Fig. 2, the average BER performance of the proposed system with LAR, without LAR ($\alpha = 1$) and with and without interference scheme is given for $N = 2$, $M = 2$, $Q = 2$ and $d_{RD} = 0.5$. System performance is getting better with LAR and without co-channel interference scheme. In Fig. 3, the performance of the system is investigated for the cases where the relay is close to the destination ($d_{RD} = 0.1$), close to the source ($d_{RD} = 0.9$) and in the middle of the link between the sources and the destination ($d_{RD} = 0.5$). It can be seen from the figure that the system has a better performance when the relay position is closer $d_{RD} = 0.9$ to the sources.

In Fig. 4, error performance curves of the proposed system with LAR scheme are given for Rayleigh fading channels in case of two sources ($N = 2$) and $d_{RD} = 0.5$. It is seen that an apparent increase in slope exists with respect to BPSK signaling which shows diversity gain is obtained. It can be also seen that average BER performance of system decreases with the increase in cascaded parameter Q. In Fig. 5, average BER performance of the considered system with LAR scheme is given for different number of users is $N = 2, 3, 4$ when the cascaded parameter is $Q = 2$ and the number of relays is $M = 2$. It is also seen from the figure that the average BER performance is getting worse when the number of users increases. The SNR gain between the BER curves with LAR and $N = 2, 3, 4$ are nearly about 3 dB and 4 dB, respectively.

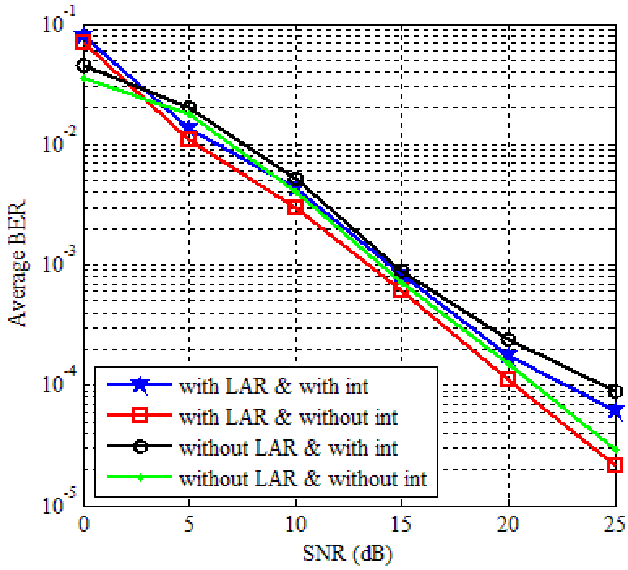

Fig. 2. MARC system simulation results with and without LAR for $N = 2$, $M = 2$ and $Q = 2$.

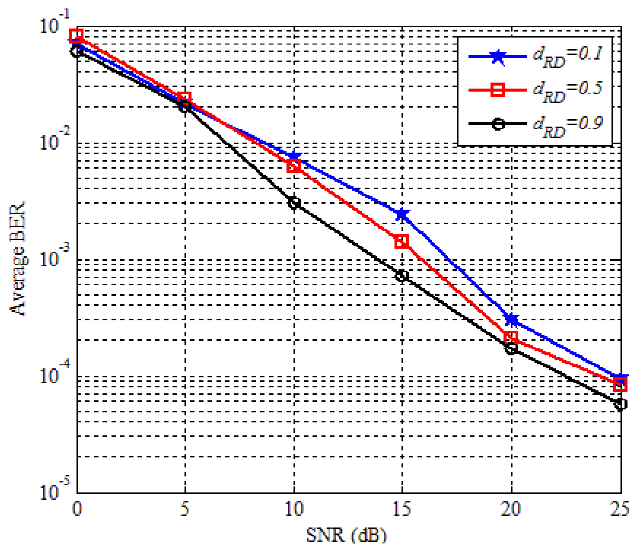

Fig. 3. MARC system simulation results with different locations of relay for $N = 2$, $M = 2$ and $Q = 2$.

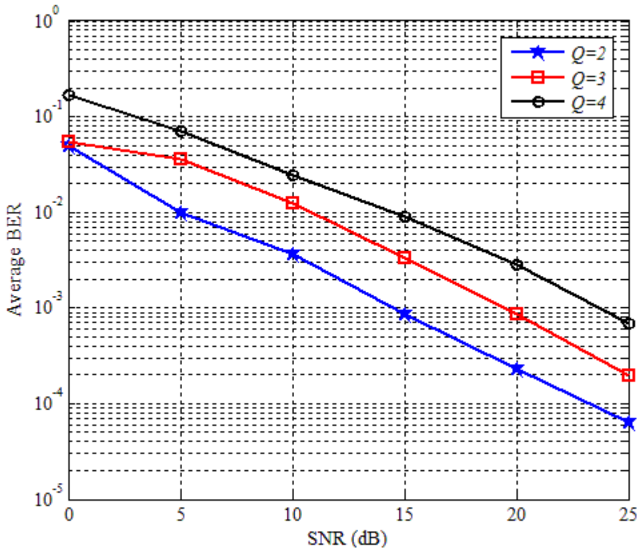

Fig. 4. MARC system simulation results in fast fading Rayleigh channel for $N = 2$ and $M = 4$.

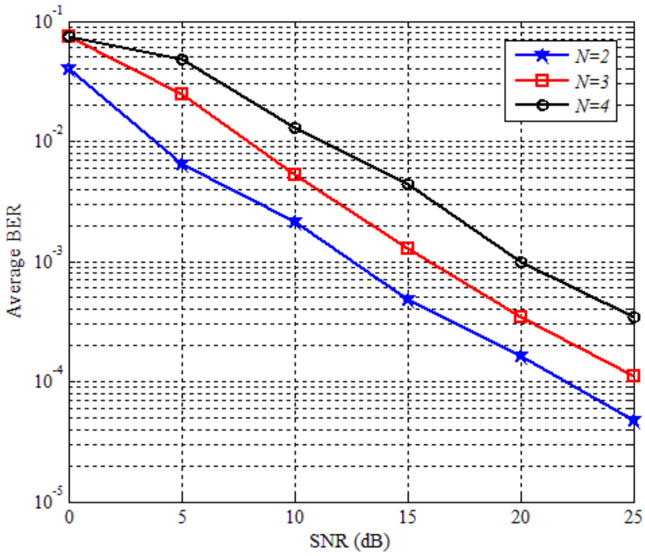

Fig. 5. MARC system simulation results in fast fading Rayleigh channel for $M = 4$ and $Q = 2$.

6. Conclusion

In this paper, average BER performance analysis of the best relay selection based MARC system with DF protocol and the co-channel interference at the relay is examined over cascaded fast Rayleigh fading channels. The numerical results clearly show that full diversity gain is obtained for different number of users, relays and cascading parameter.

7. References

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