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Dual-Hop *N*-Relay Assisted Transmission for IDMA Systems over Weibull Fading Channels

Mehmet Bilim[1], Nuri Kapucu[1], Ibrahim Develi[1]
[1]*Department of Electrical and Electronics Engineering, Erciyes University,*
38039, Kayseri, Turkey
bilim@erciyes.edu.tr

***Abstract*—This paper proposes and investigates dual-hop *N*-relay assisted transmission scheme for interleave-division multiple access with decode-and-forward relaying. In the considered system, chip-by-chip detection method is employed to suppress multiuser interference at relay and destination nodes. We assumed binary phase shift keying modulation and analyse the system under study in terms of bit error rate when the source-relay and relay-destination links experience Weibull fading. Our simulation results show that the dual-hop *N*-relay assisted decode-and-forward relaying can be a promising alternative for the performance improvement of interleave-division multiple access by efficiently mitigating the multiuser interference at the relay nodes as well as destination node.**

***Index Terms*—Dual-hop, interleave-division multiple access, Weibull fading.**

I. INTRODUCTION

Dual-hop transmission technique is a good solution to combat fading and shadowing between source and destination nodes in wireless channels. There are two main protocols including decode-and-forward (DF) and amplify-and-forward (AF) at relay nodes [1], [2]. In AF protocol, the relay node amplifies the received source signal and transmits it to the destination. On the contrary, the relay decodes the source information and forwards it to the destination in DF protocol [1], [3].

Dual-hop transmission scheme in relaying networks have greatly been examined in [2], [4]–[8]. In [2], the authors give a work on dual-hop AF relaying systems by using fixed gain relays over flat Rayleigh fading conditions. Besides, the study in [2] investigated the relay saturation influence on their proposed system performance. The authors in [4] analysed the end-to-end bit error rate (BER) performance of a dual-hop orthogonal frequency-division multiplexing (OFDM) based on AF relaying protocol. Datsikas *et al.* [5] present outage probability analysis of an *L*-relays dual-hop system in which DF relaying technique is used. Moreover, they considered Nakagami-*m* fading conditions for links between source-relays and relays-destination. The other study in [6], the BER performance of dual-hop systems using orthogonal space-time block codes (OSTBCs) for an AF/DF relaying over Rayleigh channels is analysed. Similar to [6], in [7], the performance of dual-hop communication systems using partial relay selection and semi-blind relays is presented. In [8], the outage probability of a dual-hop transmission is investigated where the environment is interference-limited. The aforementioned studies focus on dual-hop communication scheme with only modulation types or OFDM technique. However, no work in the literature considers the dual-hop relay networks by using interleave-division multiple access (IDMA) technology. IDMA is an important technology for the next generation multiple access systems [9]–[16]. In [17], cooperative communication system based on IDMA is proposed over flat Rayleigh fading channels. However, this study is undertaken for cooperative networks including direct link transmission under Rayleigh faded channels. Moreover, Rayleigh distribution is not a viable channel from the realistic point of view, due to not including the statistical characteristics of a mobile system, indoor and ionospheric radio channels [3]. On the other hand, Weibull channel model shows good fit to these characteristics [18], [19]. The Weibull channel model accommodates pliability to describe severity of fading in a wireless channel [20]. Furthermore, IEEE Vehicular Technology Society Committee on Radio Propagation reported the employing Weibull channel for works to describe changes in fading and compensate some of the disadvantage of the Rayleigh fading channel [21], [22].

Motivated by all reasons given above, we propose a dual-hop *N*-relay assisted communication model for IDMA system with DF relaying over Weibull fading channels. More specifically, chip-by-chip (CBC) detection method is used to abolish multiuser interference (MUI) at relay and destination nodes. The BER performances of the considered system for binary phase shift keying (BPSK) signalling are presented. In addition, we provide a simulation result that demonstrates the effects of the fading parameters belong to links between source-relays and relays-destination on the BER performance (in the case of non-identical channel assumption). It can be helpful for designing an effective dual-hop transmission scheme for implementation of new generation cellular communication systems. As stated in [23], IDMA scheme is a promising candidate for new and next generation wireless systems such as 4G and 5G due to its low complexity and high performance advantages.

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II. SYSTEM MODEL

As shown in Fig. 1, a dual-hop transmission scheme is taken into account for multiuser IDMA system. In the considered system, we use *N* relay nodes between the source cluster with single transmit antenna and the destination cluster with one receive antenna. It is assumed that source and destination clusters have *K* simultaneous users which employ IDMA procedure. The source cluster communicates with destination cluster via *N* relay nodes and direct link is not included due to the assumption of deep fading between source and destination. Each relay node decodes received message information of the source cluster and retransmit it to the destination cluster.

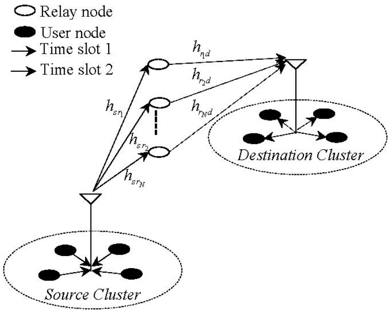

Fig. 1. Schematic block diagram of a dual-hop *N*-relay assisted IDMA system.

The channel coefficient from the source cluster to the *n*th relay is h_{sr_n}, from the *n*th relay to the destination cluster is h_{r_nd}. All channel coefficients are assumed to be flat Weibull faded. We assume that each node in source cluster is operated based on IDMA transmitter principles, while each partner node in destination cluster applies IDMA receiver procedures. To be more specific, we assume that transmission process includes two time slots. The sum of *K* simultaneous users' signals from the source cluster antenna is broadcasted to relay nodes within the first time slot. The relays send the decoded message to the destination cluster antenna in the second transmission phase.

III. REPRESENTATIONS OF RECEIVED SIGNALS

The *n*th relay node receives signal from the source cluster antenna within the first time slot and the received signal at *n*th relay node can be given as

$$r_I^{(n)}(t) = \sum_{k=1}^{K}\sum_{j=0}^{J-1} x_k(j) S_k(t - ²_k - jT_b) h_{sr_n} + n_1(t), \quad (1)$$

where $k = 1, 2, ..., K$ represents number of the simultaneous users in the source and destination clusters. *J* is the frame length of the user *k*, $x_k(j) \in \{1, -1\}$ is the *j*th data symbol of user *k*, $S_k(t)$ denotes the combined interleaving and spreading codes with spreading gain $L = (T_b / T_c)$ for user *k*, T_b is the bit period, $²_k$ is the random transmit delay of the user *k* and T_c is the chip period. $n_1(t)$ is the additive white Gaussian noise (AWGN) with zero mean and variance $±_n^2 = N_0$. In (1), h_{sr_n} denotes the channel coefficient between source and *n*th relay which is Weibull distributed with $\Omega_{sr_n} = E\left(\left|h_{sr_n}\right|^2\right) = 1$ with fading parameter, c_{sr_n}. All channel coefficients (h_{sr_n} and h_{r_nd}) are modelled as Weibull distributed. The probability density function (PDF) of h_{sr_n} is expressed as [24, eq. (2.27)]

$$p_{h_{sr_n}}(x) = c_{sr_n}\left(\frac{¢_{sr_n}}{\Omega_{sr_n}}\right)^{c_{sr_n}/2} \times$$
$$\times x^{c_{sr_n}-1}\exp\left[-\left(\frac{x^2}{\Omega_{sr_n}}¢_{sr_n}\right)^{c_{sr_n}/2}\right], \quad (2)$$

where $¢_{sr_n} = \Gamma\left(1 + 2/c_{sr_n}\right)$, $\Gamma(\cdot)$ is the Gamma function [25, eq. (8.310.1)], Ω_{sr_n} is the power scaling parameter and c_{sr_n} is the parameter expressing the severity of fading. Also, the PDF of h_{r_nd}, is the same as in (2) after replacing the subscript sr_n with r_nd. The Rayleigh model can be obtained for the case of $c = 2$.

The destination cluster antenna receives signals from their relays in the second time slot. We assume that relays in the dual-hop system can decode the source information with no decoding error. Maximal-Ratio-Combining (MRC) [26] technique is applied for combining all of the received signals from relays. Under these assumptions, the combined signal can be written as

$$r_{II}(t) =$$
$$= \sum_{n=1}^{N}\sum_{k=1}^{K}\sum_{j=1}^{J} \tilde{x}_k(j) S_k\left(t - D_{k,n} - ²_k - jT_b\right) h_{r_nd} w_n + n_{II}(t), \quad (3)$$

where h_{r_nd} is the fading coefficient between *n*th relay and destination link that is modelled based on the PDF given in (2). $D_{k,n}$ is the transmission delay during the second time slot. *N* is number of relays in the dual-hop transmission system. $\tilde{x}_k(j)$ is the decoded source information for set of user *k* at relay nodes. $w_n = \sqrt{E_b} h_{r_nd}^{*} / N_0$ is the MRC coefficient of the *n*th relay-destination cluster link. (*) is the conjugate operator.

IV. SIGNAL DETECTION AT RELAY AND DESTINATION NODES

Each relay nodes receive signals from the first time slot and the received signals have been expressed as in (1). It is assumed that there is no interference between first and second time slots. Therefore, *n*th relay node can easily apply the receiver principle of IDMA for making a decision. Note that the CBC algorithm is employed for mitigating MUI as mentioned before. The details of the CBC algorithm can be found in [9]. In the first time slot, the outputs of elementary signal estimator (ESE) and decoder (DEC), that are the *prior*

Log Likelihood Ratios (LLRs) of *k*th user's source information at the *n*th relay node, are defined below by using CBC detection algorithm in a single path procedure [9]

$$\mathrm{LLR}_{I}^{(n)}\left(x(j)\right)=2h_{sr_n}\frac{r_{I}^{(n)}-\mathrm{E}(\text{©}_{I}^{(n)}(j))}{\mathrm{Var}(\text{©}_{I}^{(n)}(j))}, \qquad (4)$$

where $\mathrm{Var}(\cdot)$ is variance function and $\text{©}_{I}^{n}(j)$ is interference from other users to user *k* at *n*th relay node and given as

$$\text{©}_{I}^{(n)}(j)=r_{I}^{(n)}-h_{sr_n}x(j)=\sum_{k\neq k'}h_{sr_n}^{k'}x_{k'}(j)+n_{I}(t), \qquad (5)$$

These LLRs are categorized by subscript which depend on whether LLRs are produced in the ESE or DECs (i.e $\mathrm{LLR}_{ese(I)}^{(n)}\left(x(j)\right)$ and $\mathrm{LLR}_{dec(I)}^{(n)}\left(x(j)\right)$). After the turbo-type CBC algorithm process is applied at the each relay node, the obtained source information is retransmitted to the destination cluster antenna in the second transmission interval.

For the second time slot, similar to (4), the ESE or DEC LLR signal of the *n*th relay node at destination cluster is expressed as

$$\mathrm{LLR}_{II}^{(n)}\left(\tilde{x}(j)\right)=2h_{r_nd}\frac{r_{II}^{(n)}-\mathrm{E}(\text{©}_{II}^{(n)}(j))}{\mathrm{Var}(\text{©}_{II}^{(n)}(j))}, \qquad (6)$$

where $\text{©}_{II}^{n}(j)$ is interference from other users to user *k* at *n*th relay node. We can denote it similar as (5).

Finally, the decision variable for $x(j)$ can be written as

$$\mathrm{LLR}_{final}\left(x(j)\right)=\sum_{n=1}^{N}LLR_{n}^{II}\left(\tilde{x}(j)\right), \qquad (7)$$

where $LLR_{n}^{II}\left(\tilde{x}(j)\right)$, which is defined in (6), denotes the LLR bits obtained from *n*th relay in the transmission.

V. PERFORMANCE RESULTS

In this section, we provide a wide range of performance results to show the BER performances of dual-hop *N*-relay assisted IDMA transmission scheme for different scenarios. Figure 2 and Fig. 3 depict the BER performance versus SNR for dual-hop *N*-relay assisted IDMA in the case of $c_{sr_n}=c_{r_nd}$ and $c_{sr_n}\neq c_{r_nd}$, respectively. The CBC detection type is used by the destination and relay nodes to get performance curves in both Fig. 2 and Fig. 3. *K* denotes the number of simultaneous users and *D* is the information bits. *S* and *B* denote spread length and number of simulation blocks. BPSK signalling is assumed in the whole transmission system. The parameters employed in Fig. 2 are $K=4,$ $S=15,$ $B=1000$ and $D=128.$ The number of iteration for the CBC algorithm is equal to 15 in the first scenario.

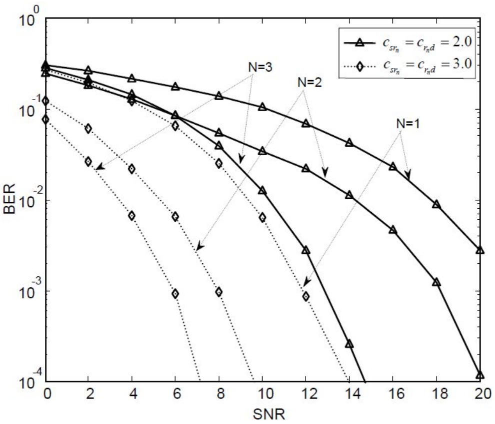

Fig. 2. BER performance versus SNR of the dual-hop *N*-relay assisted IDMA transmission scheme when the all channels are subject to Weibull fading.

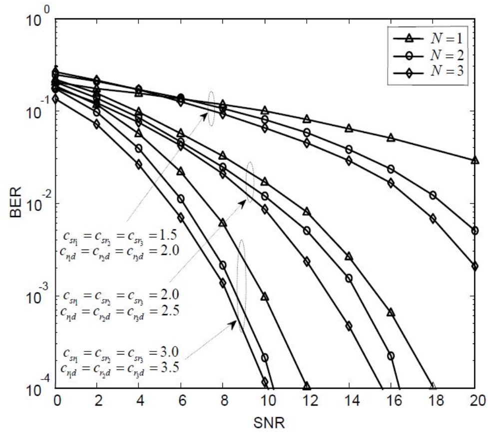

Fig. 3. BER performance versus SNR of the dual-hop *N*-relay assisted IDMA transmission scheme when the source-relays and relays-destination channels experience different Weibull fading parameters (in the case of $c_{sr_n}\neq c_{r_nd}$).

From the performance results in Fig. 2, we can obtain the following marks. First, the BER performance of the dual-hop *N*-relay assisted IDMA scheme significantly improves when the number of relay nodes are increased. Thus, we can say that the dual-hop *N*-relay assisted IDMA system is capable of succeeded the relay diversity. Second, it can be observed that the BER performances improve, while the values of the fading parameters are increased. As an example, the case of $c_{sr_n}=c_{r_nd}=2.0$ is worse than the case of $c_{sr_n}=c_{r_nd}=3.0$ as expected. As can be seen from Fig. 2, we observe that when the channel conditions are same for source-relays and relays-destination links ($c_{sr_n}=c_{r_nd}=3.0$), the BER values are 2.5×10^{-2} with $N=1$ and 9.7×10^{-4} with $N=2$ at SNR = 8 dB. Moreover, the BER level is 1×10^{-1} with the use of one relay at 10 dB for the case of $c_{sr_n}=c_{r_nd}=2.0$. When the number of relays increased to $N=2$ with the same channel conditions, the BER value equals 3.3×10^{-2} at 10 dB. However, if the value of fading parameters are changed to $c_{sr_n}=c_{r_nd}=3.0$ with $N=1,$ the BER value is 6.2×10^{-3} at the same SNR. This example shows that the performance with one relay case outperforms two relays case if the channel conditions are good enough.

We examine the impact of the fading parameter on the achievable BER results of the two-hop *N*-relay assisted IDMA system in Fig. 3. We assume that the source cluster-relay nodes as well as the relay nodes-destination cluster experience different Weibull fading model associated with different values of the fading parameter. This case is named as non-identical channel conditions [27]. When the fading parameters are equal to 2.0, source cluster-relay nodes or relay nodes-destination cluster channels experience Rayleigh fading as previously mentioned in section III. In the second simulation scenario, the parameters are assumed to be $K = 8$, $S = 15$, $B = 1000$ and $D = 256$ for $N = 1, 2$ and 3. Note that, as shown in Fig. 3, even though the different values of fading parameters are used in the second scenario, the BER performances of the dual-hop *N*-relay assisted IDMA system is improved while the value of *N* increases. This is because of achieving the relay diversity in the considered system.

VI. CONCLUSIONS

In this contribution, a dual-hop *N*-relay assisted IDMA transmission scheme has been proposed and investigated with different scenarios by varying the fading conditions. The proposed dual-hop IDMA system uses CBC detection method for suppressing MUI at the relay nodes and destination cluster. Also, the decoded signals are received from the different relay nodes and they are combined based on MRC technique at the destination cluster. According to our computer simulations, it can be confirmed that the BER performances are improved by increasing the number of relay nodes, as expected. From our simulation results, it can be concluded that it is possible to achieve better performance with lower number of relays when the channel conditions are good enough (for higher values of *c*).

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