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AF and DF Relaying Schemes in Cooperative ML IDMA Communication

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Abstract*—In this paper, we consider the bit error rate performance analysis of a cooperative relay communication system on Multi-Layer Interleave Division Multiple Access (ML-IDMA) using Maximal-Ratio-Combining technique; we examine the effect of layers number on the performance and derive the average bit error probability of the Amplify-and-Forward (AF) and Decode-and-Forward (DF) relay schemes by using the closed-form relay link Signal-to-Noise Ratio and compare between these relaying protocols. Based on the analysis, and simulation results, it is shown that although degradation in the performance is observed in both relay schemes when increasing number of layers but on the other hand we saved in the band width. Slightly performance enhancing is obtained when using DF compared to AF relaying protocol. *(Abstract)

Keywords*—cooperative transmission, multi layers, MRC, AF, DF *(Key Words)

I. Introduction

Multiple-Inputs Multiple-Output (MIMO) communications have been shown to be able to offer high diversity and multiplexing gain. However, for wireless communications, due to size and power limitations, it is not practical to mount multiple antennas on mobile devices. Recently, it has been shown that, in a cooperative system, two or more users cooperate with each other to transmit information to the destination [1].

User cooperation has shown to considerably improve the capacity and coverage of cellular systems. In a cooperative system, many cooperative signaling methods are available, depending on the physical limitation of the relay node and the complexity of the signaling allowed.

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Several cooperative diversity protocols, namely, Amplify-and-Forward (AF), Decode-and-Forward (DF), Detect-and-Forward (DtF), Estimate-and-Forward (EF) and selective-DF (S-DF) have been proposed and analyzed in [2, 3] the authors.

In the AF protocol, relay nodes amplify the signals received from a source node and transmit the amplified version of the signals to a destination node. In the DF protocol, the relay nodes decode the information received from the source and re-encode the signal before transmitting it to the destination.

As a kind of non-orthogonal multiple access scheme, Interleave Division Multiple Access (IDMA) has been widely researched [4], which is regarded as a special form of Code Division Multiple Access (CDMA) by treating interleaving index sequences as multiple access codes. In general, IDMA outperforms conventional CDMA in terms of power and bandwidth efficiency. IDMA inherits many advantages from CDMA, in particular, diversity against fading and mitigation of the user interference problem. Furthermore, it allows a low-cost turbo-type Multi-User Detection (MUD) algorithm applicable to the system with large numbers of users, which is crucial for high-rate multiple access communication. IDMA is an efficient approach to bandwidth efficiency and high speed of data transmission [6].

Motivated by the concept of IDMA, Superposition Coded Modulation (SCM) partitions the data to multi layer, where each layer is treated by a user equivalently [5]. Multi-layer IDMA (ML IDMA) is a special form of superposition coding scheme and it can be considered as a joint modulation/channel coding transmission scheme. In [6-9], authors' have paid attention to the one layer IDMA cooperative system and without using any combiner technique at the destination.

In this paper, we propose a novel cooperative transmission scheme based on ML-IDMA, we carry out performance analysis of cooperative single user ML-IDMA scheme for equidistant relaying geometry with different number of layers and a Maximal-Ratio-Combining (MRC) technique, relay protocols that are used in this paper are Amplify-and-Forward (AF) and Decode-and-Forward (DF), which are implemented for the system that uses Binary Phase Shift Keying (BPSK). MATLAB is used for the simulation of different results. In the analysis, it is assumed, that the all stations are arranged at the edges of a square with a length of one. This means that all the channels will have the same path loss and therefore the same average Signal-to-Noise Ratio (SNR).

II. ML-IDMA Transmitter

As shown in fig. 1 the source/user generates an input data sequence $d = [d(1), d(2), \ldots, d(N)]$ which is first serial-to-parallel converted into K subsequences layers. Then the data of each layer is spreaded, interleaved and modulated independently. Finally, all the data of K layers are linearly superimposed to transmission and the source broadcasts the superimposed signal to the relays.

For K-layer, the data sequence $d_k = [d_k(1), d_k(2) \ldots, d_k(I)]$ is first spreaded, generating a spreaded sequence $s_k = [s_k(1), s_k(2) \ldots, s_k(J)]$ then the spreaded sequence s_k is interleaved by a distinct chip-level interleaver π_k to produce a permutated sequence s_k. After interleaving, the randomly sequence s_k is modulated to $x_k = [x_k(1), x_k(2), \ldots, x_k(J)]$. Where $I = N / K$, N is the user data length and I is the layer data length.

The transmitted signal x_s after sum mission from K Layers can be written as:

$$x_s(j) = \sum_{k=1}^{K} x_k(j) \qquad j = 0, 1 \ldots, J \tag{1}$$

Assume that each terminal has one antenna; each relay retransmits the signal according to its relay protocol to the destination. Assume that the channel between the source and each relay is a quasi-static Rayleigh fading channel with Additive White Gaussian Noise (AWGN).

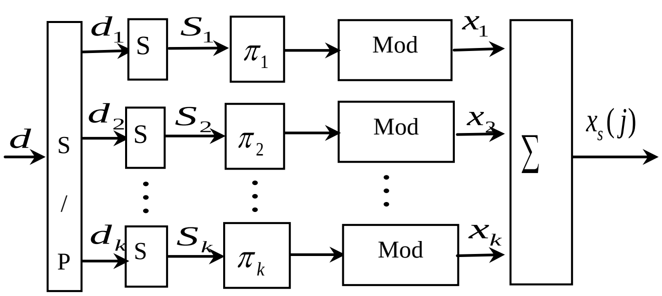

Figure 1. ML-IDMA Transmitter

III. Cooperative ML-IDMA System using AF protocol

In the case of ML-IDMA with AF, the source transmits to a relay node; the relay amplifies the received signal by an amplification factor where the power constraints are considered. Amplification factor has inverse relation to the power received [10]. The signal after being relayed is re-transmitted to destination as shown in fig. 2.

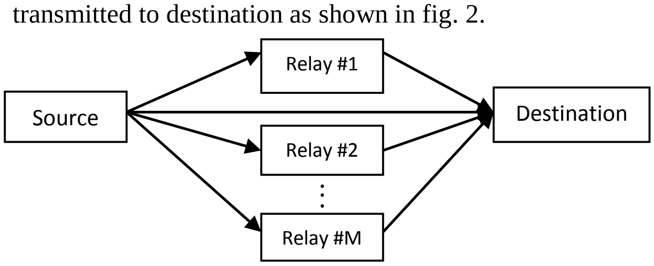

Figure 2. System model for cooperative ML-IDMA

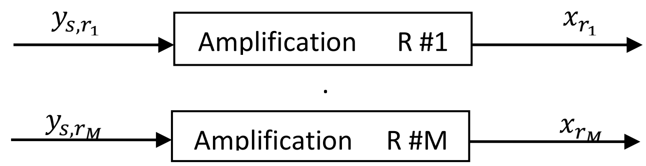

Figure 3. Relays with AF Protocol

The received signal at the relay is given by:

$$y_{s,r} = \sqrt{P_t}\, h_{s,r}\, x_s + n_{s,r} \tag{2}$$

The received power is given as:

$$E\left[y_{s,r}^2\right] = E\left[\left(\sqrt{P_t}\, h_{s,r}\, x_s + n_{s,r}\right)^2\right] \tag{3a}$$
$$= E\left[\left(\sqrt{P_t}\, h_{s,r}\, x_s\right)^2\right] + E\left[n_{s,r}^{\ 2}\right] \tag{3b}$$
$$= P_t\left|h_{s,r}\right|^2 + N_0 \tag{3c}$$

where $N_0 = 2\sigma^2$ is the average noise power. The amplification coefficient can be given by:

$$\beta = \sqrt{\frac{P_t}{P_t\left|h_{s,r}\right|^2 + N_0}} \tag{4}$$

Normalizing the power to $P_t = 1$ gives:

$$y_{s,r} = h_{s,r}\, x_s + n_{s,r} \tag{5}$$

$$\beta = \sqrt{\frac{1}{\left|h_{s,r}\right|^2 + N_0}} \tag{6}$$

Thus the fading amplitude and noise are considered by amplification coefficient. Some other amplification coefficients are proposed in [11]. Amplification coefficients similar to this paper are also suggested by [10, 12-13]. This kind of amplification factor considers the channel response of inter-user channel and effect of noise when added to the received signal.

The signal after amplification becomes:

$$x_r = \beta\, y_{s,r} \tag{7a}$$
$$= \beta\left(x_s h_{s,r} + n_{s,r}\right) \tag{7b}$$

The relayed signal when received at destination is given by:

$$y_{r,d} = h_{r,d} x_r + n_{r,d} \tag{8a}$$
$$= h_{r,d}\left(\beta\left(x_s h_{s,r} + n_{s,r}\right)\right) + n_{r,d} \tag{8b}$$

The received signal at the destination at the first phase is given by:

$$y_{s,d} = h_{s,d}\, x_s + n_{s,d} \tag{9}$$

The total received signal for Maximum-Ratio-Combining (MRC) receiver is given by:

$$r = h_{s,d}^{*} y_{s,d} + \sum_{m=1}^{M}\left(h_{s,r_m}^{*} * h_{r_m,d}^{*}\right) y_{r_m,d} \tag{10}$$

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Using a single-path / one relay system, we can rewrite (10) as:

$$r = (h^*_{s,r} * h^*_{r,d})\, y_{r,d} \quad (11a)$$

$$r = (h^*_{s,r} * h^*_{r,d}) h_{r,d} x_r + (h^*_{s,r} * h^*_{r,d}) n_{r,d} \quad (11b)$$

Where $h = (h^*_{s,r} * h^*_{r,d}) h_{r,d}$ and $n = (h^*_{s,r} * h^*_{r,d}) n_{r,d}$

$$r = h \sum_{k=1}^{K} x_k(j) + n\,(j) \quad (11c)$$

Where "*n*" represents the composite noise, $h_{s,d}$ is the channel coefficient between the source and the destination, $h_{s,r}$ is the channel coefficient between the source and the relay, $h_{r,d}$ is the channel coefficient between the relay and the destination and "*n*" is a sample of an AWGN process with zero mean and variance σ^2 per dimension. Amplify-and-forward is a simple cooperation scheme, in which relay does not require extra processing capability but still it can achieve full diversity [12].

IV. Cooperative ML-IDMA System using DF protocol

In the case of ML-IDMA with DF, the original data is extracted from the received signal by using iterative multi-user detection (MUD) at each relay. Decoded data is further encoded by the relay in the similar way as encoded by the source. Encoded signal is finally sent to the destination. In literature, decode-and-forward is termed as re-generative relaying protocol [12].

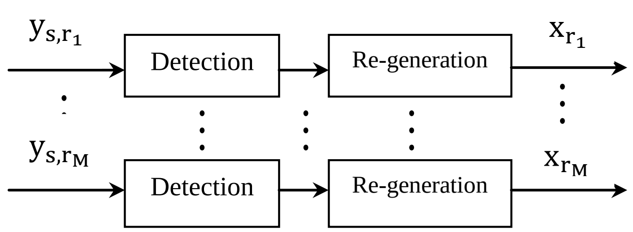

Figure 4. Relays with DF protocols

The received signal at the relay is given by:

$$y_{s,r} = \sqrt{P_t}\, h_{s,r}\, x_s + n_{s,r} \quad (12)$$

Normalizing the power to P_t=1 gives:

$$y_{s,r} = h_{s,r}\, x_s + n_{s,r} \quad (13)$$

The received signal at the destination at the first phase is given by:

$$\mathrm{y_{s,d}} = h_{S,D}\, x_s + n_{s,d} \quad (14)$$

The relayed signal when received at the destination is given by:

$$y_{r,d} = h_{r,d} x_r + n_{r,d} \quad (15)$$

where x_r is the received signal at the relay after detection and regeneration.

We can obtain the total received signal for MRC receiver as discussed before in (10-11c).

V. ML-IDMA Receiver

Since each layer of ML-IDMA systems can be treated as one user of multi-user systems, the suboptimal iterative detection [4] and [13] can be applied in ML-IDMA systems. The receiver of ML-IDMA is illustrated in Fig. 5, which is composed by an Elementary Signal Estimator (ESE) and *K* de-spreaders (DESs). They are applied to solve inter-layer interference and the spreading constraint separately [14, 15]. The receiver performs the iterative processes to update the extrinsic information between ESE and DESs. After the last iteration, the DESs produce de-spreading signal.

For the detection of layer-*k*, we can rewrite (11c) or (17c) as:

$$r(j) = h\, x_k(j) + \xi_k\,(j), \quad j=1,\, 2\ldots,\, J \quad (18)$$

where $\xi_k(j)$ represents the interlayer interference with respect to layer-*k*.

The ESE function is to calculate the extrinsic LLR for estimating the transmitted signal. From the definition of the extrinsic LLR, the output of ESE function can be obtained by:

$$e_{ESE}\big(x_k(j)\big) = 2h\,.\frac{r(j)-E(\xi_k(j))}{Var(\xi_k(j))} \quad (19)$$

where,

$$E\big(r(j)\big) = h \sum_k E\big(x_k(j)\big) \quad (20)$$

$$Var\big(r(j)\big) = |h|^2 \sum_k Var\big(x_k(j)\big) + \sigma^2 \quad (21)$$

$$E\left(\xi_k(j)\right) = E\big(r(j)\big) - h\; E\big(x_k(j)\big) \quad (22)$$

$$Var\left(\xi_k(j)\right) = Var\big(r(j)\big) - |h|^2\, Var\big(x_k(j)\big) \quad (23)$$

The mean and variance of $x_k(j)$ can be calculated by the feedback from DESs, as follow:

$$E\big(x_k(j)\big) = \tanh\left[\frac{e_{DES}(x_k(j))}{2}\right] \quad (24)$$

$$Var\big(x_k(j)\big) = 1 - \big(E\big(x_k(j)\big)\big)^2 \quad (25)$$

Thus we can analyze and detect the signal of each layer through the mean and variance of the interlayer interference. And then the updated extrinsic LLR from ESE function goes through the layer-specific de-interleaver and gets into the DESs iteratively [16, 17].

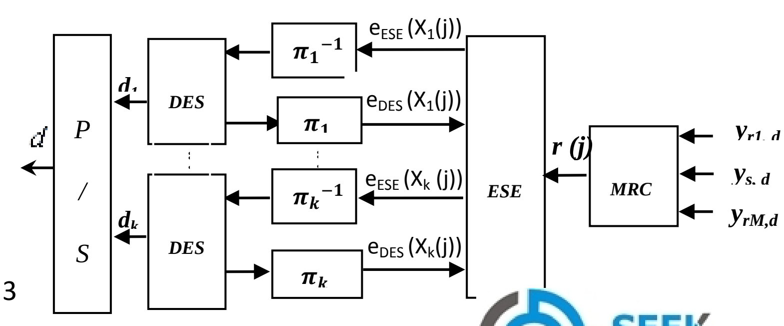

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Figure 5. ML-IDMA (iterative) receiver

VI. Simulation Results

In this paper, we carry out the performance analysis of cooperative single user ML-IDMA scheme for equidistant relaying geometry with different number of layers and a MRC technique. The applied relay protocols are Amplify-and-Forward (AF) and Decode-and-Forward (DF), which are implemented for the system that uses Binary Phase Shift Keying (BPSK). MATLAB is used to simulate the obtained results. In this paper it is assumed that all stations are arranged at the edges of a square with a length of one. That means that all channels will have the same path loss and therefore the same average Signal-to-Noise Ratio (SNR).

To simulate the cooperative ML-IDMA scheme, we assume that the channel is Rayleigh fading channel, equidistant relaying geometry, BPSK signaling is used, frame length (N) = 512, Spreading Length (SP) =32, number of relays (R) =1…, 4, number of layers (K) =2, 4 and number of iteration (it) =3.

Fig. 6 shows that there is degradation in the BER performance by increasing the number of layers. In the case of without relay, K=2 and Eb/N0=16 dB, the BER performance was 10^{-4} while increasing K to 4, degraded BER performance to $5*10^{-3}$.The observed degradation in the BER performance by increasing the number of layers is due to increasing in the signal amplitude which cause signal distortion.

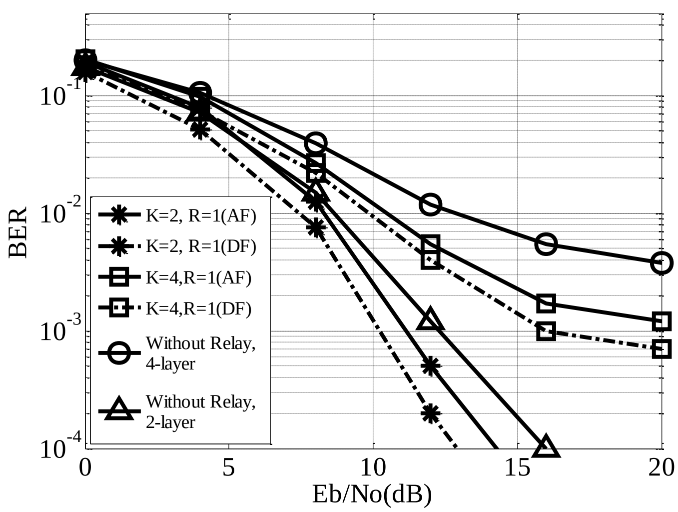

Figure 6. BER of cooperative ML IDMA in Rayleigh channels with AF and DF Protocols, K=2, 4, N=512, it=3, SP=32 and R = 1

Fig. 6 shows also In the case of AF relay protocol for single relay (R=1), in the case of double layer (K=2), the improvement of the BER performance is 1.7 dB compared to without relay system. Also in the case of four layer (K=4) and Eb/N0 = 20 dB, the BER improvement was found to be about $2.6 *10^{-3}$ when compared to without relay system. In the case of DF relay protocol, for single relay (R=1), in the case of double layer (K=2), the improvement of the BER performance is 3 dB compared to without relay system. Also in the case of four layer (K=4) and Eb/N0 = 20 dB, the BER improvement was found to be about $3.1 *10^{-3}$ when compared to without relay system.

Fig. 7 shows the improvement in BER performance by increasing the number of relays to R=4 at K=2 by about 4 dB at the case of AF relay protocol and by about 7 dB at the case of DF relay protocol when compared to without relay system.

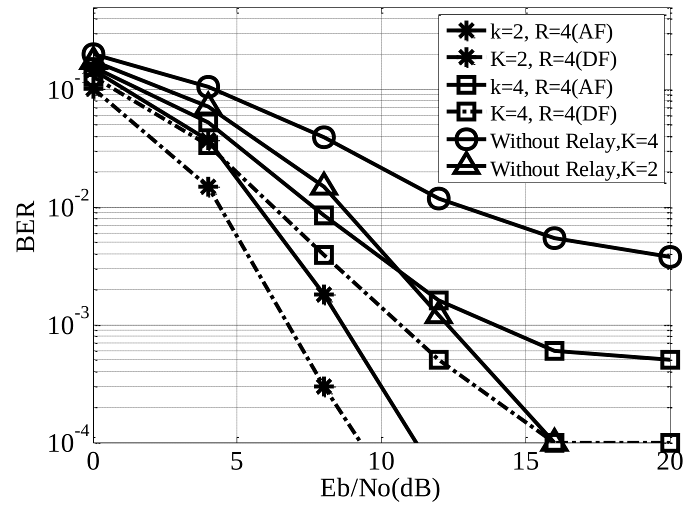

Figure 7. BER of cooperative ML IDMA in Rayleigh channels with AF and DF Protocols, K=2, 4, N=512, it=3, SP=32 and R = 4

Fig. 8 show that R= 4 is superior to the case of R=1 by about 3.5 dB at the BER of 10^{-4}. We can conclude that the co-operative environment, which added up two signals of different links, performs better than systems designed without relay environment. We can also see that when additional relay is deployed, the performance in the co-operative environment gets better. The analysis showed that the addition of different path powers in co-operative environment results in a lower Bit-Error-Rate (BER).

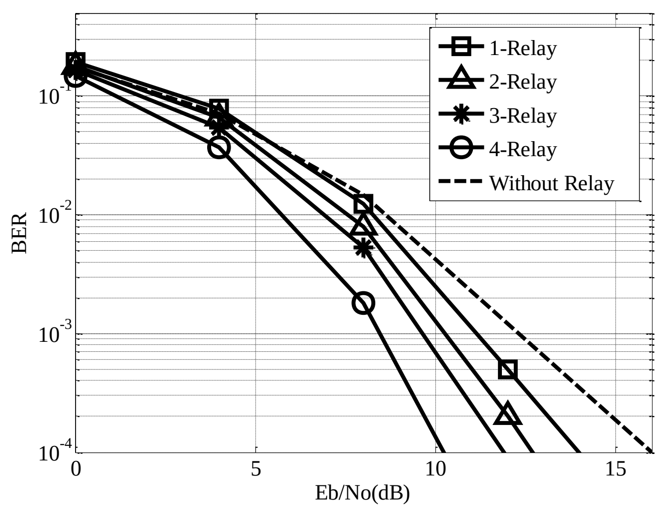

Figure 8. BER of cooperative ML IDMA system in Rayleigh channels with AF Protocol, R=1, 2, 3, 4, K=2, N=512, it=3 and SP=32

Fig. 9 shows that increasing the Spreading Length (SP) can improve the performance significantly. By increasing the SP we were able to get larger spreading gain of the spread spectrum signal that improves the performance efficiency as the signal becomes larger.

It is obvious from fig. 10 that DF performs better than AF protocol by about 1 dB as in AF scheme it amplifies the received signal along with inter-user channel noise. It means that AF cannot eliminate the noise from the received signal.

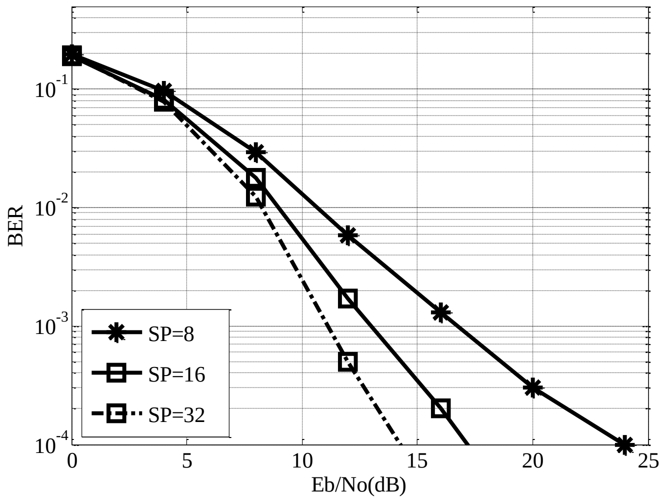

Figure 9. BER of cooperative ML IDMA system in Rayleigh channels with AF Protocol, SP=8, 16, 32, R=1, K=2, N=512 and it=3

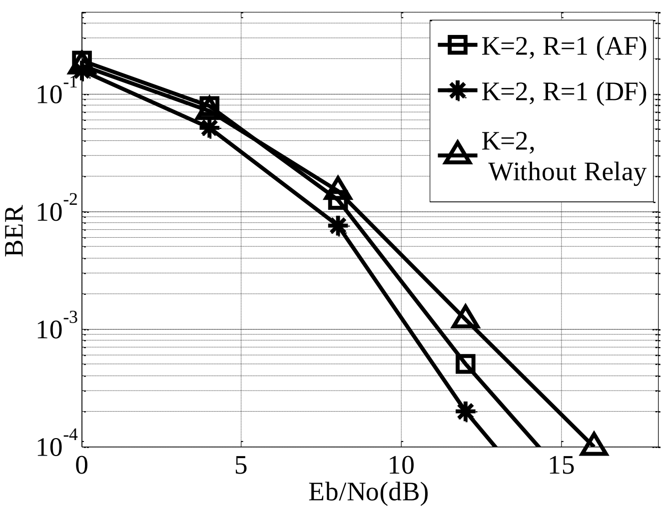

Figure 10. BER of cooperative ML IDMA in Rayleigh channels with different Relays systems, K=2, N=512, it=3, SP=32 and R = 1

VII. Conclusion

In this paper, a cooperative communication scheme based on ML-IDMA is proposed for a network which has one source-destination and multiple common relays. The proposed system is based on the chip-by-chip detection algorithm. Data reaches the destination through two different paths, i.e. a direct path from source to destination and a relayed path where Amplify-and-Forward (AF) and Decode-and-Forward (DF) relay protocols are applied to the data which finally reaches the MRC combiner at the destination.

Above described system has been simulated to see the performance of ML-IDMA with different numbers of layers with Maximal-Ratio-Combining (MRC) technique in the cooperative environment. The simulation results showed that by increasing number of layers we observe degradation in the performance but on the other hand we save in the Band Width (BW) by (1/K).

The simulation also show that the cooperative environment, which added up two signals of different links, performs better than the without relay environment. And when another additional relay is deployed the performance in the cooperative environment gets better, which means that the addition of different path powers in cooperative environment actually results in a lower Bit Error Rate (BER) in the Eb/N0 vs. BER curve. We also observed that, the performance of cooperative environment with two or more relays is better in all the layers numbers those are used in this work. Finally, we observed that DF is better than AF as in DF it has less errors as compared to AF . It will be interesting to investigate the performance of ML-IDMA cooperative schemes with Multi User (MU) system, in the future.

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