COOPERATIVE VERSUS MULTIPLE ACCESS CHANNEL DIVERSITY

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ABSTRACT: The shift of reliability sensitive applications of medical and banking transactions on mobile phones has alarmed researcher to cope with the unreliability issue of wireless channel between mobile nodes. Diversity technique is a viable method to send data reliably from one point to another. In this work, we study and compare diversity gain achieved with cooperative and relay assisted transmission. We evaluate the performance of a pair of cellular user which transmits in a collaborative fashion with another pair of cellular users which are assisted by a relay node. Network coding is used to realize the cooperation and diversity gain. With the help of extensive simulations, it has been shown that the user cooperation and the users assisted by multiple access relay perform symmetrically up to certain user-relay distance. However when user-relay distance cross that point user cooperation always performs better than the users assisted by multiple access relay.

1. INTRODUCTION

To fulfill the demand posed by the explosive growth in speed hungry applications like High Definition Television (HDTV), Vehicle to Vehicle communications, Ultra High Definition Video (UHDV) and holographic technology, the next generation mobile communications standard 5G is supposed provide speed of 20Gbps. Therefore, work on the next generation of mobile communications called 5G has already been started by IMT-2020 in its meeting held in 2013[1].

Various strategies are being proposed to meet the requirement set by 5G for enhancing the reliability as well as the throughput of wireless channel. Diversity gain is a strategy which increases the reliability as well as the throughput of the message being received at the destination [2]. It is achieved by having multiple versions of the same message at the destination. These versions are then combined or processed in an appropriate way to get the strengthen signal at the receiver [3]. The multiple replicas can be made available at the receiving end by using different methods like frequency, time and space; the resulting diversity is called frequency, space and time diversity. Space diversity is achieved by sharing spatial resources to provide a Multiple-Input Multiple-Output (MIMO) environment to achieve diversity [1, 2].

In this paper, we study two scenarios to provide space diversity, namely cellular user cooperation and cellular users' transmission assisted by a relay node and compares their performance by simulating Bit Error Rate (BER) during transmission from a cellular user to destination base station. In the first scenario, we take a pair of cellular users, which transmit their information in cooperative manner to the base station, where the transmitting users assist each other for reliable delivery of their message at the base station and this strategy is known as user cooperation [5, 6]. In the second scenario, two cellular users are assisted by a fixed relay [5] which has nothing to send but helps others cellular user in their surroundings to achieve diversity gain [3, 4].

With the help of Matlab simulations, we show that user cooperation performs better than multiple access relay channel except where the user-relay distance is lower than the user-base station distance. The results are based on BER curves achieved using various values of Signal to Noise ratio (SNR) curves [6, 7].

To present the comparative study details, we organize rest of the paper in the following way. In Section 2, we present our system model used in this paper to simulate the schemes being compared. In Section 3, we present a brief overview of user cooperation and multiple access relay. Results are presented and discussed in Section 4. Finally the last Section numbered as Section 5 draws the conclusions.

2. SYSTEM MODEL

For simplicity, we approximate the hexagonal cellular shape by a circle with unit radius. The cellular users are initially placed at a distance of 3/4 units from the base station and the relay is assumed to be at 1/2 units from the base station , i.e. half way between cellular users and the destination. The wireless channel between cellular users and from cellular users to the relay and the base station is assumed to follow Rayleigh distribution with probability density function *pdf* defined as follows [12].

$$P_X(x) = x/\sigma^2 e^{-x^2/2\sigma^2} \qquad (1)$$

The channel gains are represented by h, the white noise at receiving end has been modeled as Additive White Gaussian Noise (AWGN) which is represented by n_i. σ is the variance of the noise. The standard zero mean and unit variance are the parameters of noise taken during the simulations. Moreover, interference is minimized by allowing only half duplex transmission by the transmitting nodes. This implies that the nodes can either transmit at one time or can receive.

3. OVERVIEW OF THE SCHEMES BEING COMPARED

In this section, we discuss the operation details of the schemes we are comparing in this work. The common thing between them is the equal number of time duratioin used and the basis of cooperation that is network coding for cooperation. The idea of network coding was proposed in [8] and since then it has been extensively investigated for its use in wired as well wireless communications [9, 10].

The functional details and the way both of the schemes work differ in using network coding is described as follows.

Firstly, User CU_1 transmits x_1 and this transmission is received by the second user CU_2 and the base station. Secondly, the second user CU_2 transmits which is received by the first user and the destination. Thirdly, both of the users, CU_1 and CU_2 decode the information which has been received from the other node exploiting decode and forward strategy introduced by Laneman during his PhD thesis at MIT [8]. The decoded messages are then used to form network coded bits to be received by the base station. The network coding is implemented with using bit-wise Ex-OR operation.

Furthermore, both of the users are allocated orthogonal channels which have been assigned using Time Division Multiple Access (TDMA) as shown in Fig. 2.

2.1 USER COOPERATION

We consider two cellular users CU_1 and CU_2 sending jointly their information to the base station as depicted in Fig. 1.

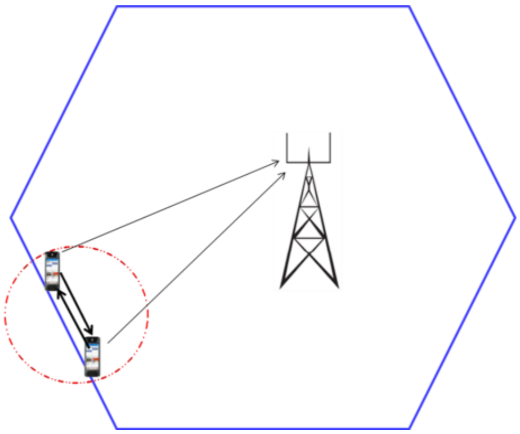

Figure 1. Snapshot of User Cooperation in a Cellular Network

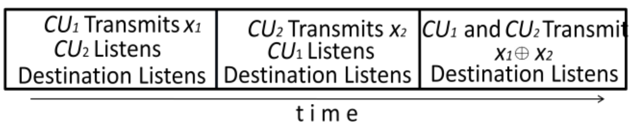

Figure 2. Orthogonal Channel Assignment to Cellular Users

As seen, CU_1 and CU_2 are supposed to transmit in first two time durations and they receive from each other in turn. In the third time duration, both of the cellular users send Ex-OR coded message to the base station.

2.1.1 SIGNALS RECEIVED

As depicted in Fig. 2, during first and the second transmission cellular users exchange their information with each other and the signals received at CU_1 and CU_2 can be written as follows.

$$y_1 = x_1 h_{1\to 2} + n_{CU1} \qquad (2)$$
$$y_2 = x_2 h_{2\to 1} + n_{CU2} \qquad (3)$$

y_1 and y_2 represent the received signal at CU_1 and CU_2 x_1 and x_2 are the transmitted messages. Channel gain represented by h and the subscripts $1\to 2$ and $2 \to 1$ describe the channel gain from CU_1 to CU_2 and vice versa.

After receiving the messages x_i, i = 1, 2 from each other, the users CU_1 and CU_2 decode it and finds Ex-OR of these messages and send it to the destination base station. The received signal at the base station in matrix notation is shown to be.

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} h_{CU1,\to BS} & 0 & 0 \\ 0 & h_{CU2\to BS} & 0 \\ 0 & 0 & h_{CU1,CU2\to BS} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_1 \oplus x_2 \end{bmatrix} + \begin{bmatrix} n_{d1} \\ n_{d2} \\ n_{d3} \end{bmatrix} (4)$$

Here, the vector element y_1 represent the received signal from cellular user CU_1, y_2 from CU_2 and y_3 shows the received signal during third time duration framed through network coding. In the same way, $h_{CUi\to BS}$ represents the channel gains from user CU_i to the destination base station. n_{di} is the noise at destination during reception from user CU_i, i = 1, 2.

2.2 MULTIPLE ACCESS RELAY CHANNEL

This scenario comprises of two cellular users, one relay and a base station as illustrated in Fig. 2. The transmission of messages from cellular users is assisted by a relay in the form of a network coded message to the base station.

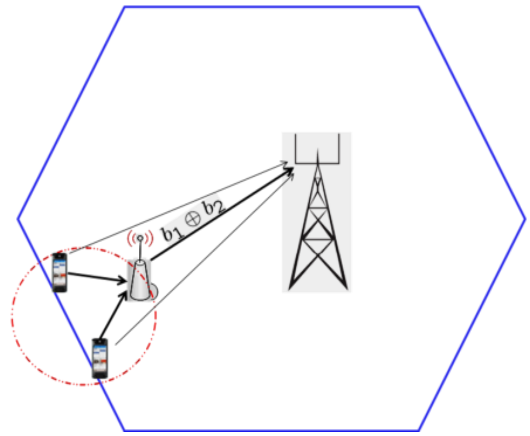

Figure 3. Snapshot of Multiple Access Channel

The relay nodes receive these messages from the two cellular users and decode them during two separate transmissions from cellular user CU_1 and CU_2.

These decoded messages are then used to calculate the Ex-OR bits of these messages to be forwarded to the destination

The cellular user as well as a relay node use separate time or frequency slot to avoid interfering in each other's transmission. In this paper, the time slot distribution as shown in Fig. 4 is used.

As seen, the relay as well as the based station listens for the first two time durations and in third time duration relay transmits $x_1 \oplus x_2$ to the base station.

Figure 4. Orthogonal Channel Assignment to Cellular Users and Relay Node

Here the first time duration is reserved for transmission from the relay receiver and the second time duration is utilized by the relay to form Ex-OR message and forward it to the destination.

2.2.1 SIGNALS RECEIVED

After reception from both of the cellular users, CU_1 and CU_2, the signal received at the relay is:

$$\begin{bmatrix} y_{R1} \\ y_{R2} \end{bmatrix} = \begin{bmatrix} h_{CU1\to R} & 0 \\ 0 & h_{CU2\to R} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_{R1} \\ n_{R2} \end{bmatrix} \quad (5)$$

The vector containing y_{R1} and y_{R1} represents the received signal from cellular user CU_1 and CU_2 at the relay node during time durations one and two as shown in Fig. 4. $h_{CU1\to R}$ represents the channel gains from user CU_i to the destination. n_{Ri} is the noise at destination during reception from user CU_i, i = 1, 2.

In the time slot three of Fig. 4, the relay sends $x_1 \oplus x_2$ to the base station.

After all these three times, the destination has received the following signal.

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} h_{CU1,\rightarrow BS} & 0 & 0 \\ 0 & h_{CU2,\rightarrow BS} & 0 \\ 0 & 0 & h_{R,\rightarrow BS} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_1 \oplus x_2 \end{bmatrix} + \begin{bmatrix} n_{d1} \\ n_{d2} \\ n_{d3} \end{bmatrix} \quad (6)$$

The above matrices show the signals received at base station when users exploit a fixed relay to forward the redundancy using network coding. The notations y_i show output signal, h_{di} represent channel variation from user CU_1, CU_2 and the relay and from CU_1, CU_2 and base station.

4. RESULTS

The simulations are performed in Matlab. As mentioned before, the hexagonal shape of cell is taken to be circular for simplicity. The schematic placement of participating nodes of user cooperation and multiple access relay is taken as illustrated in Fig. 1 and Fig. 3. Moreover, the cellular users are simulated to transmit random binary message from $\{x_1, x_2 \epsilon (-1,1)\}$. With the help of simulations, BER is calculated by counting the number of bits which has been inverted and then dividing this number by the total number of information bits transmitted. SNR at receiving end is varied from -15dB to 10 dB to cover a wide range of wireless applications.

The first simulated curve shown in Figure 5 is achieved when the relay node is located approximately at a distance of 1/4 units from the user CU_1 and CU_2, and 3/4 units from the base station.

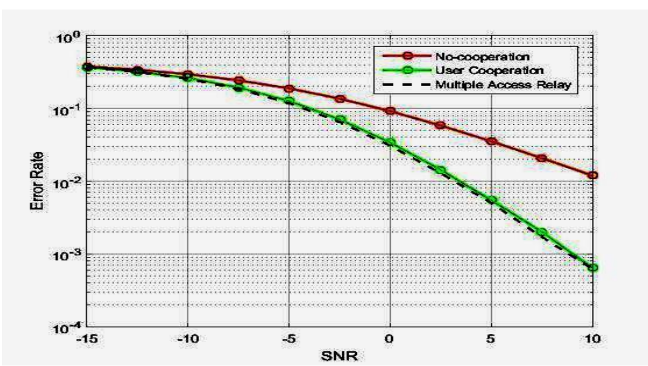

Figure 5. BER curves when the relay nodes is placed at a distance of 1/4 units from the user CU_1 and CU_2 and 3/4 units from base station

As seen from the slope of the achieved BER curves, user cooperation and multiple access channels perform better than no cooperation. However, as seen with these conditions both of the schemes of user cooperation and multiple access channel relay have similar performance. This is very important result to consider because it dictates a solid rule about which strategy to use in the given condition.

The second result in Fig. 6 is obtained by changing the distance of the relay terminal which has now been placed exactly between the user CU_1 and CU_2 and the base station. The result indicate that the performance of the fixed relay is worse than the user cooperation; hence it indicates that when the relay is at a certain distance away from the cellular users, it does not perform better than user cooperation.

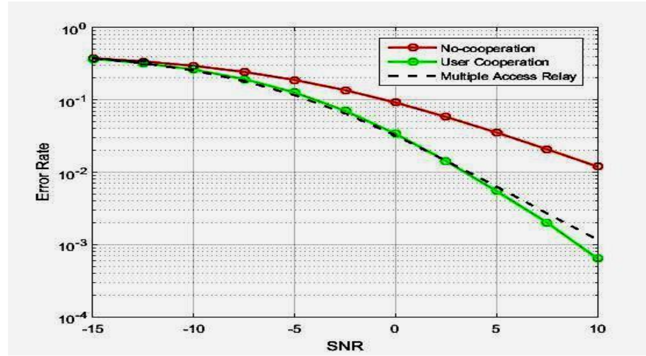

Figure 6. BER curves when the relay nodes is placed half way from the cellular users to the base station

Lastly, we strengthen our argument that farther the distance of the relay terminal from the cellular user the worse the performance of the multiple access channels becomes and the user cooperation leads. This is based on the simulation results shown in Fig. 7.

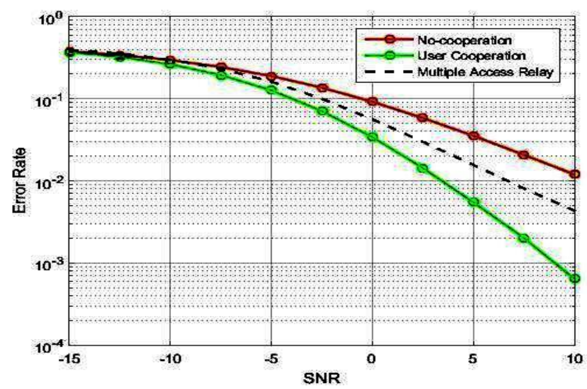

Figure 7. BER curves when the relay nodes is placed at a distance of 3/4 units from the user CU_1 and CU_2 and 1/4 units from the base station

As seen in the BER curves achieved with simulations that as we keep increasing the distance between cellular users and the relay, the user cooperation scheme proportionally keeps offering better performance in terms of BER as compared to multiple access relay.

5. CONCLUSION

In this paper, we compared the performance in terms of diversity gain of two cooperating cellular users and two cellular users assisted by a relay. The cooperation is based on network coding which is implemented using bit wise Ex-OR operation. Based on a cellular scenario, we varied the distances between cellular user and the relay and simulated the probability of error. The simulation results achieved indicates that both of the schemes perform symmetrically upto a distance of 1/4 between cellular user and relay. However, beyond that distance from cellular users, the user cooperation performs better than multiple access relay using network coding.

ACKNOWLEDGEMENT

The authors would like to appreciate Prof. Dr. Zhong Ting from University of Electronic Science and Technology, Chengdu, China for valuable discussion during Matlab simulations of this work.

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