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Performance Evaluation Of Decode and Forward Cooperative Communication Protocol

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ABSTRACT

Fourth generation (4G) of mobile communication systems are expected to significantly enhance the data rates and coverage as compared to the existing third generation (3G) of mobile communication. In order to achieve that a recently proposed concept for 4G standard i.e., LTE-Advanced is Cooperative Communication. Cooperative communication allows single antenna mobile (i.e. Single User) to temporary (Logically) share the antenna of other users in a system and thus creates a virtual multiple antenna Array that allows it to achieve diversity gain & other benefits of multiple input multiple output (MIMO) systems in a cost effective manner. The scope of this research paper is to evaluate the Performance of Decode and Forward cooperative communication Protocol in term of its Bit Error Rate (BER), throughput and outage probability.

Keywords: *Fourth generation (4G), Decode and forward (DF), Amplify and Forward (AF), Bit Error Rate (BER), Multiple Input Multiple Output (MIMO), Maximum Ratio Combining (MRC)*

1. INTRODUCTION

Cellular communication has grown rapidly over the last two decades and this trend is expected to continue in the future as well. Today, there is an increasing demand for high data rates in order to support high speed interactive internet services and advanced multimedia applications such as mobile TV, online gaming etc [1]. However, wireless transmission of higher rates i.e. bandwidth demanding services always limited by the impairments caused by the wireless channel like shadowing, fading effects and path loss. Tradition way to compensate these impairments was to increase the transmit power/ bandwidth and using error control coding (ECC).

However problem was that the power and bandwidth are not only scarce but also expensive radio resources and ECC results in a reduced transmission rate. Hence, achieving High data rate services with reliability and compensating the channel impairments becomes a major challenge for future technologies. Another way to cope up with the channel impairments is the use of multiple antennas at the Transmitter and receiver i.e. MIMO (multiple-input multiple-output) systems [2]. It has been widely accepted that by using multiple antennas at both side of communication system, one can achieve high data rates without demanding more bandwidth and power resources. But when it comes to its implementation MIMO system yields several limitations. One of them is the fact that multiple antennas at the small tiny device (Cell Phones) are impractical. [3].

To overcome these limitation Cooperative Communication have been proposed for the future networks that allows a intermediate Nodes (Users) to relay signals to a destination Node and thus increasing the coverage, throughput, reliability in addition to the Diversity benefits. [3].

In this paper, our goal is to analyze the Decode & Forward cooperative communication protocol by measuring its BER performance (reliability), throughput and probability of outage. Furthermore, the results are compared with conventional non-cooperative (egoistic) transmission. Also we have compared results found in [4] for AF cooperative communication protocol.

2. COOPERATIVE COMMUNICATION

Before going in to the detail of Cooperative Communication system it is very important to know how cooperation is made possible in wireless networks and how performance can be improved by such communication system. Wireless channel is broadcast by nature and wireless network is a set of Nodes which are communicating with each other. Due to the broadcast nature these nodes can be thought as a set of antennas distributed throughout the network. If we utilize this concept then nodes of a network can cooperate with each other and can also transmit or process other’s signals (message). Because of this concept the broadcast nature which is previously considered as a cause of interference is now becomes a source of assistance.

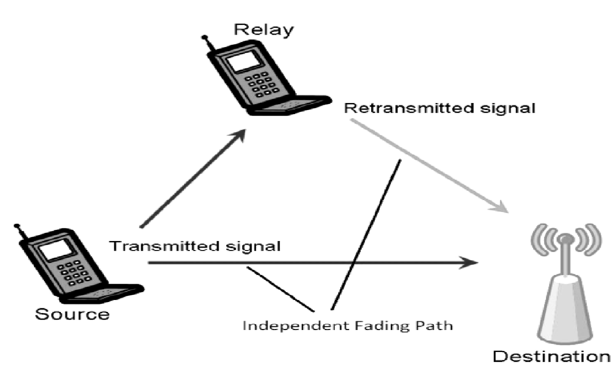

Fig. 1 Wireless Network with three cooperating nodes

For e.g. when a source node is unable to send message to the destination node due to a bad channel condition, it would be worthless to go for a repeated transmission however if another node that has better channel with the destination and has received the information due to broadcast Nature could transmit the same message to destination. This will surly results in a successful transmission with less delay as compare to re-transmission attempts from the source and thus improving the overall performance [2]. This is illustrated in Fig.1.

In conventional cellular networks mobile users operate in egoistic mode [5]. Cooperative Communication generally reduces the effect of Impairments caused by the wireless channel so that users with bad channel conditions enjoy good quality of service with sufficient data rate. This improvement is typically dependent upon level of Cooperation. More cooperation (more nodes involve in cooperation) betters the performance of system. There are various reasons to employ the Cooperative Communication in cellular networks because it gives several performance gains like path loss gain, diversity or multiplexing gain. These gains ultimately results in increased capacity or reduction in the transmission power and extend coverage [6]. Economically, the planning, maintenance and optimization cost of the system will reduced [5].

Cooperative communication protocols are divided into two families, transparent and regenerative. Transparent relaying does not modify the information rather some linear operation is performed. The famous protocols of this family are Amplify and forward, Linear Process and Forward & Nonlinear Process and Forward. In regenerative relaying information is modified in some way. Protocols using this approach are Decode and forward, estimate and forward, and coded cooperation [6]. In transparent family, Amplify and forward is most popular and from regenerative one, Decode and forward dominate the others. We have analyzed the performance of Amplify and forward cooperative communication protocol in [4]. That is why in this paper our goal is to analyze the performance of its Counterpart i.e. Decode & Forward cooperative communication Protocol.

In Decode and forward protocol relay modifies the message. For this digital baseband processing is required and thus more powerful Digital Signal Processor. In this mode after the detection of message, relay will decode it and process it to let it Error free and then re-encodes it prior to retransmission. Previously in DF mode the relays decode the message and resend it to the destination without ensuring that the decoding process was correct or not but now this issue is solved by the selective DF in which relay only forwards the message to destination when it correctly decode the message. [6]. For our simulation we have consider conventional DF protocol where relay decodes the message and forward it to the destination with the possibility of errors, where errors are random and depend upon channel impairments.

3. SYSTEM MODEL

- **Cooperative Communication**

Cooperative Communication can be model into two steps. In the First Step source send the signal to the destination but due to the broadcast nature of medium signal is also received by the nodes in the vicinity of transmission. The received signal at the destination and the relay(s) can be model as:

$$Y_{sd}=\sqrt{P_0}h_{sd}x + n_{sd} \quad (1)$$

$$Y_{sr}=\sqrt{P_0}h_{sr}x + n_{sr} \quad (2)$$

In (1) and (2) Y_{sd} and Y_{sr} are the received signals at the destination and the relay respectively, P_0 is the source transmission power, x is the user Information or Data and finally n and h represents additive noise and the channel fades, subscripts showing the respective direction.

In the second step, relay process the message and re transmit it to the destination. It can be model as:

$$Y_{sd} = \sqrt{\tilde{P}_2}h_{r,d}x' + n_{rd} \quad (3)$$

In (3) Y_{rd} represents a received signal at the relay, $\tilde{P}_2$ is the relay transmission power (In simulation we consider same transmission power for the relay and the source), x' is the re-encoded signal. Prior to Detection and combing of the two signals received from the relay and the source the destination node in practice will first estimate the channel gains viz: h_{sd} (between the source and the destination) and h_{rd} (between the relay and the destination). In our simulation we do not estimate the channel gains rather believe that the destination knows them perfectly. The combined signal at the (Maximum Ratio Combining) MRC detector can be written as

$$Y = a1Y_{sd} + a2Y_{rd} \quad (4)$$

Factors $a1$ and $a2$ are chosen as to maximized the signal-to-noise ratio (SNR) at the detector [7]

$$a_1=\sqrt{Po}\,\frac{h^*_{s,d}}{No} \;\&\; a_2=\sqrt{P_2}\,\frac{h^*_{r,d}}{No} \quad (5)$$

Transmission from a source usually hear by multiple nodes which are in the vicinity of source, not just a single relay therefore it is necessary to include scenario in which multiple relay assist the source. To simulate the multi node cooperation we consider 'N' Nodes wireless network. Due to the broadcast nature of the medium, some nodes always hear the transmission and thus can cooperate with source to send its data to the destination. Such system is shown in Fig.2.

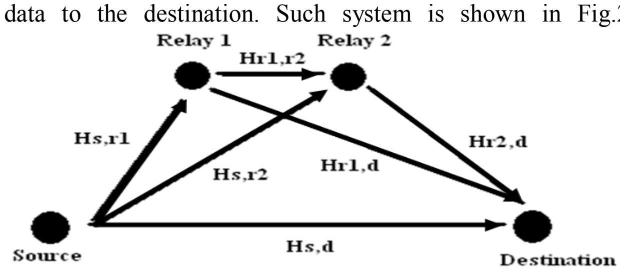

Fig.2 Multi-Relay case

In our multi-relay scenario each relay combines not only the source signal but also the signals from other (preceding) relays. For ease in simulation we consider only two relays.

When the source transmit the signal the corresponding signal at the destination and the i^th relays can be modeled as

$$Y_{sd} = \sqrt{P_0}h_{sd}x + n_{sd}$$

$$Y_{s,ri} = \sqrt{P_0}h_{sri}x + n_{sri} 1 \leq i \leq 2 \quad (7)$$

In next step(s), the intermediate relay will process the signal according to DF mode and re send it to the destination including other relays. Then other relays (Second in our case) combine the received signals from the source and the preceding (first in our case) relays using a maximal-ratio-combiner (MRC) as:

$$Y_{r2}=\sqrt{P_0}h_{s,r2}^{*}Ys,r2 + \sqrt{P_1}h_{r1,r2}^{*}Yr1,r2 \quad (8)$$

In (8) Y_{r2} is the combined signal at the second relay and $Y_{r1,\, r2}$ represents the signal received at the 2nd relay from the *1st* relay, and can be modeled as

$$Y_{r1,\, r2}=\sqrt{P_1}h_{r1,r2}x + n_{r1,r2} \quad (9)$$

In (9) P_1 relay 1 transmission power, in last the destination will combines all the signals it received. This can be mathematically model as [7]:

$$Y_d=\sqrt{Po}h_{s,d}^{*}Ysd + \sum_{i=1}^{2}\sqrt{Pi}h_{ri,d}^{*}Yri,d \quad (10)$$

- **Capacity and Throughput**

Let 'C' be the Capacity of the channel, 'S' be the Signal Power and 'N' be noise Power at the receiver. Then the capacity of the system when only additive white Gaussian noise (AWGN) channel is considered is:

$$C=Log_2(1 + \frac{S}{N})$$

Equation (11) has been normalized by the bandwidth and the units are hence [C] = bits/s/Hz [6]. Now including the channel fades 'h' due to the wireless channel in (11). Hence the overall capacity of the system with channel fade 'h' is represented in [2] as:

$$C=Log_2(1 + \frac{S}{N}|h|^2) \quad (12)$$

From the above capacity relation we can hypothetically determine the throughput of the system as:

$$\text{Throughput}= (1\text{-BER}) \times \text{Capacity} \quad (13)$$

- **Outage Probability**

To calculate the probability of Outage, let $\acute{y}$ be the *Signal to Noise* Ratio at the Receiver that yields capacity C($\acute{y}$)= log2(1 + $\acute{y}$) in bits/s/Hz. The Node is in outage if the capacity of the system falls below the information rate C($\acute{y}$). The probability of outage according to [6] can be model as.

$$P_{out} = P_r(\gamma < (2^R - 1)) = \int_0^{2^R-1} P\gamma\,(\gamma)\, d\gamma \quad (14)$$

In (14) P_r() represent the probability and $P\gamma(\acute{y})$ is the probability density function (PDF) of the SNR as given in [6], the probability of outage is.

(6)

$$P_{out}= 1\text{-exp}\,(- (2^R - 1)\,/\bar{\gamma}) \quad (15)$$

Equation (15) clears that the outage probability decreases with increasing SNR.

4. RESULT AND DISCUSSION

We have used Matlab as a Simulator, the simulation parameters are as fallow: Channel gains are model as single tap Rayleigh Fading channel along with additive white Gaussian noise (AWGN). BPSK modulation is used for simplicity however extension to modern modulation would be straight forward. In practice a receiving node always estimates the channel gains for detection but for simulation we assume that both Relay node and Destinations perfectly knows the Channel gains as *Yi Wu* & *Patzold* shows in [11].

We first compare the BER performance of DF Protocol for single relay and multi relay transmission with and without cooperation. The results are shown in the Fig.3.

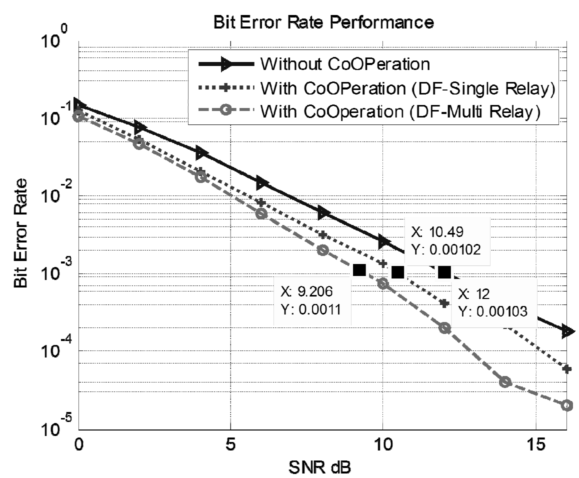

Fig.3 Bit Error Rate Performance of Decode & Forward

Result clearly demonstrates the BER improvement achieved with the cooperation of Single relay and multi relay. For example when there is no cooperation in a network BER of 10^{-3} (standard for Voice Communication) is achieved at 12 dB SNR, however, with the cooperation of single and multi (two in our case) relays same BER is achieved at 10.4 dB and 9.2 dB, resulting in a 2dB SNR saving with the cooperation of single relay while 3dB SNR saving in a multi relay case. This result clearly shows that as the Cooperation increases (number of cooperating relays increases) performance of the system also increases.

Secondly we compare the BER performance of AF with DF. AF is simpler in terms of complexity; however, the AF-relay amplifies the noise as well while DF has the advantage of reducing the noise effect with the penalty of inherent delay due to decoding and encoding process. This clearly indicates the need of a tradeoff between the two cooperation protocols. Some researcher like *Lanenan* In [12] indicates that the "AF mode is superior to the DF mode". While some other favors the DF protocol. Recent research shows that it is the Channel conditions that specifies which protocol would be the best. As the authors of [13] and [14] points to the inter-user channel (Source to Relay Channel) as the deciding factor: when the Source to Relay Channel is statistically worse than channel between Relay and destination, Amplify and Forward performs well while in the reverse condition Decode and Forward protocol performs better. The reason for this consideration is that Relay is normally closer to the source, so it is more likely that inter-user Channel has a better link quality and under such condition relay can correctly decode the message and hence enhances the performance. Fig.4 shows the BER performance of AF compared with DF when inter-user Channel is statistically good.

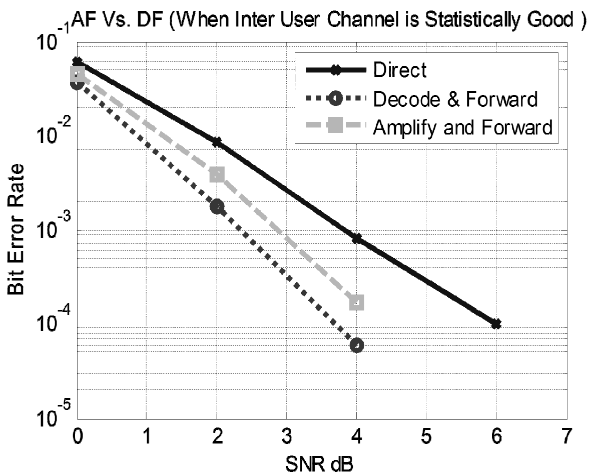

Fig.4 Amplify Forward versus Decode & Forward – statistically good channel

Fig.5 shows the BER performance of AF compared with DF when inter-user Channel is statistically bad or worse.

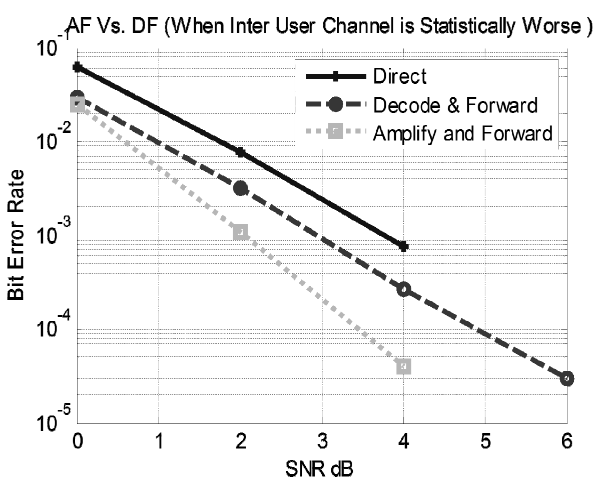

Fig.5 Amplify Forward versus Decode & Forward – statistically bad channel

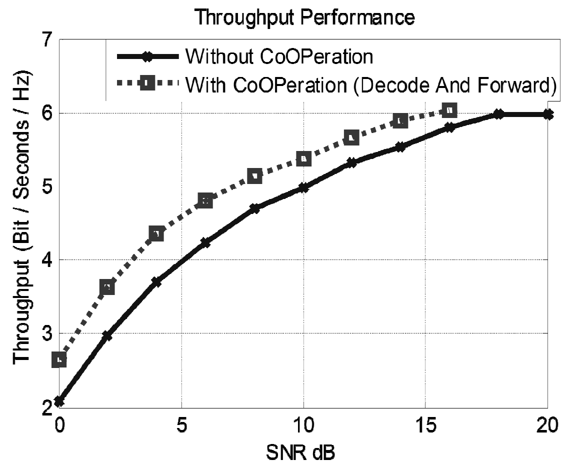

Fig.6 Throughput:

Fig.7 shows the Outage probability with and without Cooperation.

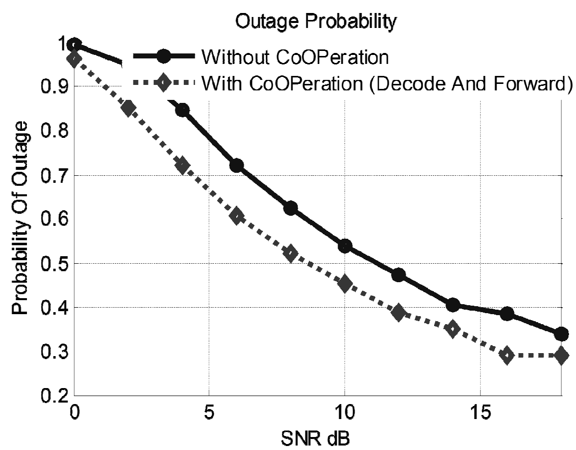

Fig.7 Probability of outage: Decode & Forward Protocol

In last we measure the throughput and outage probability for a single relay operating in DF mode. Fig.6 shows the improvement in throughput due to a single relay in comparison with the direct transmission. Throughput curve shows a significant deference between the two modes of transmissions, right from the beginning the cooperating relay out class the direct transmission. Outage curve also yields fine results, outage probability for a cooperative case decay more rapidly than the direct transmission. But as the number of cooperating relays increases probability of node outage also increases.

5. CONCLUSION

In a cooperative communication users (nodes within a network) cooperate with each other in order to achieve better Service. Cooperation among user defiantly results in an improver throughput, reduction in the power and better Outage Probability. Despite of several advantages and performance gains there are several aspects of Cooperative system needs attention, for e.g. Security, latency etc, for Cooperative system to be implemented.

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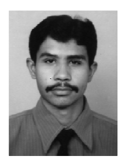

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