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Cooperative Communication: New Trend in Wireless Communication

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Abstract

Transmit diversity generally requires more than one antenna at the transmitter. However, many wireless devices are limited by size or hardware complexity to one antenna. Recently, a new class of methods called cooperative communication has been proposed that enables singleantennamobiles in a multi-user environment to share their antennas and generate a virtual multiple-antenna transmitter that allows them to achieve transmit diversity. This paper gives an overview of cooperative communication which is a technique that acts as virtual MIMO. Inthis paper we analyze cooperative communication in detail. We study the steps to cooperation and differentcombining strategies at the destination.

Keywords: *Cooperative communication, Transmit Diversity, Multiple Input Multiple Outputs*

1. Introduction

In wireless communication networks, direct transmission between the source and destination requires high transmitted power which is very costly and it makes the network's life shorter *i.e.*, battery drain becomes fast and interference increases. Fading also occurs which reduces the signal strength going through the channel and the signal received at the destination differs from original signal transmission. Multiple input multiple output systems (MIMO) uses diversity technique to offer significant increase in data throughput and link range without additional bandwidth or transmit power. Diversity technique reduces the fading by transmitting the data or information over multiple paths or multiple independent fading channels. These multiple copies of the same transmitted signal are combined at the receiver using any of the diversity technique i.e. maximum ratiocombining or equal gain combining diversity etc. But for MIMO multiple antennas are required at transmitter side as well as receiver side which increase the complexity of the system.

MIMO has become an important part of wireless communication due to its innumerable advantages. Although transmit diversity, which is inherent feature of MIMO, is advantageous but it may not be practical for all the scenarios. Especially due to cost, size or hardware limitations, a wireless agent, for example: a mobile phone may not be able to support multiple transmit antennas [11, 12].

Recently a new concept is introduced as an alternative to MIMO which is called as Cooperative Communication. Cooperative communication provides transmit diversity to single antenna users. In cooperative communication, more than one, cooperative users get the transmitted signal copies and retransmit those copies of the signal towards the destination. These users are called relay nodes. Relaynodes may be virtual antenna elements which have wide separation and wireless communication link between them. In

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relayed transmission, the signal or data from source node follows individual transmission paths over shorter distances in wireless communication with low power requirement and more reliability.

The signals from all transmitting relay nodes are combined at the destination node as multiple transmissions of same signal to reduce the performance degradation due to signal fading. Spatial diversity combining technique can be used as antenna sharing between relaying terminals, creating a virtual array to combat fading. Diversity technique can be used to combat fading phenomenon [1]. The users basically share their information and transmit with cooperation [2-3]. Relayed transmission extends the coverage usingspatial diversity to avoid fading in cooperative wireless communication system. [4-6].

The rest of the paper is divided into 6 sections. In Section II we will see the steps required to implement the cooperation between Source nodes, Relay nodes and Destination nodes. In Section III, models required for cooperation communication are discussed while in section IV various protocols used for communication between nodes arediscussed. Section V deals with the performance parameters used to measure the performance of system and Section VI focuses few applications of the cooperative communication.

2. Steps to Implement Cooperation:

This section elaborates the cooperation procedure which is actually implemented in real time. It is assumed that each node in the network has a distinct identification number. The steps involved in realizing this cooperation are as follows:

2.1. Neighbor Maintenance Step

Each node(S) in the cluster will broadcast at a regular interval COR (Cooperative Request).This will be broadcasted on a control channel, and will be received by all the neighboring nodes (NN) which are within the transmitting range. Once COR is transmitted there are two probable conditions. One is that the node which has received COR will cooperate and the other condition is that the node is loaded with traffic and energy constrains also exist, thus this node will not cooperate. If it is ready to cooperate with the requesting node it will send AOC (agree on cooperation), along with it will send its own user ID. In this way each requesting nodes will get cooperating nodes. The requesting nodes will store the ID of cooperating nodes, and in this way will maintain neighbor set.

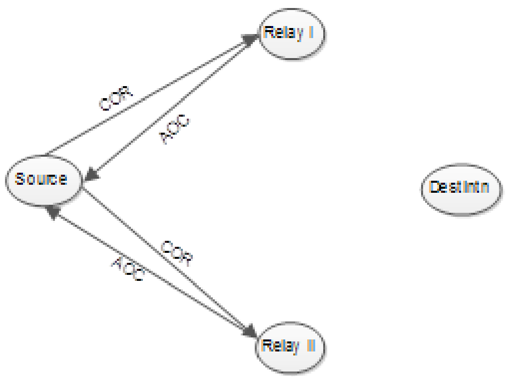

Figure 2.1. Neighbor Maintenance Step

2.2. Information Exchange Step

When AOC is received by the requesting node; it plans to transmit the information. Now the cooperating node, which is destination may be free or may be heavily occupied with its own assignments. In order to check whether it is ready to receive information the requesting node will send TR (transmission request). If it is ready to receive information it will send necessary information like CSI *etc*.

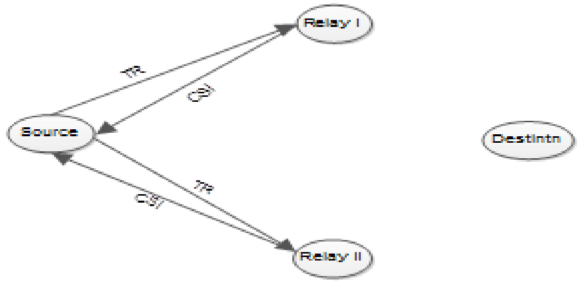

Figure 2.2. Information Exchange Step

2.3. Local Distribution Setup

After all these steps node selection and data/power allocation is done with one of the proposed algorithms. Finally data is broadcasted to each of the selected scheduled nodes, and thus cooperation is achieved& established.

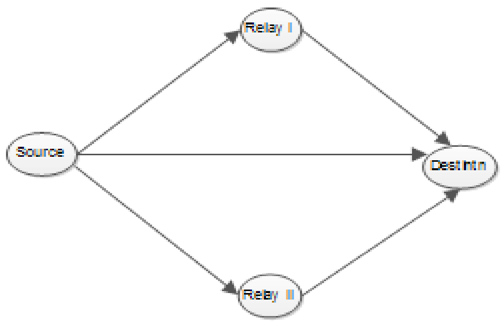

Figure 2.3. Local Distribution Step

3. Cooperative Relaying System Model

Cooperative relaying techniques can be realized in systems with either single relay or multiple relays per user. These system models are illustrated below [2].

3.1. Single Relay System Model

The basic model for cooperative system is a three terminal system model with one source node, one relay node and one destinationnode as shown in the Figure 3.1.Suppose source node and destination node want to communicate with each other but the link between them is too weak and there is another terminal i.e. relay node which resides in between sourceand destination. However, the link from relaynode to both sides is fairly good, so it will act as a relay to assist the direct communication. Relay node receives the data from the source node, performs some signal processing and then forwards that processed data to the destination node. The terminals may interchange their roles as source, relay and destination at different instants of time.

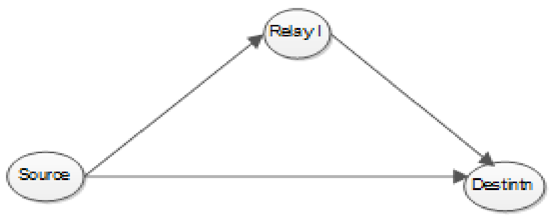

Figure 3.1. Cooperation using Single Relay

3.2. Multi Relay System Model:

However, in practical systems there are multiple sources, all transmitting at the same time to the multiple destinations? This requires multiple relays in the system as depicted in Figure 3.2. In this case, relays form a virtual antenna array and exploit some of the benefits of MIMO systems. But this scenario causes problems in resource allocation strategies, since multiple relays have to be allocate resources to assist the cooperation between them. Thus, multiple access schemes must be devised to separate their signals in time (TDMA), frequency (FDMA), code (CDMA) or space (SDMA).

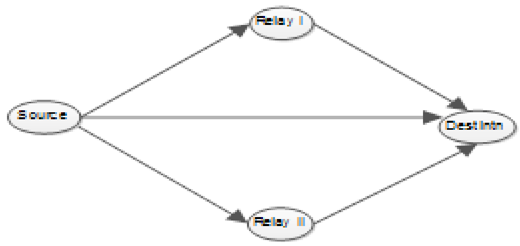

Figure 3.2. Cooperation using Multiple Relay

3.3. Combining Strategies

As we have seen from the previous sections, that there is more than one incoming transmission with the same burst of data, the incoming signals have to be combined and the original signal which was transmitted has to be retrieved. The possible strategies by which we combine these signals are as follows:

3.3.1 Selection Combining: In this technique, diversity branch with highest SNR is selected at receiver node.

3.3.2 Switch and Stay Combining: In this technique, receiver node selects another branch if the SNR of current branch falls below required threshold value.

3.3.3 Maximum Ratio Combining: This is the most complex scheme, in which all available paths are optimally combined at the receiver node. For MRC, SNR of individual paths may be below the threshold value but the combined SNR may be above threshold value.

3.3.4 Generalized Selection Combining: In this technique, receiver optimally combines only those paths whose channel SNR are above particular threshold value.

4. Cooperative Relaying Protocols

A cooperation strategy is modeled into two orthogonal phases, either in TDMA or FDMA, to avoid interference between the two phases:

In Phase 1, source node sends (broadcast) information to its destination, and the information is also received by the relay node (due to broadcast) at the same time as it shown in Figure 4.1 below:

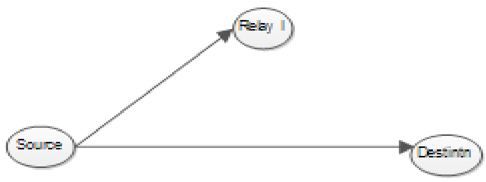

Figure 4.1. Phase I

In Phase 2, the relay can help the source node by forwarding or retransmitting the Information to the destination as it shown in Figure 4.2.

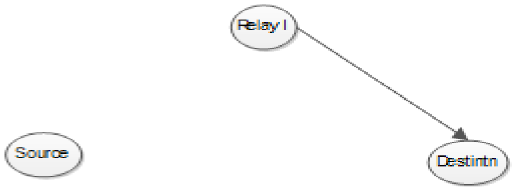

Figure 4.2. Phase II

In cooperative communications, the transmitting users not only broadcast their own message but they also relay some information, on behalf of each other, to the destination. The way or strategy, by which they relay this information to destination, is known as protocol. Various protocols have beenintroduced so far. We describe some of the basic relaying protocols here.

4.1. Amplify & Forward

In a fixed AF relaying protocol, which is often simply called an AF protocol, the relay node Scales the received version and transmits an amplified version of it to the destination node. The amplify-and-forward scheme is presented in Figure 4.3.

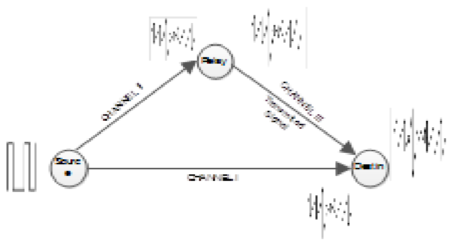

Figure 4.3. Amplify and Forward

4.2. Decode and Forward

Another processing possibility at the relay node is to decode the received signal, re-encode it, and then retransmit it to the receiver node. The decode-and-forward scheme is presented in Figure 4.4.

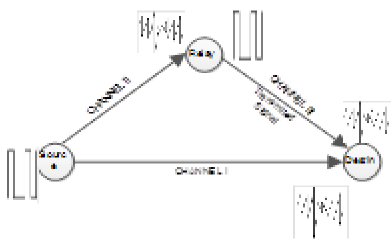

Figure 4.4. Decode and Forward

4.3. Compress and Forward

The main difference between compress-and forward and decode/amplify-and-forward is that while in the later the relay node transmits a copy of the received message, in compress and forward the relay node transmits a quantized and compressed version of the received message. Therefore, the destination node will perform the reception functions by combining the received message from the source node and its quantized and compressed version from the relay node.

4.4. Adaptive Relaying Protocols

Fixed relaying has the advantage of easy implementation, but the disadvantage of low bandwidth efficiency. This is because half of the channel resources are allocated to the relay for transmission, which reduces the overall rate. This is true especially when the source–destination channel is not very bad, because in such a scenario a high percentage of the packets transmitted by the source to the destination could be received correctly by the destination and the relay's transmissions would be wasted. To overcome this problem, adaptive relaying protocols can be developed to improve the efficiency. We consider two such strategies: selective DF relaying and incremental relaying [12].

4.4.1. Selective DF Relaying

In a selective DF relaying scheme, if the signal-to noise ratio of a signal received at the relay exceeds a certain threshold, the relay decodes the received signal and forwards the decoded information to the destination. On the other hand, if the channel between the source and the relay suffers a severe fading such that the signal-to-noise ratio falls below the threshold, the relay idles. Selective relaying improves upon the performance of fixed DF relaying, as the threshold at the relay can be determined to overcome the inherent problem in fixed DF relaying in which the relay forwards all decoded signals to the destination although somedecoded signals are incorrect.

4.4.2. Incremental Relaying

For incremental relaying, it is assumed that there is a feedback channel from the destination to the relay. The destination sends an acknowledgement to the relay if it was able to receive the source's message correctly in the first transmission phase, so the relay does not need to transmit. This protocol has the best spectral efficiency among the previously described protocols because the relay does not always need to transmit, and hence the second transmission phase becomes opportunistic depending on the channel state condition of the direct channel between the source and the destination.

5. System Performance Analysis

To analyze the performance of cooperative communication wireless network, the bit error rate (BER) and probability of outage of the system are considered for a given transmitted signal to noise ratio (SNR**).**

5.1. Average Signal-to-Noise Ratio (γ)

It is measured at the output of the receiver and is thus related directly to the data detection process itself. It is easiest to evaluate among all the existing system performance measures. It serves as an excellent indicator of the overall fidelity of the system. The term noise in signal to noise ratio refers to the thermal noise which is present at the input of the receiver in the context of a communication subject to fading impairment.

Signal-to-Noise-Ratio is defined as the power ratio between a signal (desired information) and the background noise (unwanted signal), that is:

$$SNR = \frac{Psignal}{Pnoise} \quad \text{Where P is the average signal power}$$

SNR could also be expressed in decibels using the equation:

$$SNR_{db} = 10\ Log_{10} \frac{Psignal}{Pnoise}$$

5.2. Outage Probability (Pout)

It is defined as the Probability that the instantaneous error probability exceeds a specified value or equivalently, the Probability that the output SNR, Y, falls a certain specified threshold. Threshold value of total SNR is the value at which system is not in outage. Outage is a condition of a system at which user becomes unable to get the proper service from the system.

5.3. Bit-Error-Rate (BER)

The performance of a wireless channel is measured at the physical level by bit-error-rate (BER), block-error-rate, symbol-error-rate, or probability of outage. BER is defined as the percentage of bits that have errors due to noise, distortion or interference relative to the total number of bits received in a transmission.

6. Applications

This section highlights some of the areas where the cooperative relaying strategies can be applied.

6.1. Virtual Antenna Array

The field of high-data-rate, spectrally efficient and reliable wireless communication, is currently receiving much attention. It is a well known fact that the use of MIMO antenna system improves the diversity gain of wireless systems. However, multi-antenna technique is not attractive for tiny wireless nodes due to limited hardware and signal processing capability. Diversity can be achieved through user cooperation, whereby mobile users share their physical resources to create a virtual array, which thus, removes the burden of multiple antennas on wireless terminals.

6.2. Wireless ad-hoc Network

Ad hoc network is a self organizing network without any centralized infrastructure. In this n/w, distributed nodes form a temporary functional network and support seamless leaving or joining of nodes. Such network has been deployed for military communication and civilian applications including commercial and educational use *etc*.

6.3. Wireless Sensor Network

Lifetime of sensor network can be increased by deploying cooperative relaying hence, energy consumption in sensor nodes got reduced. We knew, communication through weaker channels requires huge energy as compared to relatively strong channels. So, careful incorporation of cooperating relay nodes into routing process can select better communication links and precious battery power can be saved.

6.4. Cooperative Sensing for Cognitive Radio

In cognitive radio system, secondary users can utilize the resources which are employed for licensed primary users. When primary users want to use their licensed resources, secondary users have to vacant these resources. Thus, secondary users have to constantly sense the presence of primary user. Probability of false alarming can be reduced with the help of spatially distributed nodes, which thus improve the channel sensing reliability by sharing the information.

7. Conclusion

A cooperative communication, field of high data rate, spectrally efficient and reliable wireless communication is fetching much attention. It is emerging as an effective technique for combating the effects of path loss, shadowing, and multipath fading. Cooperative relaying provides diversity gain, reduces outage and improves BER performance. Various types of relays, modes of operation, types of relaying, parameters performance measurement have been discussed here.

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