INTERNATIONAL JOURNALOF RESEARCH SCIENCE & MANAGEMENT

RELAY-BASED CO-OPERATIVE COMMUNICATION FOR WIRELESS NETWORKS – A SURVEY

Shachi P.*
*Department of Electronics and Communication Engineering, NHCE, Bangalore, India

Keywords: Co-operative communication, spatial diversity, MIMO, relays, base-station, mobile-station.

Abstract

Fading is one of the serious issues of concern in a wireless communication [1]. The concept of spatial diversity led to the evolution of MIMO (Multiple-In Multiple-Out) systems which gave helped to mitigate the effects of fading but with the cost of increased hardware requirement. Co-operative communication which creates a virtual MIMO is a promising solution to overcome the effect of fading. It is one of the evolving techniques which offers reduced interference and error probability while providing increasedthroughput and power efficiency. This paper gives an overview of the co-operative communication, with more importance given to therelay-based co-operation. With a basic relay-network model, we have discussed on modes of operation of relay and various protocols for data-forwarding.

Introduction

Co-operative communication is a technique which allows single-antenna mobiles to reap some of the benefits of MIMO systems. The basic idea is that single-antenna mobiles in a multi-user scenario can "share" their antennas in a manner that creates a virtual MIMO system. In particular, spatial diversity is generated by transmitting signals from different locations, thus allowing independently faded versions of the signal at the receiver.

Consider the case when there are L transmit antennas and 1 receive antenna, the MISO channel. It is often cheaper to have multiple antennas at the base-station than to have multiple antennas at every handset. It is easy to get a diversity gain ofL: simply transmit the same symbol over the L different antennas during L symbol times. The concept is termed transmit diversity and this forms the basis for the co-operative communication in cellular networks. Multiple antenna terminals at the base station can be considered to give user side multi-cell interference cancellation capability.This concept is the basis for base-station co-operation.

Another method of co-operative communication is mobile-to-mobile co-operative, which is described in Fig. 1. This figure shows two mobile agents communicating with the same destination. Each mobile has one antenna and cannot individually generate spatial diversity. However, it may be possible for one mobile to receive the other, in which case it can forward some version of "overheard" information along with its own data. Because the fading paths from two mobiles are statistically independent, this generates spatial diversity.

A conventional single hop system uses direct transmission where a receiver decodes the information only based on the direct signal while regarding the relayed signal as interference, whereas the cooperative diversity considers the other signal as contribution.

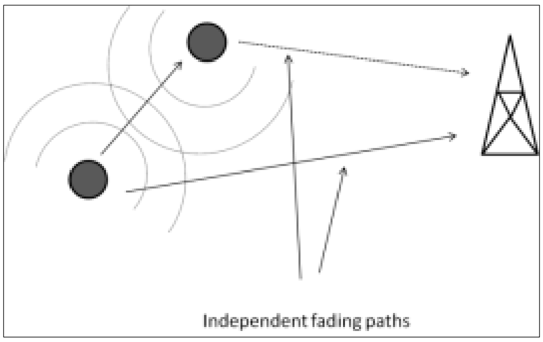


Fig.1Mobile-to-mobile co-operation scenario

Combining the advantages of diversity technology and relay transmission technology, cooperative transmission enables a distributed virtual Multiple-Input Multiple-Output (MIMO) system (in cooperative communication, virtual MIMO refers to a transmission system where several relay nodes naturally form a virtual antenna array, and they simulate conventional MIMO application environment by coordinating and communicating with each

INTERNATIONAL JOURNALOF RESEARCH SCIENCE & MANAGEMENT

other, thus achieving joint space-time coding). It can obtain a transmission gain approximating to that of multi-antenna and multi-hop transmission without adding antennas. Meanwhile, the destination node receives the signals not only directly from the source node, but also forwarded by the relay nodes. With sufficient valid information provided, e.g. the radio link status and the signal quality, the destination node can choose a proper method to combine these signals, thus achieving diversity gains and greatly improving data transmission rate.

History of co-operative communication

The origin of cooperative communication can be traced back to the work of Cover and El Gamalon the relay channel in 1979. [2] It was a three-node model consisting of a source, a relay and a destination. Cover and El Gamal' works demonstrates that the capacity of a discrete memory-less Additive White Gaussian Noise (AWGN) relay channel is better than that of the source-destination channel. Most channel capacity analysis is carried out with respect to an additive white Gaussian noise (AWGN) channel whereas in recent developments the concept of fading channels is taken into consideration. The relay's sole purpose is to help the main channel, whereas in cooperation the total system resources are fixed, and users act both as information sources as well as relays. Co-operative communication is a combination of the advantages of diversity technology and relay transmission technology, which providing a transmission gain equivalent to MIMO scenario. Hence the term virtual-MIMO evolved.

Interference cancellation

In cellular systems it is important to consider the effect of inter-cell interference on the performance of the system. One of the metrics denoting the level of interference is SINR (signal-to-interference-plus-noise ratio). Since wireless communication is subject to fading, the strength of received desired signal as well as noise will be fluctuating over time. Multiple relays forming virtual MIMO compensates for these fluctuations. This has in-turn effect on increase in spatial-reuse of the network.

Amplitude and phase randomization at the base-station transmit antennas is an issue of concern when co-operative communication exploits these fluctuations. They increase the fluctuations in the received signal as well as the interference to adjacent cells. Opportunistic beamforming is a solution to this, as it performs opportunistic nulling simultaneously: while randomization of amplitude and phase in the transmitted signals from the antennas allows near coherent beamforming to some user within the cell, it will create near nulls at some other user in an adjacent cell [1]. Hence this avoids interference for that particular user.

Types of co-operative communication

According to [3], co-operative communication can be deployed in three fashions. The difference is with respect to the co-operative elements involved. Three types of cooperative MIMO schemes have been proposed for cellular systems: coordinated multipoint transmission (CoMP), fixed relay, and mobile relay (Fig. 2). Here we have merged fixed relay and mobile relay under generalized category of relay-based co-operation.

Coordinated Multipoint (CoMP) method deals with co-operation between base-stations i.e., data and channel state information (CSI) is shared among neighbouring cellular base stations (BSs). The co-operation is carried out in order to coordinate their transmissions in the downlink and jointly process the received signals in the uplink. The system architecture is illustrated in Fig. 2a. CoMP techniques can effectively turn otherwise harmful inter-cell interference into useful signals, enabling significant power gain, channel rank advantage, and/or diversity gains to be exploited. But it requires a high-speed backhaul network for exchanging the information between the BSs.

Apart from co-operation between base-stations, there are two more types of co-operation which involves an element called "relay". Relays in co-operative communication refer to that intermediate elements which process and forward the data to intended destination. The function of relay is different from that of usual repeaters because of the signal processing process involved. Depending on if the relays are stationary or mobile, there are two types of co-operation involved viz. fixed relay and mobile relay co-operation.

Fixed relays

Fixed relays are low-cost and fixed radio infrastructures without wired backhaul connections (Fig. 2b). They store data received from the BS and forward to the mobile stations (MSs), and vice versa. Fixed relay stations (RSs) typically have smaller transmission powers and coverage areas than a BS. By combining the signals from the relays and possibly the source signal from the BS, the mobile station (MS) is able to exploit the inherent diversity of the relay channel.

Mobile relays

ISSN: 234-5197
Impact Factor: 2.715

INTERNATIONAL JOURNALOF RESEARCH SCIENCE & MANAGEMENT

Mobile relays differ from fixed relays in the sense that the RSs are mobile and are not deployed as the infrastructure of a network. Mobile relays are therefore more flexible in accommodating varying traffic patterns and adapting to different propagation environments. For example, when a target MS temporarily suffers from poor channel conditions or requires relatively high-rate service, its neighbouring MSs can help to provide multi-hop coverage or increase the data rate by relaying information to the target MS. Moreover, mobile relays enable faster and lower-cost network rollout. Similar to fixed relays, mobile relays can enlarge the coverage area, reduce the overall transmit power, and/or increase the capacity at cell edges. On the other hand, due to their opportunistic nature, mobile relays are less reliable than fixed relays since the network topology is highly dynamic and unstable.

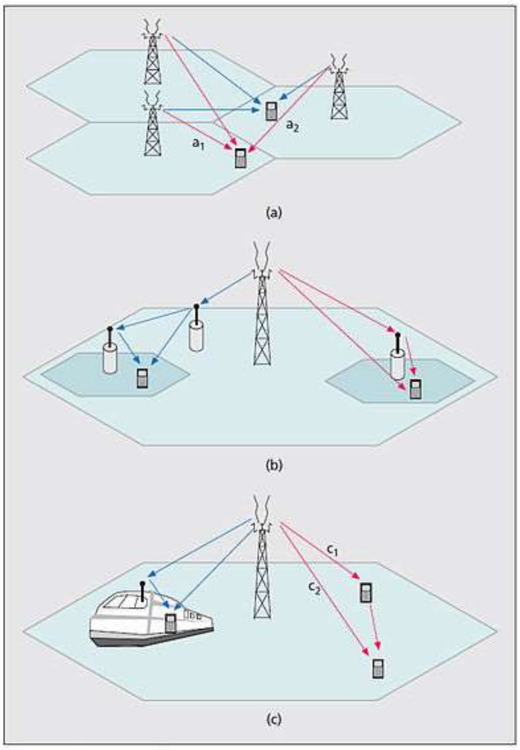


Fig.2Three types of co-operativecommunication schemes: a) CoMP; b) fixed relay; c) mobile relay [3]

Relay-assisted co-operation

In modern cellular systems, the presence of dedicated relays is considered to be instrumental in extending coverage by enabling cooperation at the user level. In the previous section we discussed two types of relay-based co-operative schemes. For further studies we narrow down to fixed-relay infrastructure. Relays will be the data processing and forwarding unit which links BS and MS. Multiple relays form a virtual arrayand cooperate with one another to work. Orthogonal channels (I and Q) channels of the same frequency will be utilized for the links between BS-RS and RS-MS and space-time block codes provide the required orthogonality of superimposed signals.It is possible to consider channelmodels in which a separate relay node is available to assist thedirect communication within eachcell.

If the signals can be transmitted via different paths, then it should be exploit time-division. Fig. 3 gives an illustration of frame-by-frame fashion of transmission. Let us assume that each frame is divided into two phases. In the first phase, the source node transmits its data to the destination node. Due to the broadcast nature of wireless transmission, the relay node can overhear the data. In the second phase, the relay node forwards the data to the destination after processing, depending on the relaying-protocol used.

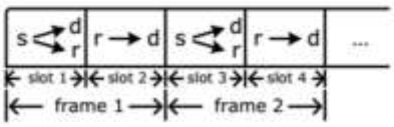


Fig.3Exploitingtime-division in relay-based co-operation

INTERNATIONAL JOURNALOF RESEARCH SCIENCE & MANAGEMENT

Relay-based co-operation increases the coverage of a given base-station and as well reduces the power consumption at the base-station. Also they enhance the capacity of a specific region with high traffic demands, and/or improve signal reception. Relay communication is relevant to the multi-cell MIMO network because it can be beneficial not only in strengthening the effective direct channel gain between the BS and the remote users, but also in helping with inter-cell interference mitigation. To state few disadvantages, relay-based co-operation introduces additional delays due to the relaying process, and the potentially increased levels of interference due to frequency reuse at the RSs. The solution to the increased delay is adaptive (increased) coding rate [4]. The proposed solution to interference due to frequency reuse at RSs is to utilize the secondary frequency bands (say TV-White Space) for either of the links discussed above.

Relays can be classified based on mode of operation and type of signal processing carried out at the relay. Depending on what type of signal processing is done at the relay, the relay function is also known as: hard information - when the relay takes a hard decision,soft information - the relay sends some sort of information regarding data about the correctness of the decision regarding the source signal. Relays can be operated in 2 modes – full-duplex mode in which the relay can receive and transmit simultaneously and half-duplex mode in which the relay can either receive or transmit, but not both at the same time.Depending on the type of relay chosen, a particular relaying protocol has to be employed.

System model

Let us consider a model of the relay network as shown in the Fig. 4, with one relay playing the role between source and destination.

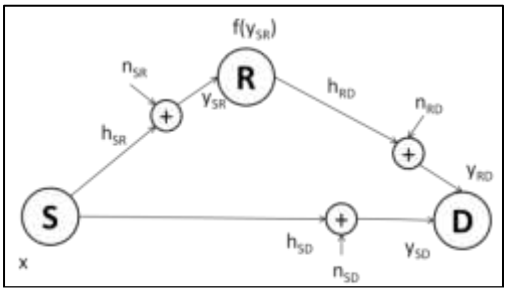


Fig.4 Relay network

The typical notations for the relay network are as follows:

- x– transmitted signal from the source
- y – received signal
- h– channel coefficient
- n – channel noise
- $f(y_{SR})$ –the relay function (the signal processing at the relay).

With these notations the system model can be defined as:

$$y_{SR} = h_{SR}.x + n_{SR}$$
$$y_{SD} = h_{SD}.x + n_{SD}$$
$$y_{RD} = h_{RD}.f(y_{SR}) + n_{RD}$$

The decoding operation at the destination is discussed further. The decoding process is similar to that of a MIMO. The received signal is modeled and linear-decoding method is applied. Under the non-cooperative scenario we have considered that the destination receives the signal via the relay wherein the relay contributes for power boosting gain. The destination decodes the data using the signal received from the relay on the second phase. The signal received from the relay node which retransmits the signal received from the source node is written as:

$$r_{dr} = h_{dr}r_{rs} + n_{dr} = h_{dr}h_{rs}x_s + h_{dr}n_{rs} + n_{dr}$$

where, $h_{dr}$is the channel from the relay to the destination nodes and $n_{rs}$is the noise signal added to h_{dr}.The reliability of decoding can be low since the degree of freedom is not increased by signal relaying. There is no increase in the diversity order since this scheme exploits only the relayed signal and the direct signal from the source node is either not available or is not accounted for.

Whereas when relay co-operation is employed, it exploits spatial diversity and decodes the combination of both the direct and relayed signals. The whole received signal vector at the destination node can be modelled as:

$$r = [r_{ds} \quad r_{dr}]^T = [h_{ds} \quad h_{dr}h_{rs}]^T x_s + \left[\sqrt{|h_{dr}|^2 + 1}\right]^T n_d \; = hx_s + qn_d$$

 ISSN: 234-5197
Impact Factor: 2.715

INTERNATIONAL JOURNALOF RESEARCH SCIENCE & MANAGEMENT

where, $r_{d,r}$and $r_{d,s}$are the signals received at the destination node from the source and relay nodes, respectively. With a linear decoding technique, the destination combines elements of the received signal vector as follows:

$$y = W^H r$$

where, 'W' is the linear combining weight vector which can be obtained to maximize signal-to-noise ratio (SNR) of the combined signals.

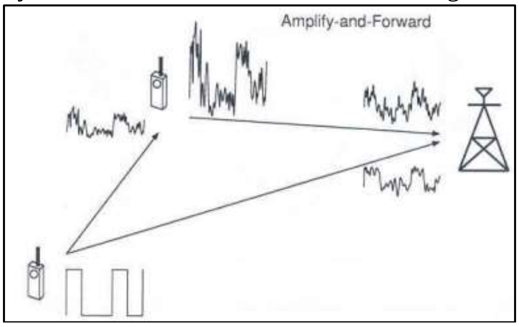
Co-operative relaying protocols

A relaying protocol includes a set of signal processing functions to be performed on the signal which is overheard from a source and to be forwarded to the intended destination. Prime factor of consideration during this signal processing is channel-state information. Depending on the detection function at the destination, relay need to consider either whole of the channel state information or a part of it [5]. Depending on the signal-processing scheme employed the relaying protocols are categorized into various schemes as: Amplify-and-Forward, Decode-and-Forward, Coded Cooperation, Estimate-and-Forward, Store-and-forward, Space-Time Coded Cooperation and Network Coded Cooperation. Among them the most popular are Amplify-and-Forward and Decode-and-Forward schemes.

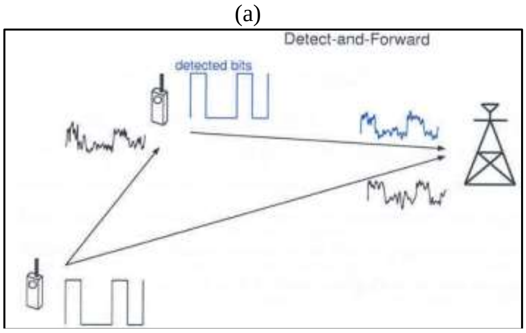
Amplify-and-forward (AF)

In case of AF protocol just amplifies the overheard signal from the source maintaining certain average transmission power. From Fig. 5(a) we can see that the application of the protocol for co-operation can be explained in 3 steps. First one is to process the

In this case, the relay just amplifies its received signal, maintaining a fixed average transmit power.As shown in Fig. 5(a), signal processing in AF scheme can be simplified into three phases: In phase 1, the source node transmits the signals by way of broadcasting, while the destination node and the relay node receive the signals. In phase 2, the relay node amplifies the powers of the signals received from the source node and forwards them to the destination node. In Phase 3, the destination node combines and decodes the signals received from the source node in Phase 1 and the relay node in Phase 2 so as to restore the original information.

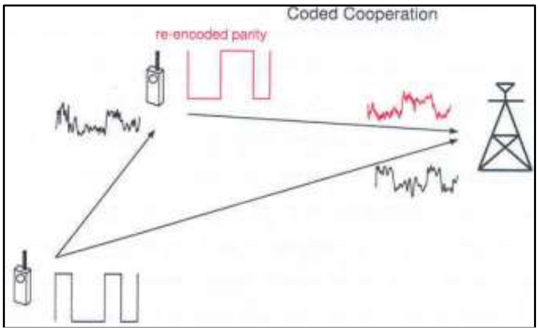


(a)



(b)

INTERNATIONAL JOURNALOF RESEARCH SCIENCE & MANAGEMENT



(c)

Fig.5 Comparison of different co-operative methods [6]

AF is also called non-regenerative relaying scheme and is the simplest method compared to others. Full diversity gain and good performance can be achieved with this scheme as the destination node can receive independent fading signals from the source and relay nodes. However, AF scheme is often affected by noise because the relay node amplifies the noise on the source-relay channel when the retransmitted signals are amplified. This might affect the SNR too and may result in erroneous detection.

Decode-and-forward (DF)

Relays following the decode-and-forward protocol, overhear transmissions from the source, decode them and incase of correct decoding, forward them to the destination. Whenever unrecoverable errors reside in the overheard transmission, the relay cannot contribute to the cooperative transmission. The DF strategy allows the combining of cooperative relaying with coding schemes, thus not only providing diversity gains but also an additional coding gain.DF makes hard decision, as the information sent by the relay does not include any additional information about the reliability of the source-relay link.

Phase 1 and Phase 3 of DF scheme are similar to that of AF. In Phase 2, the relay node decodes and detects the signals received from the source node before it forwards the signals to the destination node. Hence, DF is also called regenerative relaying scheme. Though noise is not amplified and propagated, the signal processing in DF largely depends on transmission performance of source-relay channel. With the increase in number of hops, the errors accumulate, thus hindering the relay performance.

Coded Cooperation (CC)

In AF and DF, the relay node always repeatedly forwards the information received from the source node, which often leads to decreased usage of the degrees of freedom. To solve the problem, CC scheme was proposed. Signal processing in CC scheme is shown in Fig. 5c.

In CC scheme, different segments of each user's code words can be sent via two different fading paths. Each user correctly decodes the information received from cooperative partners and then re-encodes them before forwarding them. With redundant information bits being repeatedly transmitted through different spaces, the system performance is improved. In CC scheme, each mobile terminal achieves diversity and coding gains by re-encoding and transmitting different redundant bits, thus the system performance is greatly enhanced.

This scheme does not require information feedback between cooperative nodes. When a relay node cannot correctly decode the information bits, it automatically reverts back to non-cooperative mode, ensuring the system efficiency.

Estimate-and-Forward (EF)

This protocol is also known as Compress-and-Forward or Quantize-and-Forward. At the relay, a transformation is applied to the received signal, which provides an estimate of the source signal. This estimate is also known as soft information, and it is forwarded to the destination.[7] gives a performance analysis and comparison of different relay protocols with respect to their Block Error Rate (BER). The considerations for the performance analysis are as follows:

- Binary Phase Shift Keying (BPSK) modulation is used with coherent detection at the receiver.
- Coded baseline system with the same overall rate of ¼
- RCPC code
- cooperation level of 25 percent

The BER performances of cooperative communication systems are better than that of non-cooperative system. Among the above-discussed cooperative schemes, performance of CC is often better than that of AF and DF, but it involves complicated algorithms as well as diverse coding technologies. As a result, the signal processing time

ISSN: 234-5197
Impact Factor: 2.715

INTERNATIONAL JOURNALOF RESEARCH SCIENCE & MANAGEMENT

and delay at the relay node is increasing, which is not good for the development of modern wireless communication systems. Therefore, with all factors being considered, AF and DF are regarded more practical than the other schemes.

Relay selection

There are few factors to be considered when incorporating co-operative communication. Relay selection plays an important role as it contributes to the diversity gain. The relay selection process consumes both energy and time, but in presence of mobility or in highly dynamical environments, the relay selection must be performed frequently enough in order to exploit the diversity of a better channel.

The number of relays also plays an important role since this factor contributes to the dynamism of the network and directly corresponds to thediversity order of the system. For example, a scheme where one fixed relay is used, achieves a diversity order of two. If m relays are used, the diversity order becomes m+1 [8].

Co-operation need not always bring benefits. For example, in a half-duplex mode, the data transmission rate and the utilization of the degrees of freedom will decrease. This indicates when to cooperate is a critical issue.

Conclusion

We surveyed wide variety of introductory works on cooperative communication and have extracted and depicted the basics on the evolving research area.More importance isgiven to the relay-based cooperation. We have discussed on how to model a cooperative communication scenario. Also a brief comparison on important relaying techniques is given. As relays are the building blocks of the system, we've thrown light on the relay selection which is the main driving factor of the performance of the whole system.

References

1. David Tse, PramodViswanath, "Fundamentals of Wireless Communication," 1st edition,Cambridge University Press, 2005.
2. Cover, T., Gamal, A.E., "Capacity Theorems for Relay Channel", IEEE Transactions on Information Theory, Vol. 25, Issue 5, pp. 572-584, Sep. 1979.
3. Cheng-Xiang Wang, Xuemin Hong, XiaohuGe, Xiang Cheng,Gong Zhang, John Thompson,"Cooperative MIMO Channel Models: A Survey",IEEE Communications Magazine, vol. 48, pp. 80-87, February 2010
4. Andrej Stefanov, ElzaErkip, "Cooperative Coding for Wireless Networks", IEEE Transactions on Communications, vol. 52, pp. 1470 – 1476, Sep. 2004.
5. W. Pam Siriwongpairat, K. J. Ray Liu, "Ultra-Wideband Communications Systems: Multiband OFDM Approach", John Wiley & Sons, Nov. 2007.
6. Luo Tao, HaoJianjun, YueGuangxin, "Cooperative Communication and Cognitive Radio (1)", ZTE-Communications, 2009.
7. Aria Nosratinia, Todd E. Hunter,AhmadrezaHedayat, "Cooperative Communication in Wireless Networks", IEEE Communications Magazine, vol. 42, no. 10, pp. 74-80, Oct. 2004
8. W. Elmenreich, N. Marchenko, H. Adam, C. Hofbauer, G. Brandner, C. Bettstetter, M. Huemer, "Building Blocks of Cooperative Relaying in Wireless Systems", Springer, 2008.