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Cooperative Networks

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1. Introduction

The mobile and wireless communications entered this century with an extraordinary thrust, as earlier perceived by observing the continual research and development activities, and as evidenced by the increasing levels of acceptance and penetration of such technology on a world wide scale. It is likely that 4G will follow in progression after 3G and it appears as an ultra-high speed broadband wireless network (Bohlin et al., 2004). The main challenges in 4G are reduced power, complexity on terminals and spectral efficiency. To target advanced services without the need to increase the power requirements is considered as one of the most important factors for the success of 4G systems. Space or multiple antenna diversity techniques in combination with time and frequency diversity are commonly used and to improve spectral efficiency in addition. This is not practical for a small mobile handset. To obtain the same capacity and diversity an alternative method is proposed known as cooperative networks (Sendonaris et al., 2003; Laneman, 2004). In a cooperative network, virtual multiple antenna arrays are generated due to the cooperation of multiple relays. For these networks the diversity that can be obtained is equal to the number of multiple paths between source and destination (Anghel & Kavehl, 2003; Ikki & Ahmed, 2007; Tsiftsis et al., 2004). Cooperative diversity can be obtained from single antenna mobiles to bring in the advantage of multiple inputs multiple output (MIMO) systems. In this type of communication intermediate terminals are used to relay the information from source to destination (Yuksel & Erkip, 2003). The terminals are used to transmit there data, as well as to relay the information from other users to introduce cooperative diversity.

2. Non-Cooperation (NC)

The received signal at the destination, for direct transmission from source (s) to destination (D) without any relaying, is given by:

$$y_{sd}(n) = h_{sd}(n)\sqrt{E_b}\,x + n_d(n) \tag{1}$$

where h_{sd} is the channel coefficient between user s and d at time n, E_b is the transmitted energy per bit, s is a BPSK signal and $n_d(n)$ is Additive white Gaussian noise with power spectral density of N_0. The signal to noise ratio (SNR) is given as:

$$\gamma_{sd} = | h_{sd} |^2 \frac{E_b}{N_0} \tag{2}$$

and the probability of bit error for this SNR is shown as

$$P_{e|\gamma_{sd}} = Q\left(\sqrt{2\gamma_{sd}}\right) = Q\left(\sqrt{2 | h_{sd} |^2 \frac{E_b}{N_0}}\right) \tag{3}$$

where $Q(.)$ is the standard Gaussian error function. The average error probability can be obtained by taking the average of above equation over γ_{sd}.

3. Hop Cooperative Networks

The conventional 2-hop cooperative network is shown in the Figure 1 , where the signal from source reaches the destination through direct path ($S \rightarrow D$) as well as indirect path in two stages ($S \rightarrow R$, $R \rightarrow D$).

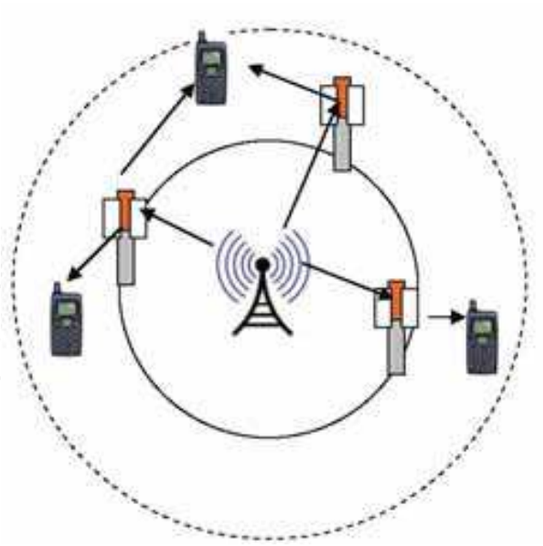


Fig. 1. 2-hop Cooperative Network

3.1. Relaying Architecture

Figure 2 shows various relaying architectures. Figure 2(a) is the two hop network, used for relaying the information to the destination. At the heart of cooperative communication

is the classical relay architecture as shown in Figure 2 (b), also known as three body problem. In the figure *S* is the source, *R* is the relay and *D* is the destination terminal. The source broadcasts the signal to both the relay and the destination. The relay then retransmits the information to the destination. When the destination is unable to hear the source, the architecture reduces to the case of a cascade multihop communication of Figure 2(a). Figure 2(c) is a user cooperation case, where other user is used as a relay. For certain services there is a need to use more than one relays, in order to improve the system performance as shown in Figure 2(d), known as multiple relay network. Figure 2(e) shows the cooperative network with inter relay cooperation, where the relays also communicate with each other.

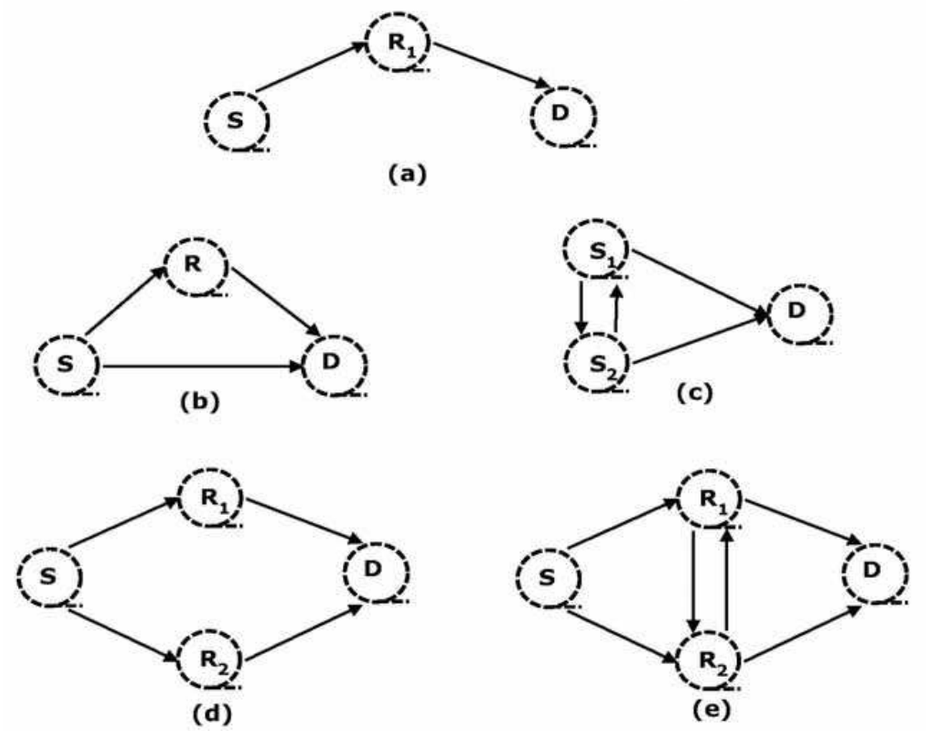


Fig. 2. Relaying Architectures (a) multi-hop cooperation (b) single-relay cooperation (c) user cooperation (d) multiple-relay cooperation (e) inter-relay cooperation

3.2. Relaying Schemes

In TDMA, the relay always forward the received signal from the source to the destination in the next time slot. These relaying schemes are given below:

- *Fixed Relaying Schemes:* Fixed relaying schemes are further divided into two main parts; i.e. Amplify and Forward (AF) and Decode and Forward (DF) relaying schemes. In AF, the relay forward the scaled version of the message received from the source. The main disadvantage of this scheme is that the relay amplifies the noise along with the original signal. On the other hand it is easier to implement. For the fixed gain relay the amplification factor will be equal to (Hasna & Alouini, 2004):

$$A = \sqrt{\frac{1}{CN_0}}$$

where C is a positive constant number. For Variable gain relay the amplification factor depends on the channel h_{sr} (coefficients the channel between source and destination) and is given as (Tsiftsis et al., 2006):

$$A = \sqrt{\frac{E_{sr}}{E_{sr} \mid h_{sr} \mid^2 + N_0}}$$

where E_{sr} is the average energy of transmission from source to relay. In decode-and-forward (DF), the relay demodulates and decodes the received signal to estimate the transmitted signal before retransmission.

- *Selection Relaying Schemes*: The selection relaying was proposed by Laneman et al., in which only some of the relays are allowed to forward the signal from the source. Only those relays with amplitude of fading gains between source and the relay greater than the threshold value will be allowed to relay the signal (Laneman et al., 2004).
- *Incremental Relaying:* The incremental relaying was proposed by Laneman et al., in which the destination directs the relay to forward the signal from source on the bases of the SNR value between source and destination. If SNR value is very high then the destination asked the relay not to forward the signal from source (Laneman et al., 2004). From the bit error rate performance comparison of all relaying protocols, the incremental relaying protocol gives a better performance (Jittilertwirum et al., 2007).

3.3. Multi-hop Transmission

Consider the multi-hop wireless system shown in the Figure 3. There are $L-1$ number of intermediate nodes between source and destination for L hop network. These intermediate nodes work as Amplify-and-forward (AF) relays.

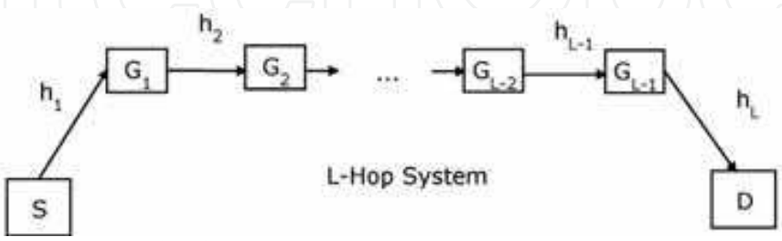


Fig. 3. Multi-hop communication system

The gain of i-th relay to satisfy the power constraint will be given as (Laneman and Wornell, 2000):

$$G_i^2 = \frac{1}{h_i^2 + N_{0,i}}$$

where h_i is the fading amplitude of the *i*-th hop and $N_{0,i}$ is the variance of additive white Gaussian noise at the *i*-th relay. The end-to-end signal-to-noise (SNR) is given by (Hasna & Alouini, 2003):

$$\gamma_{eq} = \left[\prod_{i=1}^{L} \left(1 + \frac{1}{\gamma_i} \right) - 1 \right]^{-1} \quad (4)$$

where $\gamma_i = \frac{h_i^2}{N_{0,i}}$ is SNR of the *i*-th hop.

Oishi et al. analyze the FER performance of the multi-hop cooperative networks using state transition and the theoretical showed that the performance can be improved by increasing the number of hops (Oishi et al., 2008).

3.4. Transmission Protocols

The transmission of the signal from source (S) to destination (D) through relays (R) takes place on different protocols explained below:

3.4.1. TDMA based Transmission Protocols

- *Two time slots TDMA based transmission protocol:* Three different TDMA-based protocols for the transmission of signal from Source to destination was proposed by Nabar (Nabar et al., 2004) as shown in Table 1.

Time Slot/Protocol	I	II	III
1	*S→R,D*	*S→R,D*	*S→R*
2	*S→D*, *R→D*	*R→D*	*S→D*, *R→D*

Table 1. Two time slots TDMA based Transmission Protocols

- *Three time slots TDMA based transmission protocol:* In (Fares et al., 2008), a three time slots TDMA based protocol was proposed with one extra time slot for inter relay communication. In this protocol source *S* transmits signal *s(t)* to destination *D* and relays *R* at the same time which are summarized in the Table 2. In time slot one, the source node *S* transmits the unit signal *s(t)* to destination *D* and relays *R* (*i = 1, 2*). In time slot two, there is inter-relay communications and the relays are using amplify-and-forward (AF) scheme. The best relay will be chosen on the basis of highest SNR for the source relay channel. It normalizes and retransmit the received signal to other relay as shown in Table 2. As the relay 2 receives two signals, one from source and other from relay 1, so it combines

coherently the received signals by using the adaptive antenna array (AAA) algorithm. After normalizing the signal by both relays, the signals are retransmited to the destination in time slot three and the signals from source and relays are combined constructively by using MRC combining cooperative diversity.

Time Slot 1	Time Slot 2	Time Slot 3
$S \rightarrow R,D$	$R \rightarrow R$	$R \rightarrow D$

Table 2. Three time slots TDMA based Transmission Protocols

3.4.2. Hybrid FDMA-TDMA based Transmission Protocols

A hybrid FDMA-TDMA based transmission protocol is shown in Table 3 (Adeane et. al., 2005; Khan et. al., 2009). Different frequencies are allocated to each user i.e. f_1 to user 1 (*U1*) and f_2 to user 2 (*U2*). Each time slot is further divided into two orthogonal slots. In each frequency band, there are two time frames, one frame is allocated for sending its own information and the second one is to relay the information bits of other user. In first frame *U1* at frequency f_1 and *U2* at frequency f_2 transmit their own information to each other and destination (*D*) and ind second time interval *U2* transmits *U1*'s information and *U1* transmits *U2*'s information to *D*. Hence *D* receives two signals from each user, i.e. one through the direct path and one through the other user.

	Frame 1	Frame 1
$At\ f_1$	$U1 \rightarrow U2,D$	$U1 \rightarrow D$
$At\ f_2$	$U2 \rightarrow U1,D$	$U2 \rightarrow D$

Table 3. Hybrid FDMA-TDMA based Transmission Protocols

3.4.3. OFDM-based Cooperative Protocol

OFDM-based cooperative protocol is based on the incremental relaying protocol, In which other users relay the information for the other user only in the case of direct path failure (Siriwongpairat et al., 2008). The protocol consists of two phases:

Phase 1: Each user transmits its packet to the destination and relay.The destination estimates the channel from the received signal using OFDM pilot symbols. Destination broadcasts the indices of the subcarriers of the symbols having SNR less than threshold value. This feedback will enable relay to forward these source information.

Phase 2: The relay decodes the source symbols that are unsuccessfully received by the destination and forwards it to the destination.

4. Best Relay Selection

In multiple relay networks, the 'best' relay selection depends on the source-relay (*S*−*R*) and Relay-destination *(R*−*D*) paths.

4.1 SNR-based Selection

The relay is selected by comparing the equivalent SNR (γ) value of 2-hop links from source to destination through relays (Adinoyi et al., 2008). This is expressed as

$$\gamma = \max_r \min(\gamma_{sr}, \gamma_{rd})$$

where γ_{sr} and γ_{rd} are the instantaneous SNRs of the $S \rightarrow R$ and $R \rightarrow D$ links respectively. The final equivalent SNR taken at the destination, is the minimum SNR of $S \rightarrow R$ and $R \rightarrow D$ links. Elfituri et al. proposed antenna/relay selection for coded cooperative system in DF mode with single source, a multiple-antenna relay and single destination (Elfituri et al., 2008). The relay has n_R number of antennas and selects the signal with the largest SNR from these n_R signals. The analytical results show that the scheme proposed in (Elfituri et al., 2008) obtains full diversity. With the antenna selection the DF mode can be used even if the relay is far away from the source.

4.2 Channel Power-based Selection

The channel characteristics-based selection is the simplest scheme for the 'best' relay selection. Gunawardena and Rajatheva proposed a scheme where the relay is selected, having the maximum h_{sr} (source-relay channel gain) (Gunawardena & Rajatheva, 2008). However the destination can also pick the relay with the highest channel gain between relay and destination (Beres and Adve, 2008). Bletsas et al. considered both the channels i.e. from source to relay (h_{sr}) and relay to destination (h_{rd}) (Bletsas et al., 2006), as both channels are very important to the end to end performance. The relay i is selected as 'best' relay using the following criteria (Beres & Adve, 2008; Gunawardena and Rajatheva, 2008):

$$h_i = \min\left(|h_{sr}|^2, |h_{rd}|^2\right)$$

Madan et al. proposed a scheme for selecting a subset of relays in multi relay communication. Here, the source first broadcasts the single message to relays and destination. The relays that receive the data with specific high SNR can forward the message to the destination. These initially selected relays send the training sequence to the destination. The destination estimates the channel state and selects the number of relays for the communication by giving feedback to those selected nodes (Madan et al., 2008; Luo et al., 2007).

4.3 Best Expectation Scheme

In this scheme a set of relays is selected that minimizes the expected value of total transmission time as given below (Nam et al., 2008):

$$\begin{aligned}\tilde{T} &= T_L + E\{T_C\} \\ &= \frac{D}{\min_{i\in A} C_{si} W} + E\left\{\frac{D}{C_{sAd} W}\right\}\end{aligned} \tag{5}$$

where, $\tilde{T}$ is expected value of total transmission time, T_L is the time required for the worst relay in the selected set to decode the data, T_C is the cooperative transmission time, D is the total data bits to be transmitted to the destination, W is the available bandwidth, C_{sd} is the channel capacity between source and destination and C_{sAd} is the channel capacity between the cooperating group (the source and the selected relays) and the destination. These channel capacities are given below:

$$C_{si} = \log_2\left(1 + \frac{P\,|\,h_{si}\,|^2}{\sigma^2}\right)$$

$$C_{sAi} = \log_2\left(1 + \frac{P}{\sigma^2}\mathbf{H}_{sAd}^H \mathbf{H}_{sAd}\right)$$

where P is average available power at transmitter, σ^2 is the variance of white Gaussian noise at receiver and $\mathbf{H}_{sAd}$ is the channel matrix between cooperating group and the destination, given as:

$$\mathbf{H}_{sAd} = \left[h_{sd}\ h_{i_1 d}\ h_{i_2 d}\ \cdots\ h_{i_k d}\right]^T$$

where subscript indices $i_1, i_2, \cdots, i_k$ denote the relays in a selected set (A). The optimal set of selected relay (A^*) can be written as (Nam et al., 2008):

$$A^* = \arg\min_{A\subset R}\left(\frac{1}{\min_{i\in A} C_{si}} + E\left\{\frac{1}{C_{sAd}}\right\}\right)$$

where the total amount of data and available bandwidth is normalized as $\frac{D}{W}$.

4.4 Best-m Scheme

In this scheme the optimal number of m relays are selected in order to minimize the expected total transmission time as given as (Nam et al., 2008):

$$A_m = \arg \min_{|A|=m, A \subset R} \left(\frac{1}{\min_{i \in A} C_{si}} + E\left\{ \frac{1}{C_{sAd}} \right\} \right) = \arg \min_{|A|=m, A \subset R} \left(\frac{1}{\min_{i \in A} C_{si}} \right) \quad (6)$$

The optimal number of relays m^* is given as:

$$m^* = \arg \min_{m \in R} E\left\{ \tilde{T}_m \right\}$$

Transmission time $\tilde{T}$ given in equation (4) and the expectation is taken over the distribution of the source-to-relays channels.

4.5 Fuzzy Logic based Relay Selection

Kaiser et. al. proposed a relay selection scheme based on fuzzy for 2- hop cooperative systems. The algorithm gets effective SNR (signal to noise ratio), and total time delay of the link (propagation delay and processing delay at relay) as inputs to fuzzy based controller placed at the base station (BS) as shown in Figure 4 (Kaiser et. al., 2009). It is shown that the proposed algorithm performs better than the traditional relay search algorithm reported in different research paper.

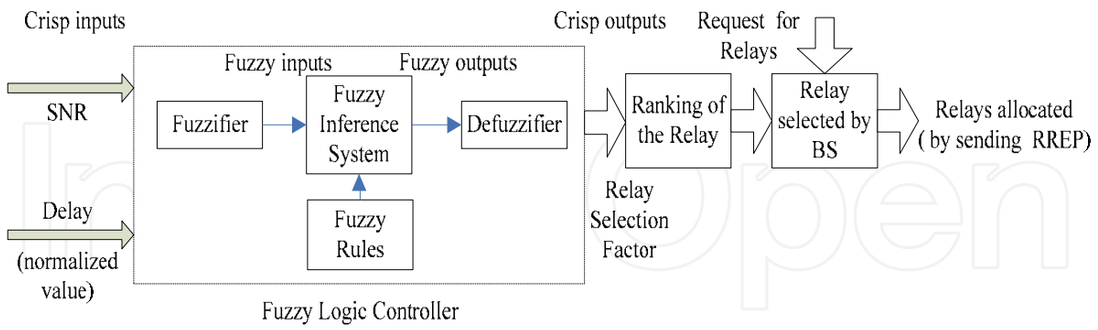


Fig. 4. Fuzzy Logic Controller for Relay Selection

The procedure of the proposed selection scheme is as follows:

Step1: At every wireless link SNR is measured periodically. If the SNR of any link is less than some threshold value, then this wireless link or the relay is not selected.

Step 2: The links between the BS and the relays are established proactively. Routes from the base station to the relay are established through the relays having SNR greater than threshold value.

Step 3: The source also select relay(s) reactively. First, the source floods the relay request (RREQ) packets. Those relay stations having SNR (SNR_i) greater than threshold value and delay time (t_i) less than some threshold, forward the received packet to the BS. BS measures the Relay selection factor, RSF, (m_i) of the each selected relay, given as:

$$m_i = nor(SNR_i) - nor(t_i)$$

Step 4: The BS sorts the relays by descending order and select at number of relays based required SER value.

The membership function represents linguistic fuzzy sets and is used to relate a grade to each linguistic term. This preprocessing of membership functions decreases the number of values to be processed. The membership functions ($G((\gamma), G(t_i))$) used to represent the fuzzy parameters are shown in Figure 5. The values of fuzzy variables assigned depend on the value of m_i .

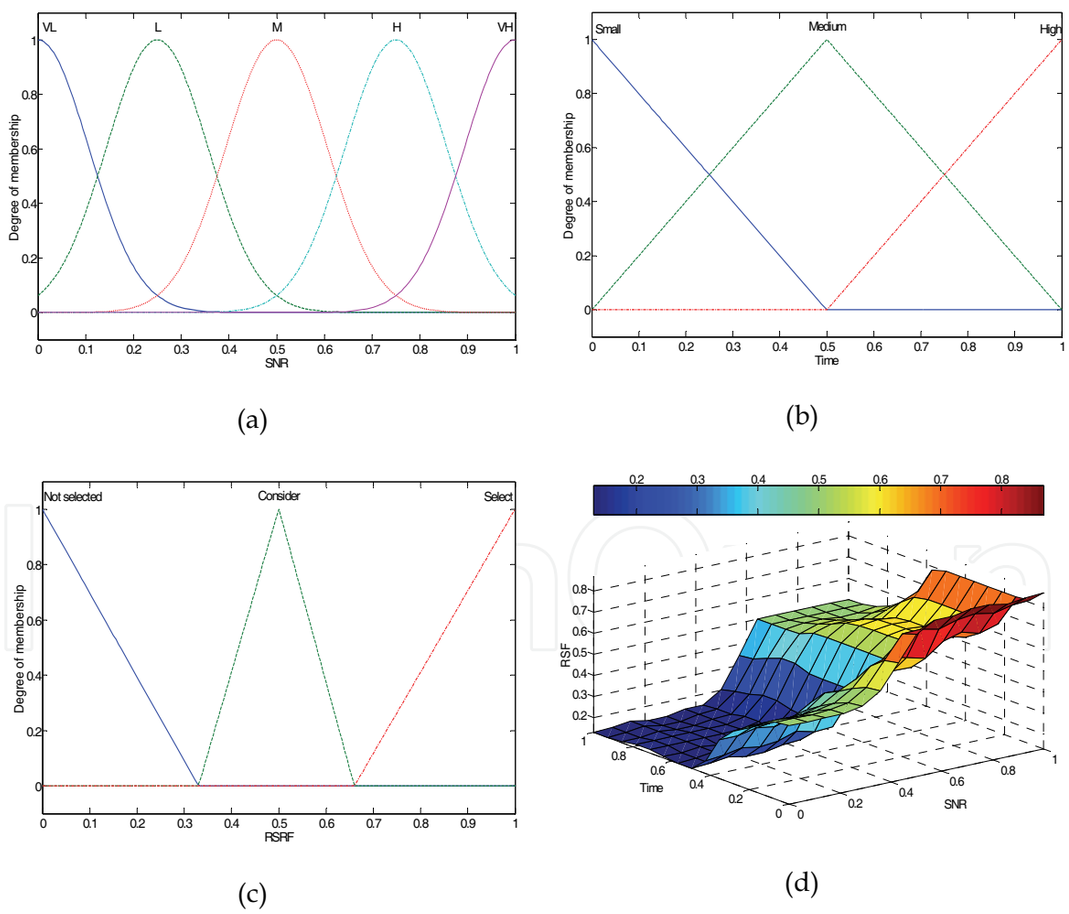


Fig. 5. Membership functions. (a) Membership function for SNR (b) Membership function for Delay (c) Membership function for RSF (d) Surface graph for the rule base system.

5. Coded Cooperation

In coded cooperation, each user's codeword is sending by means of two independent fading paths. The basic inspiration behind coded cooperation (Hunter & Nosratinia, 2002) is that each user tries to transmit incremental redundancy for his partner. If cooperation is not feasible, the users automatically relapse to a non-cooperative mode. The key to the effectiveness of coded cooperation is that, all the system is controlled automatically by code design, and there is no requirement for feedback between users. The users divide their source data into chunks that are improved with a cyclic redundancy check (CRC) code (Wicker, 1995), such that there are a total of X bits per source chunk (including the CRC bits). Each chunk is then encoded with an error correcting code so that, for an overall rate R code, the entire code bits per source chunk will be $T = X / R$. The two users cooperate by dividing the transmission of their T-bit code words into two consecutive time frames. In the first time frame, each user transmits a rate $R_1 > R$ codeword with $T_1 = X / R_1$ bits. This large rate code can be attaining by puncturing the original codeword. Each user receives his partner's first frame information and decodes it. If the user effectively decodes the partner's rate R_1 codeword, the user calculates and transmits additional parity bits T_2 for the partner's data in the second time frame. On the other hand, if a user productively decodes the partner's information but not vice versa, both users will transmit the partner's information bits in the second time frame. These bits are optimally pooled at the destination proceeding to decoding. The destination requests to know whose bits each user is transmitting in the second timeframe. An easy way out is that the destination can simply decode the information according to each of the options in sequence until successful decoding. This approach sustains the overall system performance and the rate at the cost of some additional complexity at the base station (Hunter & Nosratinia, 2002).

5.1. Bit-Interleaved Coded Modulation

Bit interleaving is the procedure performed to make the communication systems more robust against a burst error in order separate out the correlation of the channel.
In 1992, Zehavi documented that the code performance and code diversity could be further improved over the Rayleigh fading channel (Zehavi, 1992). According to the Zehavi's idea to make the code diversity equal to smallest number of distinct bits along any error event rather than symbols. This can be done by introducing the bit-wise interleaving at the output of encoder and using an appropriate soft- decision bit metric as an input to the viterbi decoder as shown in the Figure 6.

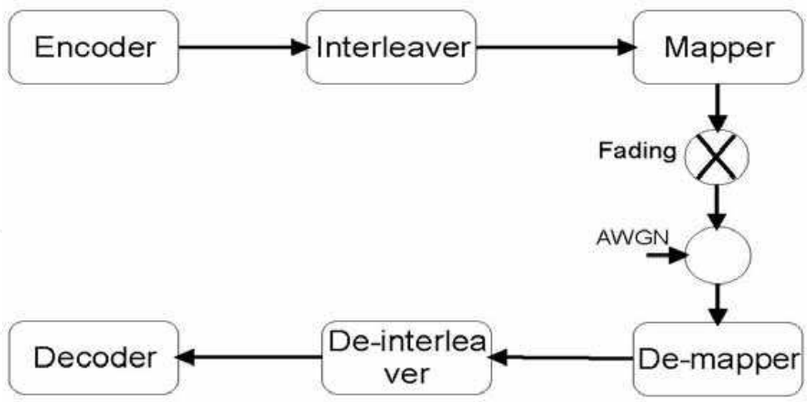


Fig. 6. BICM system

The conventional interleaving was based on symbol; therefore the diversity order was not so good because it depends upon the smallest number of different channel symbols between any two possible sequences of the coded sequences. This issue is resolved by introducing the bit interleaving to enhance the diversity order to the Hamming distance of the code (Zehavi, 1992). Lin and Costello also proved in their book Error control coding that convolutional codes are optimal with the best free Hamming distances and the increased diversity reflects in the better Bit error rate (BER) curve. One of the other important edge of BICM is to separate the single entity of coding and modulation as in TCM. By separating these entities, it becomes more flexible in designing and implementation. On the other hand there was an issue of reduced Euclidean distance in BICM due to random modulation. This caused performance degradation over TCM for AWGN channel. This issue was resolved by Li and Ritcey in 1997 and proved that the performance of the BICM can be improved by iterative decoding (ID) using hard decision feedback (Li & Ritcey, 1997). In this approach, the BICM-ID converts a 2M-ary signaling channel to M parallel binary channels. By doing this, a large binary hamming distance between coded bits can be indirectly translated into a large euclidean distance with proper bit coding. So, this result in high diversity order and large free euclidean distance and effectively combing powerful codes with bandwidth-efficient modulation and it is proved by that BICM-ID improves BICM by more than 1dB for both channel types (Li & Ritcey, 1999). Therefore, with this improvement BICM-ID can compete with TCM in any channel scenario, either it is AWGN channels or fading channels.

5.2. Coding schemes for cooperative network:

Several coding schemes are proposed to implement DF by different combination of BICM with LDPC, TCM and STBC.

5.2.1. LDPC with Interleaving

The practical low SNR coding scheme based on low density parity check (LDPC) codes proposed for the execution of DF scheme (Razaghi & Yu, 2007). So, the main purpose was to advise DF scheme with a high SNR by the combination of BICM and LDPC. In this scheme, the conventional LDPC code is used to encode the information bit and this LDPC

codeword is then interleaved and mapped to a sequence of Quadrature amplitude modulation (QAM) constellation symbols by using gray labeling. The relays decode this source codeword and append some extra parity bits with it, which are graphically represented by check node. The source codeword is modified by adding the second layer of check node to it, so, the codes are now called Bi-layer LDPC code. The destination first decode the relay generated extra parity bits and then source codeword over the bi-layer LDPC graph.

Tanoli et al. proposed a BICM-based cooperative network and analyze the performance of the system over Rayleigh fading channels (Tanoli et. al., 2009). Razaghi et al. demonstrates that bi-layer LDPC-BICM scheme can approach to the theoretical DF rate, at a bit error rate of 10^{-4} and with the gap of 0.5dB in the high SNR regime (Razaghi et al., 2007). The concept of BICM and LDPC codes for DF is also used by Kramer in 2005 (Kramer, 2005), where he gave an idea to acclimatize the space time coding scheme for half duplex relay channel. According to Kramer, the LDPC codeword is divided into two parts, the first half is transmitted by source, the relay upon decoding the first part of the codeword; transmit the second part, resembling a second antenna. This idea restricts the rate of LDPC code to be less than half, however, bi-layer LDPC scheme efficiently resolved this issue.

5.2.2. TCM with Interleaving

The TCM with Bit interleaving and iterative decoding with hard decision feed back is not only giving the better performance over conventional TCM but it also provide the same framework for TCM over channel with a verity of fading parameters (Li & Ritcey, 1999). As the TCM was proposed by Ungerboeck to combine the convolutional coding and modulation and proved that it can achieved 3dB better than un-coded QPSK without reducing bandwidth efficiency (Ungerboeck, 1987). The main parameters of TCM include signal set expansion, set partitioning labeling and modulation design. Initially, a The TCM design criterion was emphasis on the Euclidean distance between the symbols that it should be maximum in the case of additive white Gaussian noise. Later on, the emphasis of design criteria has been shifted to the large diversity order for fading channels, instead of free Euclidean distance. So, for this purpose bit interleaving was introduced in TCM by Zehavi (Zehavi, 1992).

5.2.3. STBC with bit interleaving

This is always used to be a significant challenge to achieve a reliable communications with high data rate over dynamic fading channels due to multipath reception. For this purpose many techniques have been introduced, among them, the transmit diversity is bandwidth efficient and also overcoming fading. In this approach, multiple antennas are used on the transmitter side for transmission of data to the destination. Tarokh et al. make it more effective by combining the error control coding and multiple transmit antennas and refer to as space time coding (ST) (Tarokh et al., 1998). In the same year Alamouti proposed space time block codes (STBC) which were simple and elegant (Alamouti, 1998). Although BI-ST coded systems can be regarded as special cases of BICM, the performance analysis of BI-ST is not a minor extension of BICM analysis due to the more complex structures of the space-time codes. Later on, for iteratively decoded BI-STCM, it is also proved that for correlated fading channels, the Bit error rate reaches in six iterations to the

theoretical error free feedback bound (EF bound) in the range of 7−8 dB for one receive antenna (Shahid & Rajatheva, 2008).

6. OFDMA Cooperative Networks

In (Kwak & Cioffi, 2007), an OFDMA multi-hop relaying downlink system of K users, Nr relay stations, the number of downlink subchannels is N and considering all terminals with single antenna. In (Poruahmadi et al., 2006), linear programming problem was developed for the subchannel-allocation in an OFDMA based multi-hop relaying system. Here the power optimization was not discussed, only subchannel reuse is discussed. Kwak and Cioffi proposed an algorithm for the resource allocation to maximize the sum-rate in OFDMA-based multi-hop relaying downlink systems (Kwak & Cioffi, 2007). The solution to this problem is the modified water-filling algorithm. From the simulation results it is seen that the multi-hop OFDMA relaying systems performance are much better than conventional OFDMA. The downlink frame structure is shown in Figure 7. Subchannel set B_0 of subframe 1 is used for the transmission between the BS and the users and subchannel set B_j $(1 \le j \le N_r)$ in subframe 1 is for the transmission between BS and j-th relay. In the same way, the subchannel set S_j $(1 \le j \le N_r)$ in subframe 2 is for the transmission between j-th RS and the users associated this RS. The SNR for subchannel i in subframe k is given by:

$$c_k(i) = \frac{|h_k(i)|^2}{\sigma_k^2(i)}$$

where $h_k(i)$ is the subchannel gain and $\sigma_k^2(i)$ is the variance of Gaussian noise. Now the rate for subchannel i in subframe k is given as:

$$r_k(i) = 0.5 \log_2 \left(1 + P_k(i) c_k(i)\right)$$

where $P_k(i)$ is the power for subchannel i in subframe k. In multi hop scenario, the total data rates of user assigned to j-th relay is

$$r_j = \min\left(\sum_{i_1 \in B_j} r_1(i_1), \sum_{i_2 \in S_j} r_2(i_2) \right)$$

where i_1 and i_2 denote subchannel i in subframe 1 and 2 respectively.

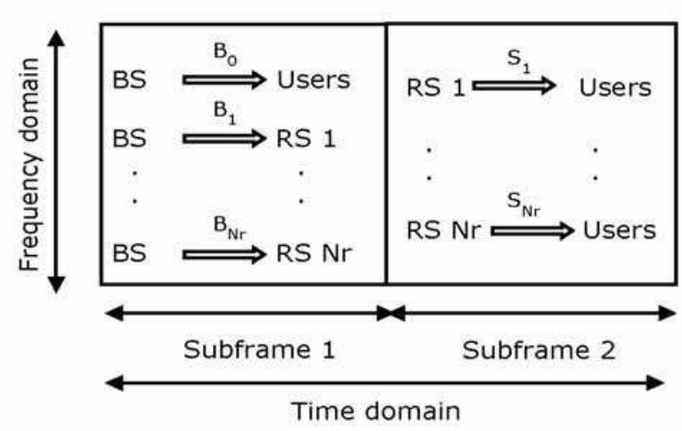


Fig. 7. OFDMA frame structure

7. Other Applications

A lot of interdisciplinary research activities are going on using the cooperation techniques. Most of theses activities target some dedicated application area. This section presents an overview of such activities.

7.1 Health Care

In (Chaczko et al., 2008) a wireless sensor networks (WSN) based solution for homecare applications is presented. The WSN are used to provide cooperation between the patients and the devices used for long-term treatments. The smart sensors network is used to assist health care workers and their patients in their daily routine.

Another study related to health care involves the computer supported cooperative work (CSCW) in a distributed environment (Ganguly & Ray, 2000). In this study the focus is on the provision of an middle ware which acts as a cooperative link (layer) between the heterogeneous platforms and the health care applications.

7.2 Vehicular

Inter-vehicular communication is emerged to be a very popular domain for providing safety to drivers. Mobile ad hoc networks (MANETs) are usually a promising solution for exchanging the information locally among the vehicles. In (Tian et al., 2003) the spatial environment and geographic distribution of the vehicles are taken into account for routing the information in MANETs. The network nodes (i.e., vehicles) generate a graph based special model with the cooperation of other network nodes, to identify topology holes. The source node then selects a route which avoids these holes during packet routing.

The project FleetNet (Enkelmann, 2003) provides Internet facility on roads. It's a German project which mainly focuses on inter-vehicular communications for providing cooperative driver-assistance, sharing of information and utilizing Internet resources. The nodes in FleetNet project are forming a position-aware MANET. The cooperation is done by using stationary gateways which allow drivers to share information among them and

access Internet. The communications protocol developed under FleetNet are used on any existing radio communications network.
Another study focus on the position-aware information for inter-vehicular communication is (Kato et al., 2008). The study focuses on the urgent communications of messages for relaying critical information and to provide support to cooperative driving. The vehicles are relatively addressed based on their lanes and hence, leading to a safe intelligent transportation system (ITS).
A study on railway system is conducted in (Wang et al., 2003). In this the railway geographical system for China is used. The work focuses on the use of component mode platform in conjunction with distributed cooperative heterogeneous structure of data and applications. A middleware known as "Information Share Platform" is added to communicate basic system information with the application component platform, hence leading to a cooperative railway system.

7.3 Emergency / Disasters

In the last decade, occurrence of frequent natural and / or manmade disasters has brought the researchers to the work for emergency communications. In (Majid & Ahmed, 2008a), a cooperative cognitive agent approach for post-disaster communications is discussed. Study discusses the birth-death process of agents which possess the cognition properties. A cooperative communication mechanism among the agents to relay information regarding disaster victims is also presented in study.
Cooperative deployment of IEEE 802.22 wireless regional area network (WRAN) groups is proposed in (Majid & Ahmed, 2008b). In this study the IEEE 802.22 WRAN concept is used to provide cooperative communication among different organizations involved in disaster response activities. Different organizations such as TV broadcast, rescue teams, NGOs etc. are deploying their own networks (i.e., WRAN groups) in the disaster affected areas. A mechanism to relay information from one WRAN group to another is elaborated in the study. This cooperative relay of information provides cost-effective and efficient communications in emergency situations.
Another study in (Majid & Ahmed, 2009a) uses the mobile handsets (MS) as the sensing nodes for emergency situations. The MS nodes communicate among them in a cooperative manner to identify the true emergency situation. The MS nodes are then used to build a hierarchical network among the disaster victims. Transfer of information from one layer to another layer of the proposed network scheme is via a cognitive radio cloud (CRC). This CRC helps in the cooperative identification of spectrum holes for the successful communication of information. Moreover, in (Majid& Ahmed, 2009b) a cooperative serial switch model is proposed. The proposed model assists the presented MAC protocol to perform successfully. The study further discusses the concept of hybrid disaster response network (DRN). The hybrid DRN is used to communicate critical information to the centralized network via a cooperative relay node.

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Edited by Maurizio A Strangio

ISBN 978-953-307-017-9

Hard cover, 636 pages

Publisher InTech

Published online 01, November, 2009

Published in print edition November, 2009

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How to reference

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Imran Khan, Shujaat Ali Khan Tanoli and Nandana Rajatheva (2009). Cooperative Networks, Recent Advances in Technologies, Maurizio A Strangio (Ed.), ISBN: 978-953-307-017-9, InTech, Available from: http://www.intechopen.com/books/recent-advances-in-technologies/cooperative-networks

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