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Implementation of Co-Operative Communication Protocol

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Abstract

In a wireless transmission the signal quality suffers severely from bad channel quality due to effects like fading caused by multi-path propagation. To reduce such effects diversity can be used thereby increasing the network capacity and coverage. In this paper we study and simulate the transmission protocols such as Amplify and Forward, Decode and Forward and Coded Cooperation. Cooperative communication refers to processing of this overheard information at the surrounding nodes and retransmission towards the destination to create spatial diversity, thereby to obtain higher throughput and reliability.

Keywords

Fading, diversity, co-operative transmission, Convolutional Codes, Multi Hop, Amplify and Forward, Decode and Forward, Coded Cooperation, Magic Genie.

1. Introduction

Transmission over wireless channel suffers from random fluctuation in signal level known as fading. One of the powerful techniques to mitigate fading is diversity. Using diversity technique the transmitter sends more than one copy of the transmitted message so the receiver can use these multiple copies to detect the sent message correctly. Since it might be difficult to provide more than one antenna in wireless devices due to small terminal size and other factors, other ways of realizing diversity have been introduced. Different samples of the same signal are transferred over essentially independent channels. In the absence of a clear line of sight (LOS) between transmitter and receiver, the signal is reflected along multiple paths before finally being received. Each of these bounces can introduce phase shifts, time delays, attenuations, and even distortions that can interfere with one another at the aperture of the receiving antenna. Antenna diversity is especially effective at improving these multipath situations. It is one in a superset of wireless diversity schemes that utilizes two or more antennas to improve the quality and reliability of a wireless link.

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Here, project diversity is realized by using a third station as a relay. In such a system combinations of several relaying protocols and methods are examined to see their effects on the performance. The transmission protocols used are Amplify and Forward, Decode and Forward and Coded Cooperation.

2. Single link transmission

2.1Signal Model and Modulation

The transferred data is a random bipolar bit sequence which is either modulated with [1] Binary Phase Shift Keying (BPSK) or Quadrature Phase Shift Keying (QPSK). As illustrated in Figure 1, QPSK in fact consists of two independent (orthogonal) BPSK systems and therefore has double bandwidth compared to BPSK.

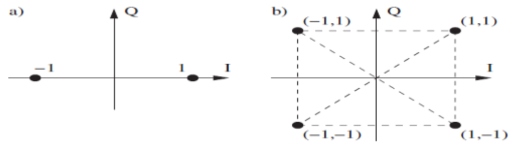

Figure 1: a) BPSK, b) QPSK, I denotes the in phase channel and Q is the quadrature channel. (Source: Theodore S.Rappaport)

2.2Channel Model

In a wireless network, the data which is transferred from a sender to a receiver has to propagate through the air. During propagation several phenomena will distort the signal. In this project thermal noise, path loss and Rayleigh fading are considered, as illustrated in Figure 2, path loss and fading are multiplicative, noise is additive. [2], [3]

$y_d[n] = h_{s,d}[n] \cdot x_s[n] + z_{s,d}[n] = d_{s,d} \cdot a_{s,d}[n]$

attenuation *path loss* *fading*

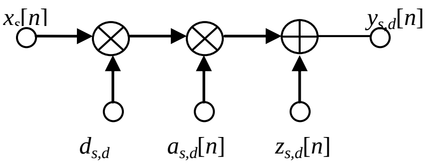

Figure 2: Channel model: path loss ds, d fading as, d[n] and noise zs, d[n]. (Source: www.edaboard.com)

2.2.1Noise

The main sources of noise in a wireless network are interference and electronic components like amplifiers. If the latter dominates, thermal noise can be assumed, which can be characterized as additive complex Gaussian noise. The scalar $z_{s,d}[n]$ can then be simulated as the sum of a real and an imaginary noise vector, both Gaussians distributed, mutually independent and zero mean with variance σ_n^2. The total noise power will be $N0 = 2\sigma_n^2$.

2.2.2Signal to Noise Ratio

The *signal-to-noise ratio* (SNR) is a widely used value to indicate the signal quality at the destination. [4], [5]

$$\text{SNR}=\left(\frac{S}{N_0}\right)=\frac{|h_{s,r}|^2.\xi}{N_0}$$

(2.2)

In (2.2) $\xi = E[|x_s|^2]$ denotes the energy of the transmitted signal and N_0 the total power of the noise.

2.2.3Path Loss and Fading

The signal is attenuated mainly by the effects of free-space path loss and fading, both included in $h_{s,d} = d_{s,d} \,.\, a_{s,d}$ [4]. The path loss $d_{s,d}$ (assuming a plane-earth model) is proportional to $1/R^2$ .As long as the distance between the sender and receiver does not change too much, it can be assumed to be constant for the whole transmission. The power of the received signal is attenuated proportional to $1/R^4$ .In a wireless network it occurs quite often that the line-of-sight link is blocked. Instead of this direct connection, the signal will propagate to the sender on many different ways. This occurs especially in an urban environment, where buildings prevent a line-of-sight link but enable various different ways for indirect connection by reflecting the propagating signal. This effect is referred to as *multi-path* propagation. Only small changes in the whole system might change the characteristic of the channel and therefore the signal quality considerably. This effect, known as fading, will alter the signal by attenuating it and adding a phase shift to it. The *fading* coefficient $a_{s,d}$ can be modeled as a zero mean, complex Gaussian random variable with variances $\sigma^2_{s,d}$ This means that the angle $\measuredangle a_{s,d}$ is uniformly distributed on $[0;\ 2\pi)$ and the magnitude $|a_{s,d}|$ is Rayleigh distributed. This Rayleigh distributed magnitude can have a bad effect on the signal quality at the receiver. Even a system with a high SNR might experience significant errors due to fading.

2.2.4Receiver Model

The receiver detects the received signal symbol by symbol. In the case of a BPSK modulated signal the symbol/bit is detected as

$$\hat{y}_d[n] = \begin{cases} +1(\text{Re}\{y_d[n]\} \geq 0) \\ -1(\text{Re}\{y_d[n]\} < 0) \end{cases}$$

(2.3)

For a QPSK modulated signal there are two bits transferred per symbol, which are detected as

$$\hat{y}_d[n] = \begin{cases} [+1,-1](0° \leq \angle y_d[n] < 90°) \\ [-1,+1](90° \leq \angle y_d[n] < 180°) \\ [+1,-1](-90° \leq \angle y_d[n] < 0°) \\ [-1,-1](-180° \leq y_d[n] < -90°) \end{cases}$$

(2.4)

2.2.5BER of a Single Link Transmission

The signal quality received at the destination depends on the SNR of the channel and the way the signal is modulated.

Table 2.1:Theoretical BER for a single link transmission $\bar{\gamma}_b$ denote average signal-to-noise ratio, defined as $\bar{\gamma}_b = \frac{\xi}{2\sigma^2}E(a^2)$,where $E(a^2)=a^2$.

Modulation Type	No Fading	Rayleigh Fading
BPSK	$P_b = Q(\sqrt{\frac{\xi}{\sigma^2}})$	$P_b = \frac{1}{2}\left(1-\sqrt{\frac{\bar{\gamma}_b}{1+\bar{\gamma}_b}}\right)$
QPSK	$P_b = Q(\sqrt{\frac{\xi}{2\sigma^2}})$	$P_b = \frac{1}{2}\left(1-\sqrt{\frac{\bar{\gamma}_b}{2+\bar{\gamma}_b}}\right)$

Fading is considered as the most important factor when describing the channel and predicting system performance for most practical wireless communication channels. This section addresses fading causes and fading types.

Fading refers to the time variation of received signal power due to change in transmission medium or paths. Fading in mobile environment is the most challenging technical problems facing communication system engineers.

3. Types of Fading

3.1 Types

Fading [3],[4] can be classified from time variant view point into fast fading and slow fading, and from time spreading view point into selective fading and flat (nonselective) fading.

3.1.1 Slow Fading

The average signal power attenuation or path loss due to moving over large or long distance area represents the Slow fading[3] [6]. As the environment changes over long distance, slow fading is affected by hills, forests, clumps of buildings, etc. that exists between transmitter and receiver. A channel introduces a slow fading when the signal correlation time of the signal is longer than the symbol transmission time.

3.1.2 Fast Fading

The rapid changes in signal power and phase that occur due to small movement over distance of about half wavelength refer to fast fading. A channel introduces fast fading when the coherence time of the signal is shorter than the symbol duration time. Therefore fading character of the channel can change many times during the same symbol.

3.1.3 Selective Fading

A channel experiences selective fading [6] when the received multipath component of a symbol extends beyond the symbol time duration. In selective fading the coherent bandwidth of the channel is smaller than the bandwidth of the signal, which make some of the signal's spectral component falling outside the coherent bandwidth, hence all signal's spectral components are not equally affected by the channel.

3.1.4 Flat Fading

Flat [3], [6] or nonselective fading occurs when all received multipath component of a symbol arrive within the symbol time duration. In flat fading coherent bandwidth of the channel is larger than the bandwidth of the signal. Hence all of the signal's spectral component will be affected by the channel in similar manner.

3.2 Fading Channel [8]

When designing a communication system, the communication engineer has to consider all the factors that may affect the propagation of the signal; hence he needs to estimate the effect of multipath fading and noise on mobile channel. Some typical fading channels are introduced below.

3.2.1 Additive White Gaussian Noise (AWGN) Channel

The thermal noise is the only impairment that resists the propagation of transmitted signal. Noise is associated with physical channel itself, as well as the electronics at, or between, transmitter and receiver. In AWGN channel the signal is degraded by white noise which has constant spectral density and a Gaussian distribution of amplitude.

Fixed gain channel is found to have rapid decorrelation which is useful when employing diversity to combat fading. 3.2.2Rayleigh Fading Channel Rayleigh fading occurs when there are multiple indirect paths between transmitter and receiver and no direct non-fading or line-of sight (LOS) path. It represents a worst case scenario for transmission channel. Rayleigh fading assumes a received multipath signal consists of large number of reflected waves with independent and identically distributed phase and amplitude. The envelope of the received signal is statistically described by Rayleigh probability density function (PDF).

3.3 Channel Coding Techniques

Techniques to control the error probability are based on insertion of redundancy into the transmitted sequence so the receiver can detect and possibly correct errors that occur during transmission. The redundancy bits are added by an encoder at transmitter side and will be removed by a decoder at receiver side.

Although the addition of redundancy decreases the bandwidth efficiency, the use of error coding may increase the operational range of communication system, reduce the error rates and reduce the required Eb/N0 for fixed bit error rate. The decrease in the required power for coded system is referred to as coding gain.

With respect to the properties of the set of code words, we distinguish between linear and nonlinear codes. A code is said to be linear if any two code words in the code can be added in modulo-2 arithmetic to produce a third code word in the code. According to how the system makes use of the code capabilities, we now distinguish between error detecting and error correcting codes.

3.3.1 Error Detection Codes

Error detection is used to implement either error monitoring or automatic repeat request (ARQ). In the case of error monitoring, the decoder monitors the quality of the received sequence and supplies it to the user, so that, when the reliability becomes too low, the sequence can be discarded. In the case of ARQ, the transmitter is asked to repeat unsuccessful transmissions.

3.3.2 Error Correction Codes

In forward error correction (FEC), the decoder attempts to restore the correct transmitted sequence whenever errors are detected in the received sequence.

There are many different error correcting codes. These codes have been classified into block codes and convolution codes. The difference between them is that block codes are memory-less.

3.4 Convolutional Codes

Convolutional codes [7] are one of the channel coding techniques which incorporate both error detection and correction. It operates on serial data, one or a few bits at a time. Data sequence is divided into *k* bits message. Each message is encoded into *n* bits code word. The code word depends not only on the corresponding k-bits message but also on previous *m* messages. Hence the encoder has memory of order m.

Convolutional codes are used where message bits come in serially rather than in large blocks. A convolutional encoder operates on the incoming message continuously in a serial manner. Normally convolutional codes are portrayed in graphical forms which take one of three equivalent forms known as code tree, trellis and state diagram.

3.5 Decoding Of Convolutional Codes

In convolutional codes [3], [7] the receiver needs to decode the incoming coded message so as to produce the original transmitted massage. There are two types of decoding: hard decoding and soft decoding.

3.5.1 Hard Decoding

Here the demodulator output is quantized to two levels 0 and 1. The decoder attempts to recover the information sequence by using the code words redundancy for either detecting or correcting the errors that are present at the demodulator output. The receiver use Hamming distance to choose the closest code word to the received word [3].

3.5.2 Soft Decoding

In soft decoding [3] the decoder use non-quantized output of the demodulator. The decoder stores the n outputs corresponding to each sequence of n binary waveforms and builds 2k decision variables. The receiver chooses the transmitted sequence corresponding to the n-bit code word which is closest, in the sense of the Euclidean distance, to the received sequence.

3.6 Diversity

Multiple channels can be used between transmitter and receiver to compensate for error effects. Diversity reception does not completely eliminate errors but reduces the probability of occurrence of errors caused by fading by combining several copies of the same message received over different multiple channels. The independent fading channels are obtained by antenna, site, time, frequency and polarization.

3.6.1 Antenna (Micro) Diversity

Multi array of antennas are used to transmit different copies of the signal and then combine them at receiver to construct the transmitted message. The antennas are located in the same place (e. g. base station tower) and their spacing is of a few wavelengths.

3.6.2 Site (Macro) Diversity

In site diversity the receiving antennas are located in different places so as not only the multipath fading is independent but also the shadowing and path loss will be independent to some extent.[3],[8]

3.6.3 Time Diversity

In time diversity the same message is transmitted many times at different instances of time. For effective time diversity, the time difference should be more than coherent time of the channel. [3], [8]

3.6.4 Frequency Diversity

In frequency diversity more than one copy of the message is transmitted by spreading the signal out over large bandwidth or carried on multiple frequency carriers. To achieve effective diversity using frequency diversity, the carrier frequencies should be separated by more than bandwidth coherence. [8]

3.6.5 Polarization Diversity

Obstacles scatter waves differently depending on polarization. Polarization diversity use a set of cross polarized receiving antennas so that the received waves do not cancel each other. [3]

4. Multi hop

There are several approaches to implement *diversity* in a wireless transmission. Multiple antennas can be used to achieve space and/or frequency diversity. But multiple antennas are not always available or the destination is just too far away to get good signal quality.

To get diversity, an interesting approach might be to build an ad-hoc network using another mobile station as a relay.

The model of such a system is illustrated in Fig. 3. The sender S, sends the data to the destination D, while the relay station R is listening to this transmission. The relay sends this received data burst after processing to the destination as well, where the two received signals are combined**.**

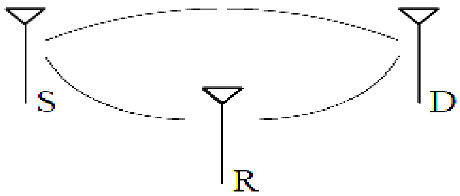

Figure 3: The data is transmitted on one hand directly to the destination, and on the other hand the data is sent to the receiver via the relay. (Source: edaboard.com)

The cooperative transmission protocols used in the relay station are Amplify and Forward (AAF), Decode and Forward (DAF) and Coded Cooperation. [1], [3], [5] these protocols describe how the received data is processed at the relay station before the data is sent to the destination.

4.1 Amplify and Forward

This method is often used when the relay has only limited computing time or power available, or the time delay caused by the relay to decode and encode the message has to be minimized. This protocol is used when an analog signal is transmitted. [1]

The idea behind the AAF protocol [1] is simple. The signal received by the relay was attenuated and needs to be amplified before it can be sent again. In doing so, the noise in the signal is amplified as well, which is the main downfall of this protocol.

The incoming signal is amplified block wise. Assuming that the channel Characteristic can be estimated perfectly, the gain for the amplification can be calculated as follows. The power of the incoming signal is given by:

$$E[|y_r^2|] = E[|h_{s,r}|^2]E[|x_s|^2] + E[|z_{s,r}|^2] = |h_{s,r}|^2 \xi + 2\sigma_{s,r}^2,$$

(4.1)

Where *s* denotes the sender and *r* the relay.

To send the data with the same power that the sender did, the relay has to use a gain of

$$\beta = \sqrt{\frac{\xi}{|h_{s,r}|^2 \xi + 2\sigma_{s,r}^2}}$$

(4.2)

The above term has to be calculated for every block and therefore the channel characteristic of every single block needs to be estimated. Figure 4[1] shows a basic amplify and forward protocol.

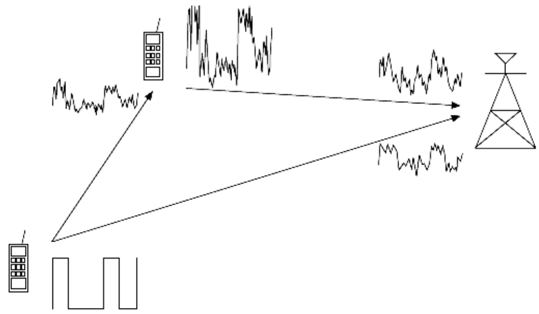

Figure 4: Amplify and forward protocol (source: ref [2])

4.1.1 Decode and Forward

Nowadays, wireless transmission is very seldom analogue and the relay has enough computing power, so DAF[2],[3] is most often the preferred method to process the data in the relay. The received signal is first decoded and then re-encoded. So there is no amplified noise in the sent signal, as is the case using an AAF protocol. There are two main implementations of such a system.

The relay can decode the original message completely. This requires a lot of computing time, but has numerous advantages. If the source message contains an error correcting code, received bit errors might be corrected at the relay station. Or if there is no such code implemented a checksum allows the relay to detect if the received signal contains errors. Depending on the implementation an erroneous message might not be sent to the destination but it is not always possible to fully decode the source message.

The additional delay caused to fully decode and process the message is not acceptable, the relay might not have enough computing capacity or the source message could be coded to protect sensitive data. In such a case, the incoming signal is just decoded and re-encoded symbol by symbol. So neither an error correction can be performed nor a checksum calculated.

Magic Genie

In this thesis, no error correcting code has been implemented. So it is not possible to correct the signal received by the relay. To simulate this scenario, an all knowing *magic genie* is used. The genie, sitting on the relay station, checks every decoded symbol and allows this symbol to be re-encoded and sent if and only if it was correctly detected. This is a much more powerful approach than deciding block wise (up to some hundred symbols) if all symbols in it are correct. The overall performance of a system supported by a magic genie is similar to one using error correction and therefore an error correcting code can be simulated in this way. Figure 5 [2] illustrates Decode and Forward protocol.

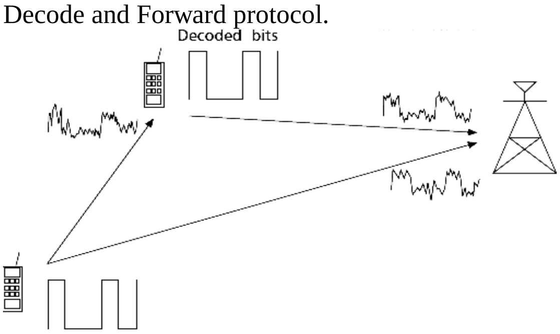

Figure 5: Decode and Forward Protocol (source: ref [2])

4.1.2 Coded Cooperation

In coded cooperation [2], [3] each of the users' data is encoded in code word that's partitioned into two segments. Likewise the data transmission period is divided into two segments. Each user sends its code word via two independent fading paths. The basic idea is that each user tries to transmit incremental redundancy to its partner when that is possible; otherwise the users revert to non-cooperative mode. The key to efficiency of coded cooperation is that all this managed automatically through coded design. The code may be block or convolution or combination of both In addition cooperative relaying can be selective where the partners choose a suitable cooperative or non-cooperative action according to the measured SNR between them. Figure 6 [2] shows the division of data transmission period in coded cooperation.

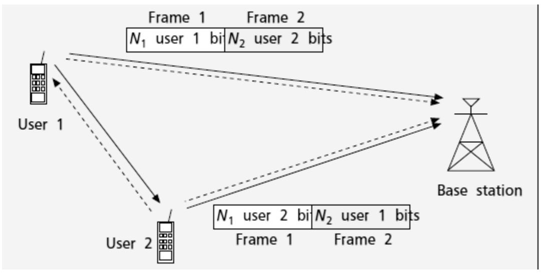

Fig 6: Coded Cooperation (source: ref [2])

4.2 Combining Type

As soon as there is more than one incoming transmission with the same burst of data, the incoming signals have to be combined before they are compared [9].

4.2.1 Equal Ratio Combining (ERC)

If computing time is a crucial point, or the channel quality could not be estimated, all the received signals can just be added up. This is the easiest way to combine the signals, but the performance will not be that good in return.

$$y_d[n] = \sum_{i=1}^{k} y_{i,d}[n]$$

Within this project just one relay station is used so the equation simplifies to

$$y_d[n] = y_{s,d}[n] + y_{r,d}[n], \quad (4.3)$$

Where $y_{s,d}$ denotes the received signal from the sender and $y_{r,d}$ the one from the relay.

4.2.2 Fixed Ratio Combining (FRC)

A much better performance can be achieved, when fixed ratio combining is used. Instead of just adding up the incoming signals, they are weighted with a constant ratio, which will not change a lot during the whole communication. The ratio should represent the average channel quality and therefore should not take account of temporary influences on the channel due to fading or other effects. But influences on the channel, which change the average channel quality, such as the distance between the different stations, should be considered. The ratio will change only gently and therefore needs only a little amount computing time.

The ratio will change only gently and therefore needs only a little amount computing time. The FRC can be expressed as

$$y_d[n] = d_{s,d} \cdot y_{s,d}[n] + d_{s,r,d} \cdot y_{r,d}[n]. \quad (4.4)$$

where $d_{s,d}$ denotes the weight of the direct link and $d_{s,r},d$ the one of the multi-hop link.

4.2.3 Signal to Noise Ratio Combining (SNRC)

A much better performance can be achieved, if the incoming signals are weighted on an intelligent way. An often used value to characterize the quality of a link is the SNR, which can be used to weight the received signals.

4.2.4 Maximum Ratio Combining (MRC)

$$y_d[n] = h^*_{s,d}[n] y_{s,d}[n] + h^*_{r,d}[n] y_{r,d}[n]$$
(4.5)

The *Maximum Ratio Combiner* (MRC) [9] achieves the best possible performance by multiplying each input signal with its corresponding conjugated channel gain. This assumes that the channels' phase shift and attenuation is perfectly known by the receiver.

5. Simulations

In this section the performance of different combinations of the methods described in the last chapter are analyzed to illustrate their potential benefits. It is assumed that the three stations (sender, relay and destination) have an equal distance from each other and therefore the same path loss and average signal-to-noise ratio is assumed. This chapter includes simulation results along with the algorithm of the codes.

The key results include the following:
1. Single link transmission using Rayleigh Fading Channel.
2. Amplify and Forward protocol.
3. Decode and Forward protocol.
4. Coded Cooperation.
5. A graph comparing all the three protocols.

5.1 Single Link Transmission with Rayleigh Fading Channel

The severe effect of fading in a single link transmission with Rayleigh channel is shown Figure 7.

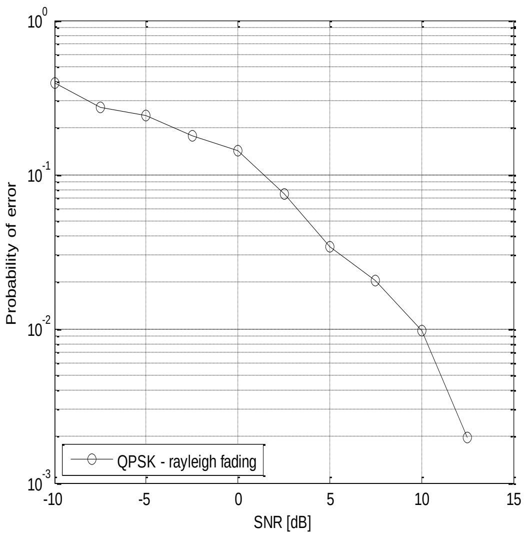

Figure 7: Fading in a single link transmission

5.2 Amplify and Forward

This is an equidistant arrangement, where the signal over the multi hop arrangement has to propagate over twice the distance than over the direct link. The transferred signal in an AAF system contains some information that allows correcting of a small difference in the channel quality.

The result of the simulation illustrated in Figure. 9 show the performance using ERC (Equal Ratio Combining) in Amplify and Forward protocol.

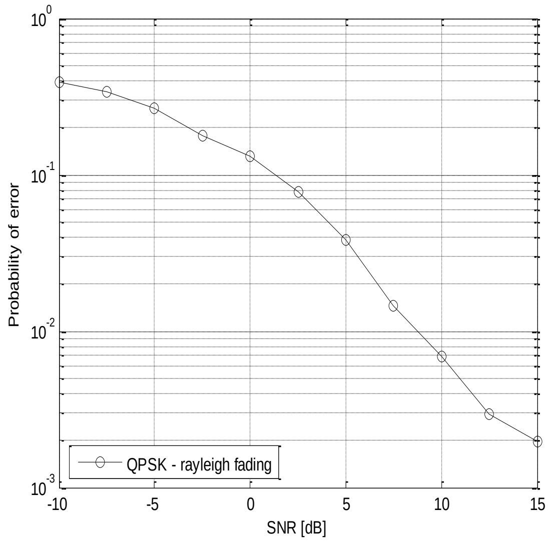

Figure 8: Performance of Amplify and Forward protocol with ERC

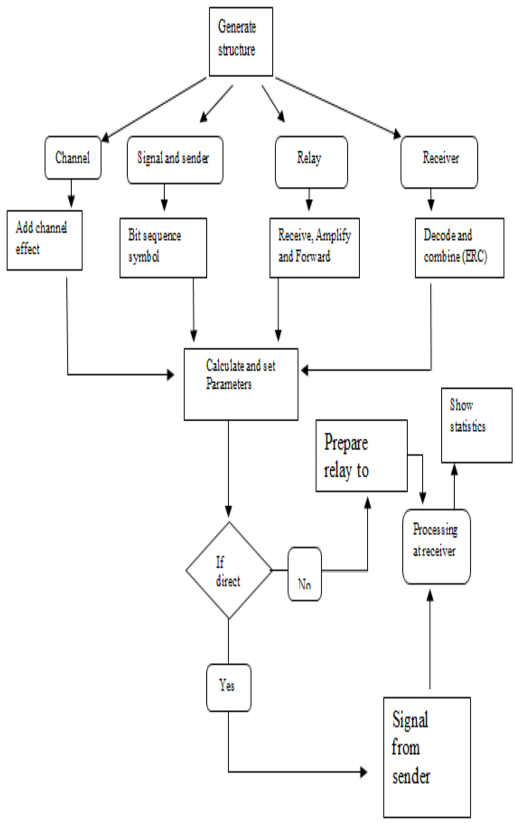

Figure 9: Algorithm for Matlab simulation of Amplify and Forward

5.3 Decode and Forward

The result of the simulation illustrated in Figure. 10 show the performance using ERC (Equal Ratio Combining) in Decode and Forward protocol.

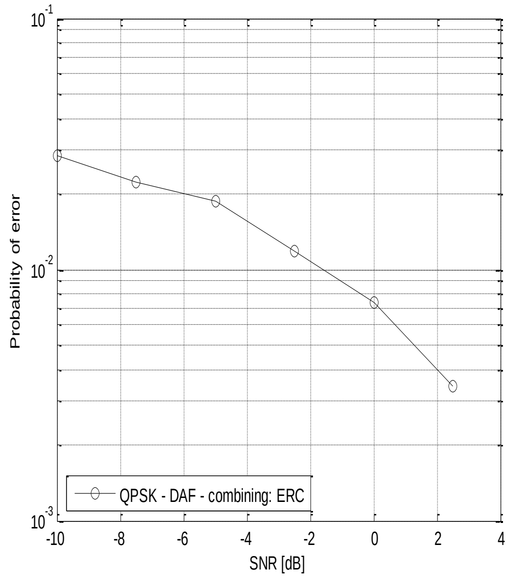

Figure 10: Performance of Decode and Forward Protocol

The algorithm involved to create the code for this protocol is being shown in figure 11.

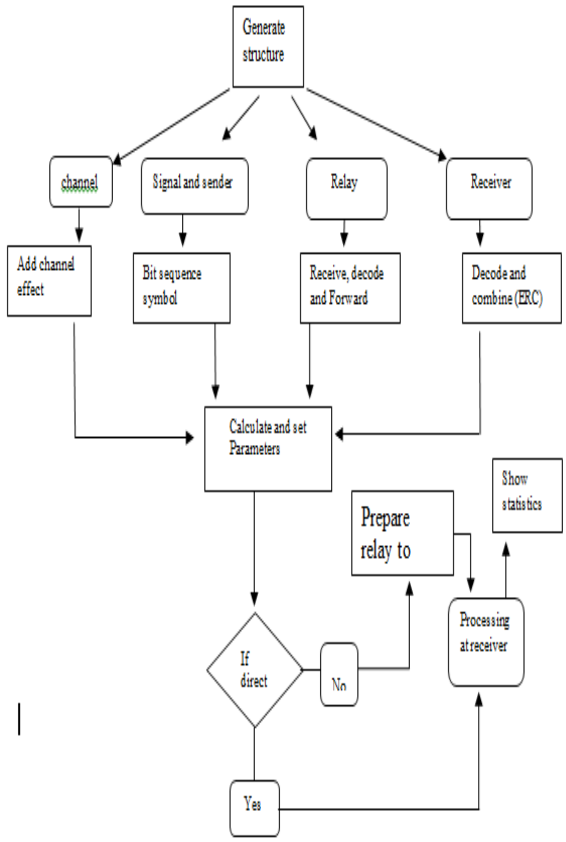

Figure 11: Algorithm for Decode and Forward Protocol

5.4 Coded Cooperation

For coded cooperation, a cooperation level of 25 percent is used. The two users transmit a code word punctured to rate 1/3 in the first frame. In the second frame, the relay transmits the bits punctured from the first frame such that the total bits received for each user form a rate 1/4 code word. Figure 12 shows the performance of coded cooperation at different SNR values.

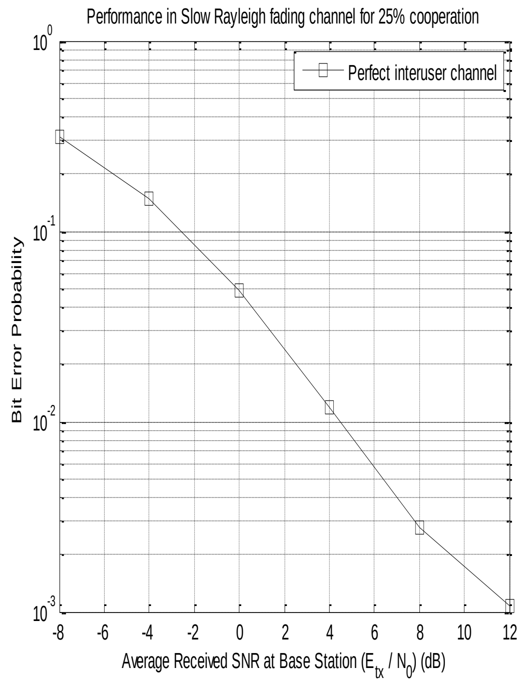

Figure 12: Performance of coded cooperation

The algorithm for coded cooperation is given in figure 13.

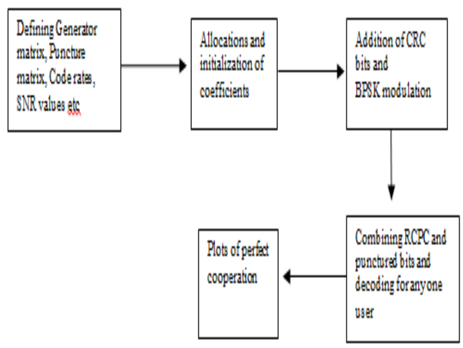

Figure 13: Algorithm for coded Cooperation

5.5 Comparison of the Three Protocols

The comparison shows that out of the three protocols, coded cooperation has the least probability of error for a given BER value .The

maximum probability of error is observed in amplify and forward protocol.
Figure 13 shows the comparison of all the three protocols.

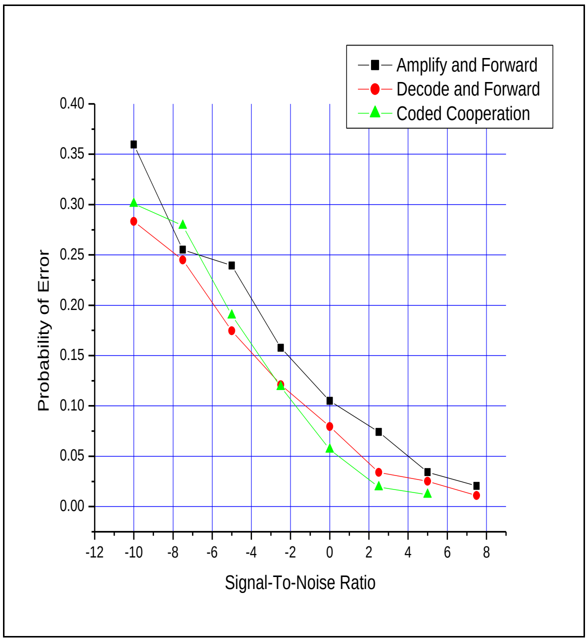

Figure 14: Comparison of the protocols

6. Conclusion

This paper has analyzed and compared the three basic protocols of Cooperative Communication, but there are a few other issues to be addressed in this field. One of which is Allocation of Partners to a particular user in a multi user network.

This can be done by communicating with a central base station, which requires a centralized mechanism. Assuming that the base station has some knowledge of all channels between the users, partners could be assigned to optimize a given performance criterion such as Block Error Rates for all users.

In a few systems which do not have a centralized system (like ad-hoc networks and sensor networks), a distributed protocol is used. Here, all the users can independently decide with whom to cooperate at a given time. Therefore, there is need to develop a Centralized protocol and a Distributed protocol as required.

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