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Comparison of different Combining methods and Relaying Techniques in Cooperative Diversity

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Abstract

An ad-hoc network with a sender, a destination and a third station act-ing as a relay is analyzed. The channels are modeled containing thermal noise, Rayleigh fading and path loss. Different combining methods and diversity protocols are compared. The amplify and forward protocol shows a better performance than the decode and forward protocol, unless an error correcting code is simulated. To combine the incoming signals the channel quality should be estimated as well as possible. Information about the average quality shows nice benefits, and a rough approximation about the variation of the channel quality increases the performance even more. What-ever combination of diversity protocol and combining method is used second level diversity is observed. The relative distances between the relay and the stations has a large effect on the performance.The aim of this project was to study the characteristics and utility of relaying in future wireless systems. The focus was mainly on the cooperative principles and relay selection in the case of mobile multihop relay structures. This project also included the study of IEEE 802.16j, the multihop relay specification for 802.16 or Wimax standard. It was an interesting assignment to study the practical realization of a concept that has evolved over a couple of years. I studied some relevant research papers (listed in the references section), modeled some simulation scenarios based on the results of these papers and gained a invaluable insight on some of the topics.

Keywords: wireless networks, cooperative diversity, relay, diversity protocols, combining methods, fading, path loss

Introduction

In a wireless transmission the signal quality surers occasionally severely from a bad channel quality due to erects like fading caused by multi-path propagation. To reduce such erects diversity can be used to transfer the different samples of the same signal over essentially independent channels.

In this project diversity is realized by using a third station as a relay. In such a system combinations of several relaying protocols and different combining methods are examined to see their erects on the performance. The transmission protocols used in this thesis are *Amplify and Forward* and *Decode and Forward.* In the simulation these can both be seen to achieve full diversity as was proved in [2]. Basically three different types of combining methods are examined which differs in the knowledge of the channel quality they need to work. One combination that achieves a good performance is then used to see the erect on the performance depending on the location of the relay. This information is crucial to decide the worth of a mobile relay.

Single Link Transmission

In this Project the system model for a single link transmission as illustrated in Fig.2.1 is presented. This thesis considers the modulator, channel and demodulator block which are described below.

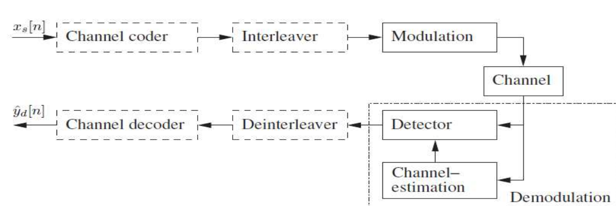

Figure 2.1: This thesis considers only the modulation, channel and demodulation block.

Signal Model and Modulation

The transferred data is a random bipolar bit sequence which is either modulated with *Binary Phase Shift Keying* (BPSK) or *Quadrature Phase Shift Keying* (QPSK). As illustrated in Fig. 2.2, QPSK in fact consists

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of two in-dependent (orthogonal) BPSK systems and therefore has double bandwidth compared to BPSK. Without any loss of generality the simulations are done in the baseband

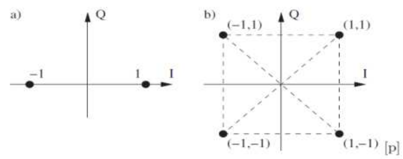

Figure 2.2: a) BPSK, b) QPSK, I denotes the in phase channel, and Q the quadrature channel.

Channel 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. Within this thesis, thermal noise, path loss and Rayleigh fading are considered, as illustrated in Fig. 2.3.

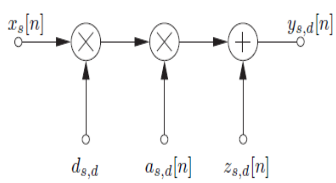

Figure 2.3: Channel model: path loss $d_{s,d}$, fading $a_{s,d}[n]$ and noise $z_{s,d}[n]$.

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. 3.1.

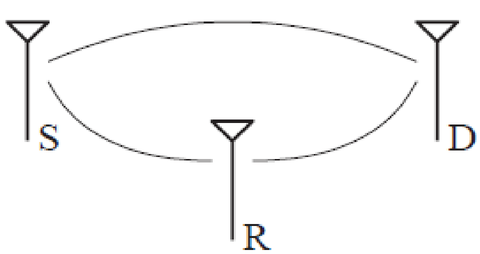

Figure 3.1: The data is transmitted on one hand directly to the destination,and on the other hand the data is sent to the receiver via the relay.

Cooperative Transmission Protocols

The cooperative transmission protocols used in the relay station are either Amplify and Forward (AAF) or Decode and Forward (DAF). These protocols describe how the received data is processed at the relay station before the data is sent to the destination

Amplify and Forward

This method is often used when the relay has only limited computing time/power available or the time delay, caused by the relay to de- and encode the message, has to beminimised. Of course when an analogue signal is transmitted a DAF protocol cannot be used. The idea behind the AAF protocol 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 (2.1) is given by

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

where *s* denotes the sender and *r* the relay. To send the data with the same power the sender did, the relay has to use a gain of

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

Decode and Forward

Nowadays a wireless transmission is very seldom analogue and the relay has enough computing power, so DAF is most often the preferred method to process the data in the relay. The received signal is burst decoded and then re-encoded. So there is no amplified noise in the sent signal, as is the case using a 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 destination1.

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.

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 will be compared.

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

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

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.

Multihop Relaying in Wimax Cooperative Principles and Relay Routing

The aim of this project was to study the characteristics and utility of relaying in future wireless systems. The focus was mainly on the cooperative principles and relay selection in the case of mobile multihop relay structures. This project also included the study of IEEE 802.16j, the multihop relay specification for 802.16 or Wimax standard. It was an interesting assignment to study the practical realization of a concept that has evolved over a couple of years. I studied some relevant research papers (listed in the references section), modeled some simulation scenarios based on the results of these papers and gained a invaluable insight on some of the topics.

The Concept of Relay

The definition of a relay as provided in IEEE 802.16j is as follows: "A generalized equipment set, dependent on a multihop relay base station (MR-BS) providing connectivity, to other RSs or subscriber stations (SS)." A relay can be thought of as a miniature base station that enjoys line of sight connectivity with another relay or a base station. Unlike a base station a relay is not connected to the wired backhaul

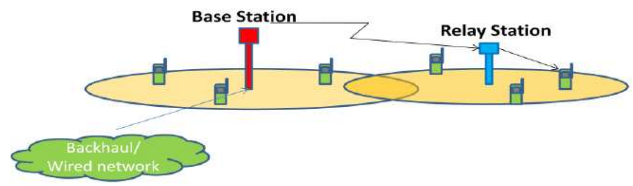

Figure 4.1 Concept of Relay

Relaying Techniques

Relays can be classified broadly into three categories based upon their forwarding schemes: Amplify and Forward (AF), Decode and Forward (DF) and Compress and Forward (CF)

Adaptive forwarding techniques based on the channel state information (CSI) between the BS and RS and also between the RS and MS has been considered.

i) **Amplify and Forward**: These relays only retransmit the amplified version of the received signal. It is the simplest form of relaying technique which assumes minimal processing power at the relay. This technique can be employed as the non transparent relaying as described in 802.16j standard, which means that the MS need not be aware of the presence of the intermediate relay. However the relay also amplifies the received noise which might degrade its performance. This technique is useful for coverage extension and covering shadow areas.

ii) **Decode and Forward**: These relays decode the data received in the first phase and perform error correction before forwarding. The data is forwarded only when it is error free. This technique is generally used with hybrid ARQ (ARQ) to deal with errors during the first phase. DF relaying performs well when the BS to RS channel is good. This ensures that the bits are decoded correctly and avoids ARQ overhead. Based on the codebook used for forwarding DF technique is classified into two types: Regenerative DF and Non-Regenerative DF. The former uses different codebook than the one with which it receives data while the later uses the same codebook. Advantage of DF relaying lies in the fact that different Adaptive Modulation and Coding (AMC) technique can be used during the two phases based upon the instantaneous CSI.

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Cooperative Diversity

Diversity implies the gain due to the multiple copies of received signal either in frequency, time or space. Space diversity is a type of diversity exploited in wireless systems due to the broadcast nature of the channel. Space diversity can be realized by using multiple antennas at the transmitter and/or the receiver which creates multiple independent fading paths, and hence adds redundancy. It is highly improbable that all the different paths experience deep fade at the same time.

As shown in the figure the RS and BS form a virtual antenna array. The relay can exploit both receive and transmit diversity. However receive diversity with single antenna at MS is possible which is explained later on.

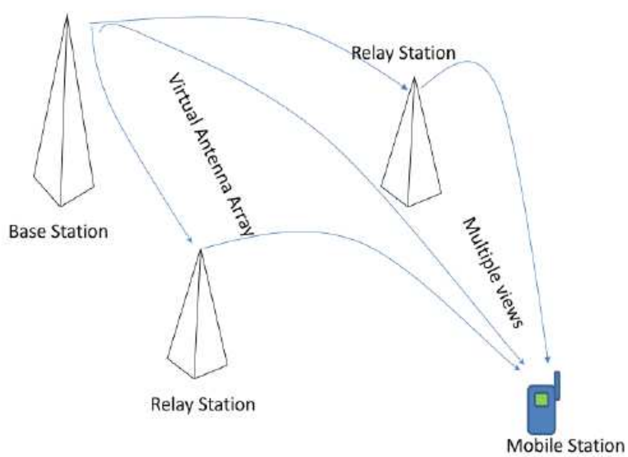

Figure 4.4 Cooperative Diversity

Cooperative diversity schemes can be classified into following types:

Cooperative MIMO Diversity: The MS and the RS listen to the transmission of BS in the first phase. In the second phase BS and RS simultaneously transmit to MS. During the second phase BS and RS make use of STBC. The MS used maximal ratio combining (MRC) to combine the multiple copies of data. This scheme is the combination of both transmit and receive diversity, hence called MIMO diversity. BS and the RS should use the same AMC scheme during the second phase.

Cooperative Transmit Diversity: The MS does not listen to the transmission of BS during the first phase. During the second phase BS and RS simultaneously transmit to MS using STBC. The advantage of this scheme is that AMC scheme can be different between two phases. Hence good channel conditions between the RS and MS can be exploited.

Cooperative Receive Diversity: The MS and RS receive data from the BS during the first phase and during the second phase only the RS transmits to the MS with the same AMC scheme. This scheme can never outperform Cooperative MIMO diversity

Simulation Results

To compare the benefits of the different combining method, the optimal ratio for the FRC needs to be evaluated first. Fig. 5.1 illustrates the effects of the different weighting. As seen, a much better performance is achieved using FRC instead of ERC simply by assuming that the direct link has in general a better quality than the multi-hop link. This is obvious in an equidistant arrangement, where the signal over the multi-hop has to propagate over twice the distance than over the direct link. The result of the simulation illustrated in Fig. 5.1 shows that the best performance using FRC is achieved with a ratio of 2:1. FRC with this ratio is now used to compare performances with one of the other combining types. In Fig. 5.2 the effect on the performance of the different combining types using an AAF protocol can be seen. The BPSK single link transmission should demonstrate if there is any benefit at all using diversity, while the QPSK two senders link indicates a lower bound for the transmission. Using the equidistant arrangement, the aim is to get as close to the latter curve as possible or to get an even better performance.

The first pleasant result is that whatever combining type is used, the AAF diversity protocol achieves a benefit compared to the direct link. Even the equal ratio combining shows advantages. But compared to the fixed ratio combining, the performance looks quite poor. Otherwise you should call to mind that the equal ratio combining does not need any channel information, except the phase shift, to perform the combining. The fixed ratio combining on the other hand needs some channel information to calculate the appropriate weighting. The signal-to-noise ratio combining (SNRC) and the enhanced signal-to- noise ratio combining (ESNRC) show roughly the same performance, which is much better than the one using FRC/ERC. This is not surprising considering that the former two combining methods are using much more detailed channel information than the latter two. Actually the big surprise is that the performance of the combining methods, which have precise information about every single block, is just about one decibel better than the one using FRC which has just average knowledge of the channel quality.

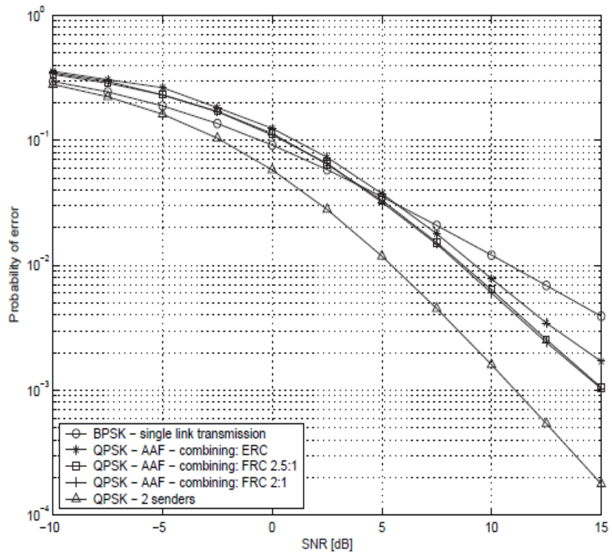

Figure 5.1: To estimate the best ratio for FRC different ratios are plotted. The ratio 2:1 gives a good result.

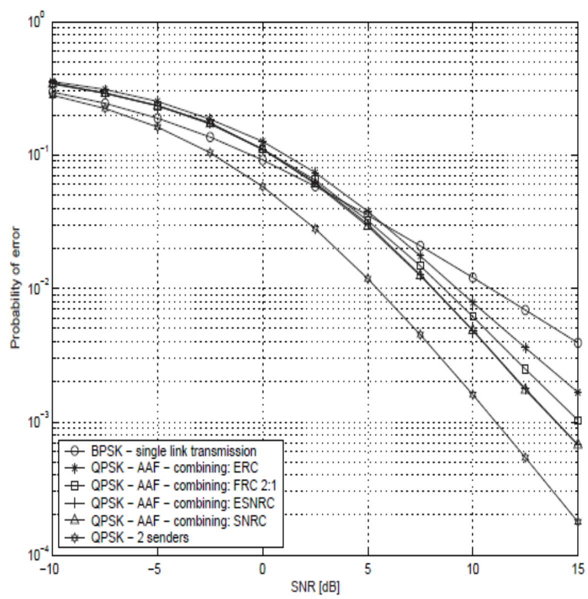

Figure 5.2: The different combining types are compared with each other.The best performance results when using SNRC/ESNR

The FRC with a ratio of 3:1 can now be used to compare with the other combining methods. The different combining methods The different combining methods using the DAF protocol are illustrated in Fig. 5.3. The first thing that attracts attention is the bad performance of the equal ratio combining. Especially for a small SNR the performance is significantly worse than the one of the BPSK single link transmission and therefore should not be used at all.

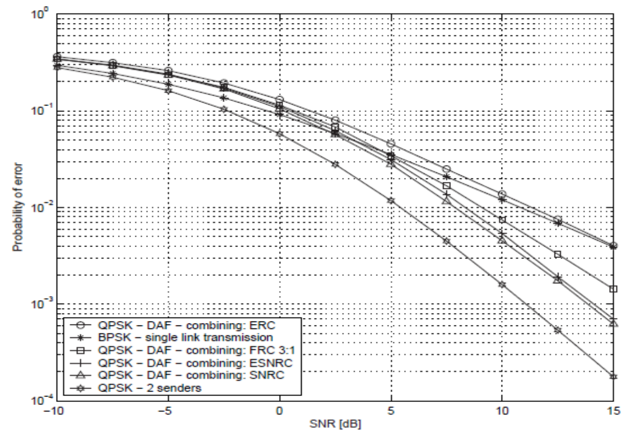

Figure 5.3: The different combining types are compared with each other.The best performance results when using SNRC

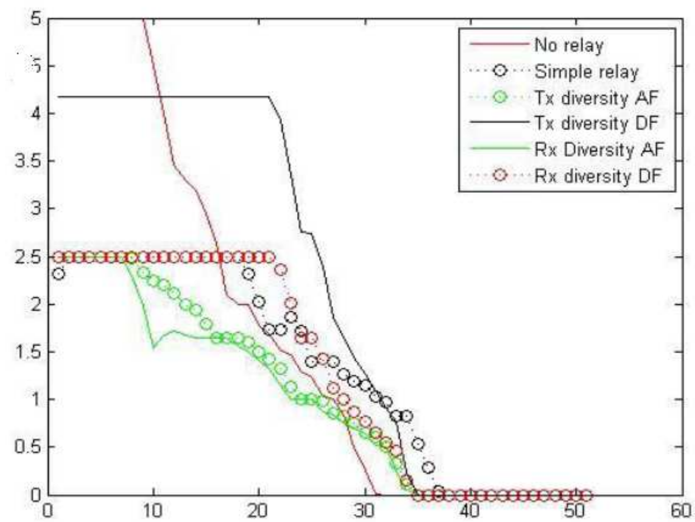

Figure5.4: Comparison of relaying techniques

Conclusion

The above network entry model can be extended to the case of mobile relays. The overhead due to the fast changing channel conditions can be measured. Also using suitable network simulation software, we can model large number of users. A distributed scheduling and relay selection algorithm can be simulated and tested for the overhead reduction versus throughput loss trade off. This project has shown the possible benefits of a wireless transmission using cooperative diversity to increase the performance. The diversity is realized by building an ad-hoc network using a third station as a relay. The data is sent directly from the base to the

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mobile or via the relay station. Such a system has been simulated to see the performance of different diversity protocols and various combining methods. The AAF protocol has shown a better performance than the DAF protocol whatever combining method was used at the receiver. But it must be considered that no error correcting code was added to the transferred signal. Therefore it was not possible to take full advantage of the DAF protocol.

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