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EXPERIMENTAL STUDY OF COOPERATIVE COMMUNICATION USING SOFTWARE DEFINED RADIOS

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Bachelor of Engineering in Electronics and Communication Engineering

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Department & Date

Dr. Murad Hizlan

Department & Date

To my parents...

ACKNOWLEDGEMENTS

I would like to thank my advisor Dr. Chansu Yu for his support and guidance during the course of my education, for giving me the freedom to work on this research work and for helping me in difficult times. I feel lucky to be a part of the community that is working on Software Defined Radios. I would also like to thank my committee members Dr. Fuqin Xiong and Dr. Murad Hizlan for being a part of my thesis committee. Under the guidance of Dr. Xiong, we were exposed to some of the advanced technologies available so far. It is his teaching that motivated me in doing additional research in communications. I am thankful to my family for their constant support and motivation that encouraged me in doing this research work. Finally, I would like to thank my fellow members of Mobile Computing Research Lab for helping me when in need.

EXPERIMENTAL STUDY OF COOPERATIVE COMMUNICATION USING SOFTWARE DEFINED RADIOS

MURALI KRISHNA MARUNGANTI

ABSTRACT

The aim of this thesis is to implement and test a real time wireless communication environment. Cooperative Communication is one of the methods by which a reliable communication can be obtained. This is performed using a Software Defined Radio. The received output is compared with the actual signal that is transmitted over the wireless channel. The wireless communications are often hindered by the noisy environments and make the system unreliable. The interference from neighboring nodes also poses a major disadvantage. There is a necessity to improve the performance of the system where the neighbor nodes can work in coordination with the sender. The intermediate nodes (also called as relay stations) cooperate in a distributed manner to prevent loss of bandwidth usage.

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LIST OF ACRONYMS

3G	Third Generations
ADC	Analog to Digital Converter
AF	Amplify and Forward
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
BSS	Base Station Subsystems
CDMAC	Cooperative Diversity Medium Access Control
CIC	Cascade Integrate Comb filter
CRC	Cyclic Redundancy Check
DAC	Digital to Analog Converter
DBPSK	Differential Binary Phase Shift Keying
DDC	Digital Down Converter
DF	Decode and Forward
DSP	Digital Signal Processor
DSTBC	Distributive Space Time Block Coding
DUC	Digital Up Converter
EGC	Equal Gain Combining
FCC	Federal Communications Commission
FPGA	Field-Programmable Gate Array
GPS	Global Positioning Systems
GRC	GNU Radio Companion

LPF	Low Pass Filter
LOS	Line Of Sight
MIMO	Multiple Input Multiple Output
MRC	Maximum Ratio Combining
NCO	Numerically Controlled Oscillator
OFDM	Orthogonal Frequency Division Multiplexing
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
SDR	Software Defined Radio
SNR	Signal to Noise Ratio
USRP	Universal Software Radio Peripheral
UWB	Ultra Wide Band

CHAPTER I

INTRODUCTION

In wireless communications, multipath propagation is a severe form of interference that results in loss of information. The use of diversity techniques can extenuate the signal loss. In diversity techniques, redundant signals are transmitted over independent paths (distributed in time, frequency, and space) and combined at the receiver to collect diversity gain. Spatial diversity techniques (e.g. multiple antennas) are especially attractive because they can be easily combined with either time, frequency or code diversity, without affecting the performance gain.

Unfortunately, the use of multiple antennas might be impractical in mobile devices due to the limitation of size. The separation distance between collocated antennas should be longer than a half-wavelength to make all channels independent (at most slightly correlated), and thus the deployment of additional antennas eventually increases the size of mobile devices. This problem can be mitigated even without the use of multiple antennas by using cooperative diversity. A virtual antenna system can be formed using multiple nodes to realize distributed spatial diversity [27]. In cooperative diversity technique, the “relay" node, assists the communication from the “source" to the “destination".

1.1 Objectives

In this thesis, we consider Amplify and Forward (AF) relaying protocol. Since simple AF relaying does not achieve diversity gain, we implement fixed AF protocol with 3 Universal Software Radio Peripherals. In fixed AF protocols, relay amplifies the signal from source and decides whether it forwards the data to the destination or not. Relay delivers the data to the destination only when the signal is not received correctly from source during the first phase. Through this selection, diversity gain is achieved as shown in Figure 1.

Our goal is to confirm the diversity gain achieved by fixed AF relaying. The diversity gain clearly appears in SNR-BER curve; however, extensive experiment is required to plot this graph. Also, assigning the desired power to each USRP is a difficult task because USRP devices are not delicate (To measure the exact received power other electronic devices such as spectrum analyzer are required). Due to these difficulties, we roughly check the diversity gain by observing the coverage extension effect.

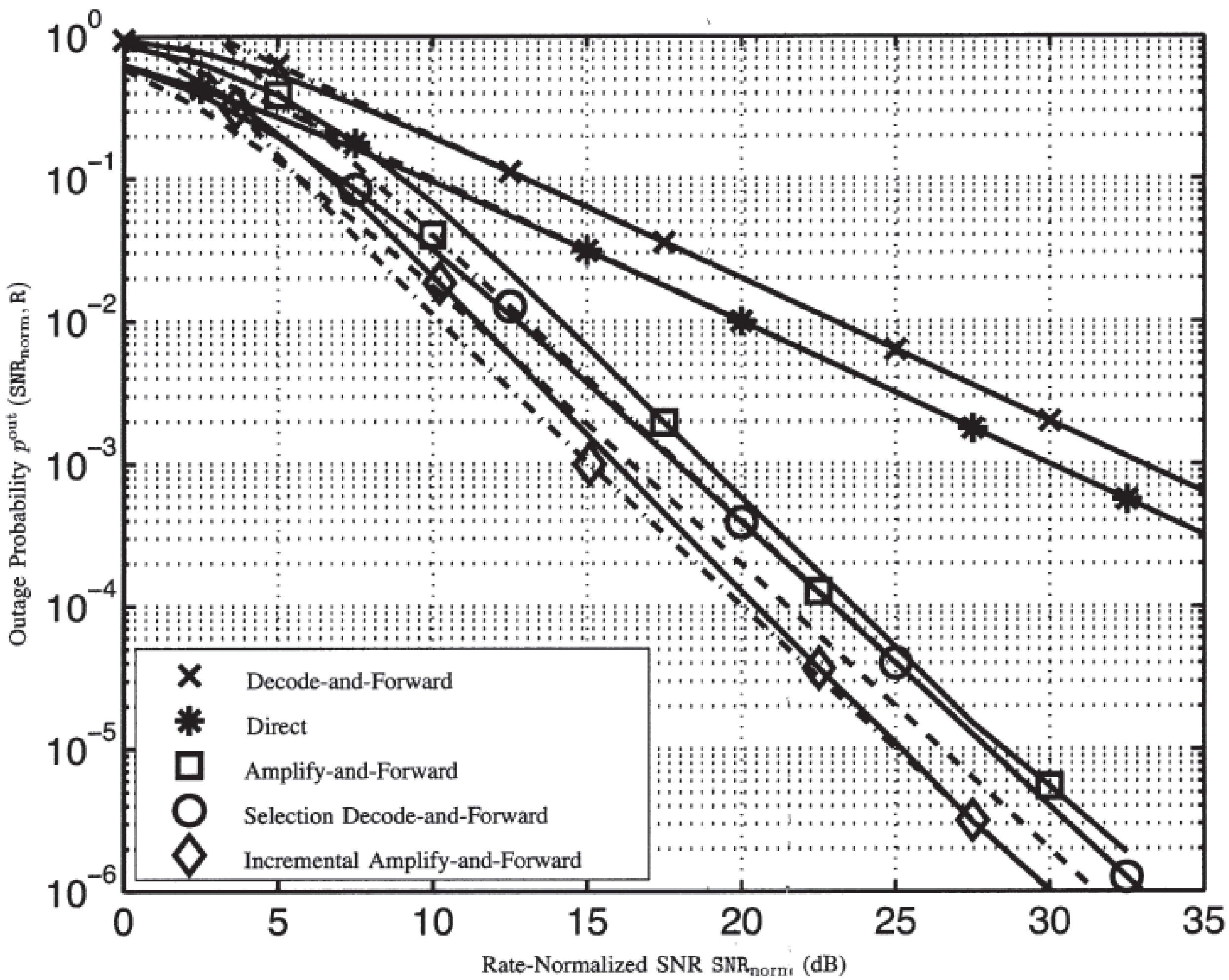


Figure 1: Simulation of BER versus SNR [8]

1.2 Cooperative Communications

In recent years, the field of wireless communication systems has shown a tremendous amount of development with respect to research and practice. Applications range from the daily needs like mobiles, Wi-Fi, to commercial uses like satellite communications. With the aid of current technology, it is possible to communicate with any corner of the world. These technologies require a reliable and integrated system for better performance. Wireless communications are often hindered by noisy environments and that make the system unreliable. The interference from neighboring nodes also poses a major disadvantage. Hence there is a necessity to improve the performance of the system where the neighbor nodes can work in coordination with the sender.

Cooperative Communication is one of the methods by which one can obtain a reliable communication. In this method, intermediate nodes called the relays cooperatively communicate with each other to transmit the information i.e. cooperative communication by multiple users in a diverse environment can be called as *cooperative diversity* [14]. This type of transmission is reliable and also increases the throughput, hence it gradually improves *bit error rate* (BER). We see that the study of cooperative communication in [6], [8] is based on increasing the transmission range but our study is based on improving the reliability of the cooperative diversity technique by comparing the experimental results with the simulation results.

1.3 Software Defined Radio

Though the SDR has multiple definitions, the SDR forum has established a consistent definition in collaboration with the Institute of Electrical and Electronic Engineers (IEEE) P1900.1 group. The definition of Software Defined Radio is given as:

"Radio in which some or all of the physical layer functions are software defined"[1]

The Software Defined Radio is on the verge of replacing the conventional Hardware Defined Radios because of its flexibility to implement multiple functions using the same hardware components and modifying the software. GNU Radio is one of the software development tools that can used to implement software defined radio. The Universal Software Radio Peripheral (USRP) is a hardware kit that is compatible with GNU Radio and is used to implement the software radio. The USRP motherboard mainly comprises of a Field-Programmable Gate Array (FPGA), Analog to Digital Converter (A/D) and Digital to Analog Converter (D/A). Most of the baseband processing is performed by the motherboard, where as the daughter board is comprised primarily of a RF front-end used for transmitting and receiving purposes. A number of daughter boards are available based on the wireless application. The major advantage of SDR and USRP is that a real world scenario can be implemented to test the working of wireless applications, rather than depending on simulation results. This would aid in better understanding of the effect of noise and other interferences.

1.4 Contributions and Thesis Organization

The following chapters review the literature required for understanding the concepts of SDR and USRP. Chapter 2 reviews the literature for cooperative communications and their types. The system model is also presented in this chapter with necessary expressions. The importance of Software Defined Radio and its advantages over the hardware radios is discussed in Chapter 3. A brief introduction about the Universal Software Radio Peripheral hardware is also discussed. Chapter 4 presents the Design and Implementation of the SDR in cooperative communications and its real world experimentation. Chapter 5 shows the experimental results obtained to show the significance of using SDR’s rather than the conventional simulation results. A comparison between the simulation results and the experimental results is given for better understanding. Finally, Chapter 6 consolidates the conclusions of this thesis work followed by the future work that could be possible to develop in this field.

CHAPTER II

LITERATURE REVIEW OF COOPERATIVE COMMUNICATIONS

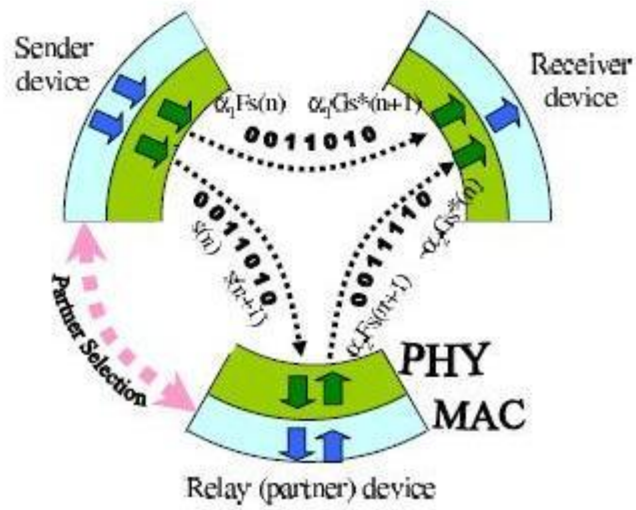
This chapter discusses the latest communication techniques available. It has been over a century since the first wireless communication was tested. Since then, it has developed into a wide range of techniques. The key factor for successful communication is to transmit and receive the exact information signal. This is made possible with the help of various modulation techniques. Even today, we use not only the traditional ways of modulation like analog modulation but also advanced methods like Wi-Fi and 3G. Each kind of communication has its own importance with respect to complexity, efficiency, accessibility and demand. With all these available techniques, we may wonder why there is a necessity for newer methods. The solution could be an upgrade of already existing techniques. With the migration from third generation (3G) to fourth generation (4G) and expanding wireless standards, there is always a demand for newer and more reliable techniques. Some of the currently emerging communication techniques are

Multiple Input Multiple Output systems (MIMO), Ultra Wide Band systems (UWB), Cognitive Radio and Cooperative Communications, Orthogonal Frequency Division Multiplexing (OFDM). Cognitive Radio is a concept that escalates the emerging SDR's.

2.1 Cooperative Communications

As mentioned earlier, Cooperative Communications help in improving the system reliability. Cooperative Diversity can be defined as a form of space diversity [28]. Some of the popular cooperatives techniques are Amplify and Forward and Decode and Forward [3, 4, 24]. In the former method, the relays receive the information, amplify the signal and forwards again to the destination, whereas in the latter method, the relays completely decode the original signal, encode again and then transmit to the destination. Since the relays also send the original signal, these methods are called repetition based cooperative algorithms. It is also clear that this method causes a decrease in bandwidth, as the nodes require separate channels within the limited bandwidth.

Distributive Space Time Coding (DSTC) [10] can be used to realize cooperative diversity to prevent the bandwidth limitations. As mentioned in [12], DSTBC is a distributed form of STBC i.e., a replica of the information is shared among the cooperating nodes for transmission. Since we are dealing with DSTBC and cooperative diversity, we consider a single relay system and emphasize these methods.



	Time slot 1	Time slot 2
Sender	s(n) s(n+1)	α_1Fs(n) α_1Gs*(n+1)
Partner		α_2Fs(n+1) -α_2Gs*(n)

Figure 2: Single channel based cooperative communication using DSTC [14].

A single channel based cooperative communication using DSTC is shown in figure 2. The system consists of a sender, a relay and a destination. During the first time slot, the transmitter sends two symbols, s(n) and s(n+1) to the relay (* denotes conjugate of the symbol, α_1 and α_2 are the real coefficients which are related as $\alpha_1^2 + \alpha_2^2 = 1$ [14], [15]). During the second time slot, the sender and relay cooperatively transmit the blocks. F and G are the coding matrices used to encode the signals. These space-time encoding matrices are orthogonal in nature. Hence they can be transmitted by the sender and relay at the same time and thereby improving the reliability of the communication as well [14].

2.1.1 Amplify and Forward

The standard method of communication is transmitting the information from sender to the receiver. In cooperative communication, the sender sends the same information to both relay and the receiver during the first time slot. In the next time slot, the destination receives another set of signals; one from the sender and the other is an amplified version of the signal in the first time slot. This amplified signal is transmitted by the relay. Now, the receiver can decode the combined signal using Maximum Ratio Combining (MRC). This can be performed with the help of a matched filter. The relay receives the information signal appended by the channel gain and noise. It is then amplified and sent to the destination. The final information received is a combination of the input signal convolved with the channel gain and Additive White Gaussian Noise (AWGN). It is easy to implement because there is no possibility for errors while decoding which could be introduced in decode and forward. The major disadvantage of this method is that the noise will also be amplified at the relay. This can be eliminated by maintaining a high threshold level at the reception. Amplify and forward method is more advantageous than decode and forward method in achieving maximum diversity. Mathematically, it can be shown that, the outage probability is inversely proportional to the square of the Signal-to-Noise ratio (SNR). Hence, an increase of 10dB SNR can reduce the outage probability by an order of 100 [2].

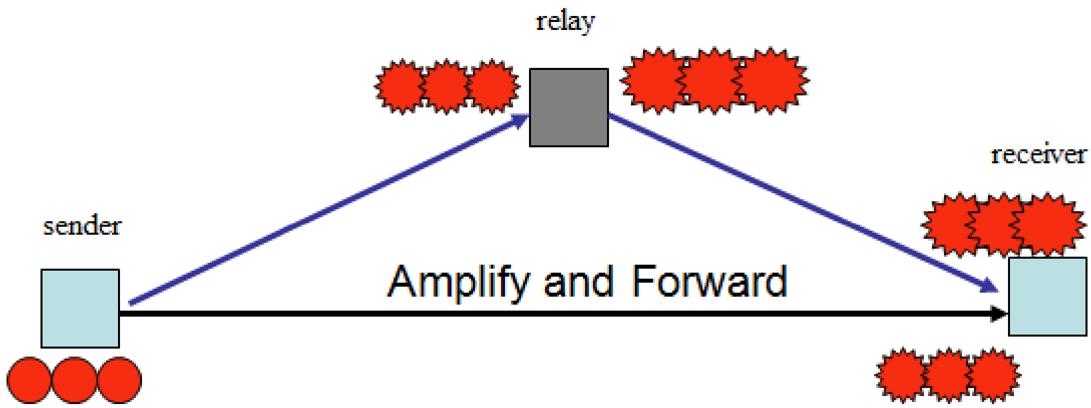


Figure 3: Schematic representation of Amplify and Forward [26]

2.1.2 Decode and Forward

In this method, the relay decodes the received signal from the sender, checks for errors and re-encodes to transmit to the destination. The receiver estimates the information signal using Maximum Ratio Combining. The relay can either decode the entire signal or it can perform symbol-by-symbol decoding [8]. When the relay decodes the received signal, the noise introduced in the information signal should be removed prior to decoding. Otherwise, it is more likely that the original signal could be corrupted. The destination must decode the signal completely. Hence the destination must be aware of both the decoding techniques in order to fully decode the signal. In real time environments, there is less certainty that the decoded signal sent from the relay would again be noise affected. Nicholas Laneman et. al. have shown in [2] that the decode and forward method fails to attain full spatial diversity. Mathematically, they proved that the outage probability is inversely proportional to the Signal-to-Noise ratio. i.e., the outage probability reduces at the same as the SNR rises.

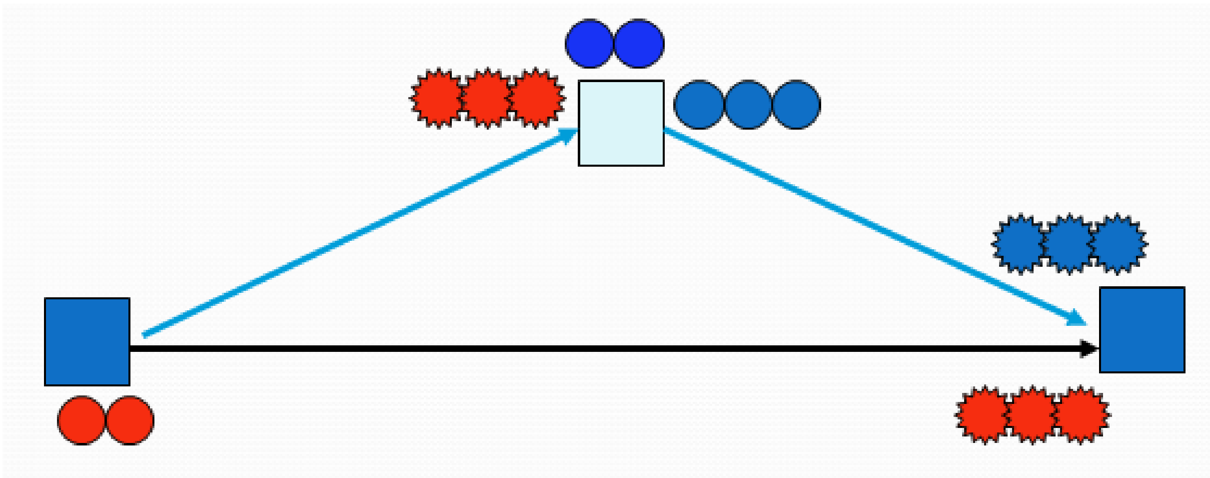


Figure 4: Schematic representation of Decode and Forward [26]

2.2 System Model for Amplify and Forward

The relay network model we considered is shown in figures 5 and 6. S stands for source, R for relay node, and D for destination node. One packet is transmitted over a consecutive two time slots, and specific procedure is represented as follows.

At the first time slot, source transmits the packet to the relay and destination and this can be mathematically represented as:

$$y_R = h_{SR}x_S + n_R,$$

$$y_{D1} = h_{SD}x_S + n_{D1}$$

The y, h, n represents the received signal, channel and noise, respectively. The signal received in the first time slot is decoded to check for good reception and r_{D1} is obtained. If the signal contains errors, the destination sends a notification. The relay amplifies and transmits the signal. To confirm the reliability of the signal from relay, cyclic redundancy check (CRC) is used. If no error is detected from CRC, this signal is exploited as the transmitted signal from the relay.

During the second time slot, the relay transmits the amplified signal to the destination which is represented as

$$y_{D2} = h_{SD}x_R + n_{D2}$$

y_{D2} is decoded and r_{D2} is obtained. Two received signals at the destination from different time slots can be combined. In this experiment, we don't estimate the channel, so we simply use the equal-gain combining (EGC). This process is expressed as

$$r_D = r_{D1} + r_{D2}$$

By decoding r_D, the decision of the transmitted data is obtained.

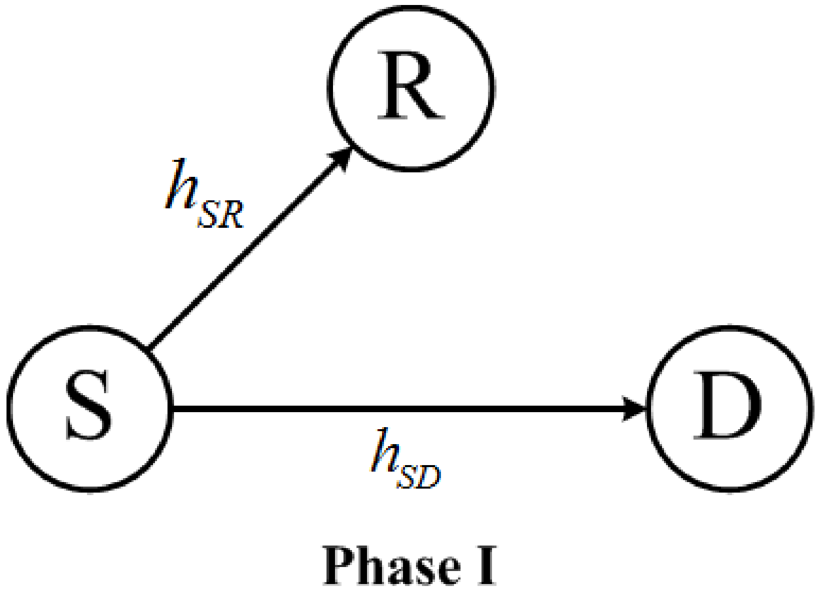


Figure 5: Schematic of Relaying Protocol during first time slot

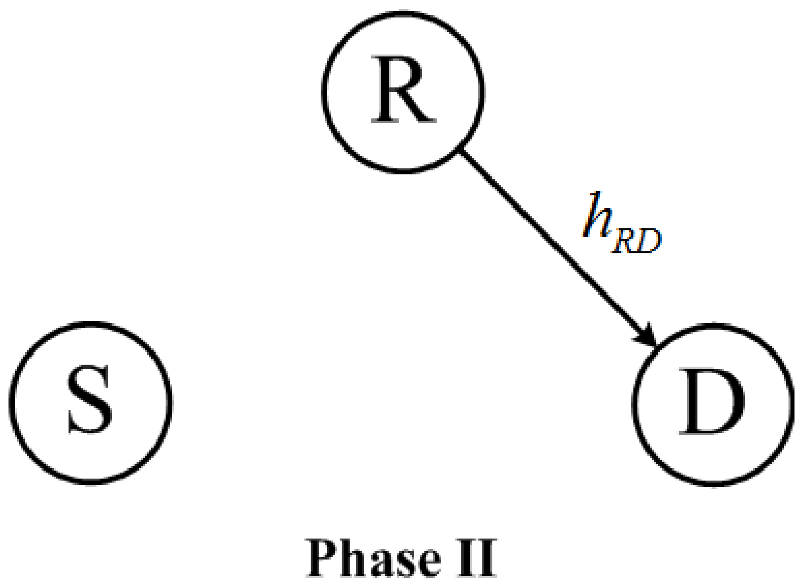


Figure 6: Schematic of Relaying Protocol during second time slot

CHAPTER III

EXPERIMENTATION PLATFORM

From the previous section, we have observed that the emerging technologies can be implemented for experimentation using SDR's. We have a wide range of SDR's available in the market. Considering the ease of programming, simple hardware implementation, durability, cost efficient, and multi functionality features, we chose the Universal Software Radio Peripheral (USRP) as test equipment. A tremendous amount of research has been carried out on USRP which is compatible with GNU Radio. This open source software enables users to perform multiple tasks on the hardware. Another major advantage of using USRP is that it can be made to run on the Windows operating systems as well. For this experiment, we installed GNU radio 3.2.2 on Ubuntu 9.10. Since we are not familiar with the usage of python script, we used the GNU Radio Companion (GRC).

3.1 Software Defined Radio

3.1.1 Replacing Hardware Defined Radios

Until the last decade, most of the research on communication system relied on hardware defined radios. It was quite difficult to implement a multi-functional hardware radio because of the system complexity. Any communication system that can be implemented on hardware could serve only a single purpose. If any block of the system has to be changed, its complete hardware has to be replaced. A typical communication system shown in figure 7 contains various blocks like A/D, D/A converters, encoders, decoders, modulators, demodulators, low pass/high pass filters and so on. In order to change a filter characteristics, the filter hardware has to be changed. These hardware components are more susceptible to wear and tear.

Consider the most common modulation techniques: Binary Phase Shift Keying (BPSK) and Quadrature Phase Shift Keying (QPSK). Mathematically, the major difference between these two methods is the representation of information bits. But the hardware implementation of QPSK requires more blocks to represent the information bits. Comparing with the SDR's, the hardware radios are not capable of diverging environments.

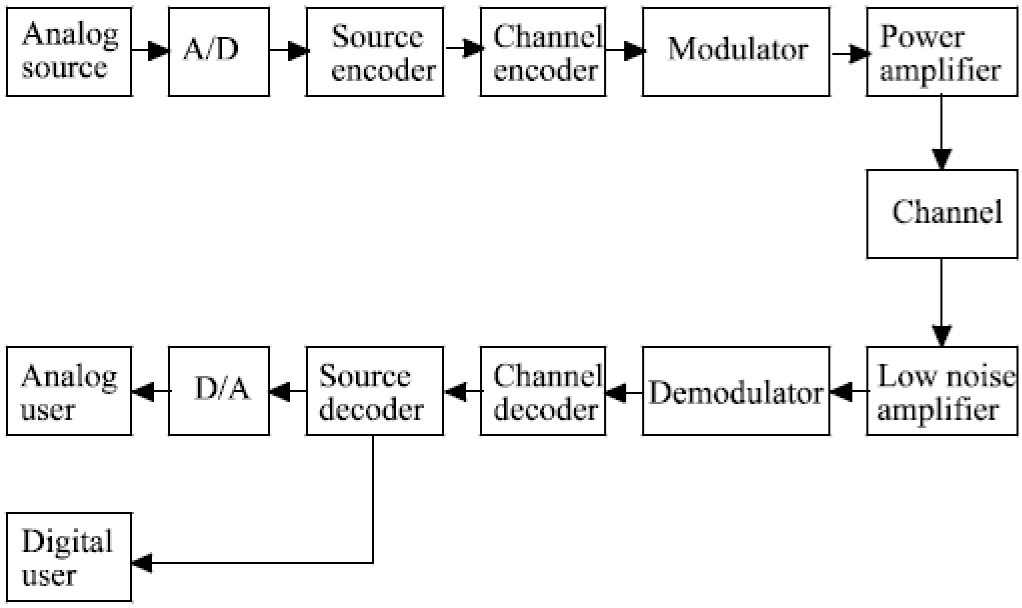


Figure 7: Block diagram of a typical communication system [5]

3.1.2 Characteristics of Software Defined Radio

The concept of an ideal SDR is to digitize the signal as close as possible to an antenna at the receiving end, and to convert the signal into analog form as late as possible at the transmitting end. For this purpose, an A/D converter can be used right after the antenna at the receiver and a D/A converter just before the antenna at the transmitter. The baseband processor should handle all the radio functions like filtering, modulation/demodulation and up/down conversions. These can be performed using a Digital Signal Processor (DSP) or an FPGA. The advantage of using an FPGA is that it can be reprogrammed as needed. The configurations (bit-stream) can be changed easily and stored in the static on-chip random access memory [9].

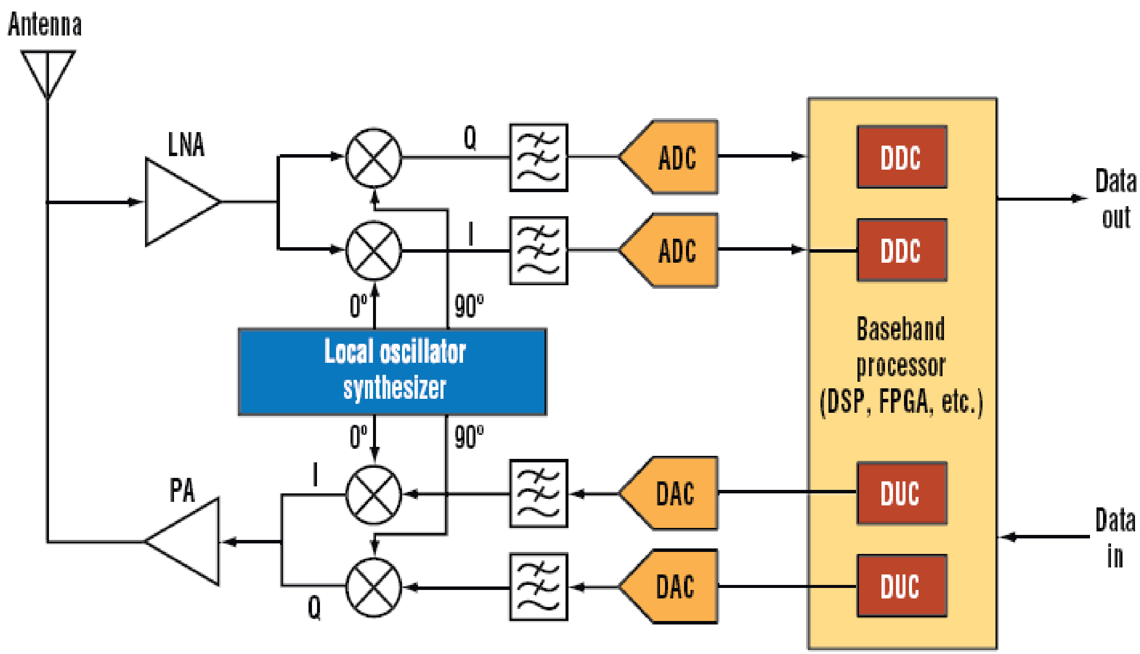


Figure 8: Functional representation of an SDR

3.1.3 Advantages and Disadvantages of SDR

The major advantage of SDR is its multi functionality. The system can be made more flexible by using the same hardware platform to perform various experiments. The re-configurability of the platform will ensure hardware reusability [10]. This will minimize the design complexity of RF front-end. The performance of SDR can be enhanced with the use of simple FPGA's that are programmable for various applications, thereby reducing the size and cost of manufacturing.

SDR's can provide a better solution in Telecommunication systems. Most of the complex hardware used in the Base Station Subsystems (BSS) can be replaced with an SDR. It can be used for trans-coding speech signals, allocating radio channels, transmission and reception. High speed FPGA's can be used for mobile networks where there is always a demand for high channel data rates. Another advantage of using SDR's can be the possibility of adapting various operating frequencies based upon the prevailing conditions.

In Satellite communications, where the size of the hardware is a major factor for the cost of designing, SDR's can be used to substitute large communication blocks. They can be employed to implement Global Positioning Systems (GPS). They also offer a wide range of applications for military purposes. The bulky transceivers used by military personnel can be replaced with more manageable devices. The ease of modifying software in SDR to upgrade the system greatly improves the time of manufacturing, thereby making the product design faster than conventional designs.

In spite of numerous advantages, the SDR's suffer some limitations. There is a possibility of violating the regulations set by the FCC. For example, if the FCC defines a certain power range for maximum output in a particular band, the SDR could operate at a higher level. Though it does not hinder the usability of SDR's, it would be impractical to govern the applications of SDR. This might affect the federal regulations and security standards.

3.2 Universal Software Radio Peripheral

USRP is a hardware platform used for implementing SDR. The FPGA is programmed to control the data rates of the wireless channel so that they can be transmitted to the host computer [17]. The USRP is connected to the host computer with the help of a USB 2.0 interface for processing the information signal. The motherboard contains an Altera FPGA, four 12-bit, 64M sample/sec A/D converters, four 14-bit, 128M sample/sec D/A converters, Analog device mixed signal processor, USB 2.0 controller input, and a DC power input. The specification details can be found in [17]. Up to four daughter boards may be mounted on the motherboard: 2 Transmitters and 2 Receivers. As a consequence, a Multiple Input Multiple Output (MIMO) system can also be realized. But, this occurs at a cost of divided bandwidth as the total bandwidth has to be shared by all the daughter boards. A wide range of daughter boards operating from 1MHz to 3 GHz are available with [16] that can be used based on the applications.

3.2.1 FPGA

The FPGA firmware consists of Digital Down Converter (DDC), which down converts the digitized signal from IF band to the base band. The FPGA contains a multiplexer that supports both real and complex input signals. The input signal from each of the A/D converter is guided to the DDC by this multiplexer [19]. The DDC comprises of a Numerically Controlled Oscillator (NCO), a Cascade Integrate Comb filter (CIC), a digital mixer and a decimating Low Pass Filter (LPF). The signal received from the A/D converter to the signal processing platform is down converted to baseband frequency range. This baseband signal is under sampled and fed to the LPF. The maximum decimation rate available in USRP is 128, which is sufficient to stream with USB 2.0.

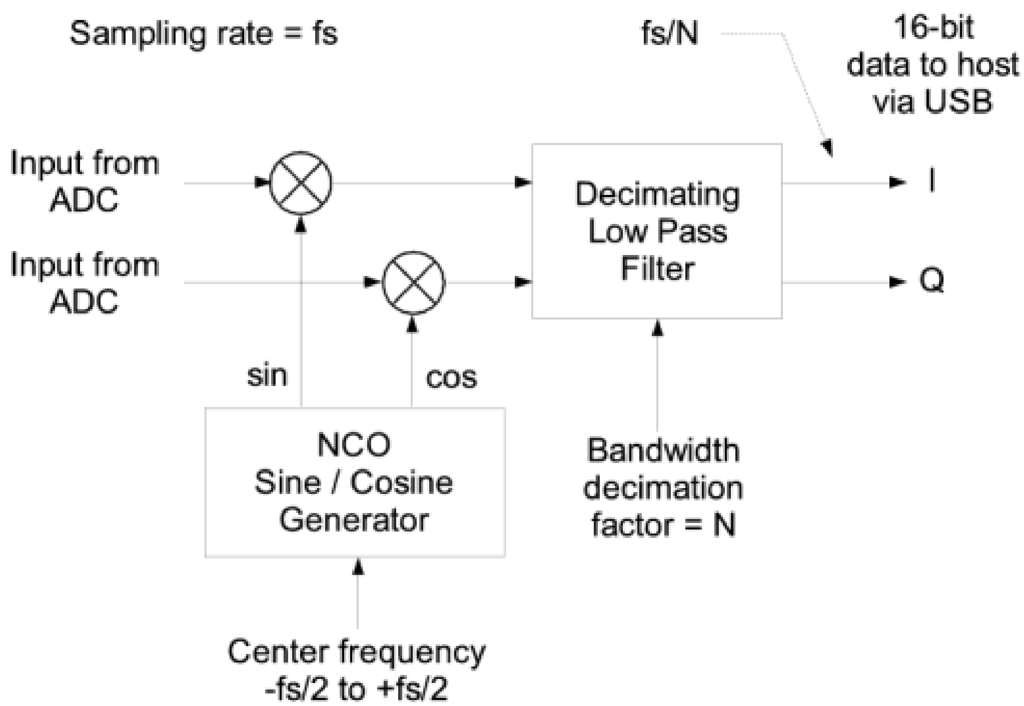


Figure 9: Block Diagram of a Digital down converter in FPGA [18]

On the transmitting end, the Digital Up Converters (DUC) are contained in AD9862 CODEC chips, but not in FPGA. The interpolators are the only transmit signal processing blocks available on the FPGA [20]. These interpolator outputs are then routed to the CODEC chips for up-converting the signal to IF band.

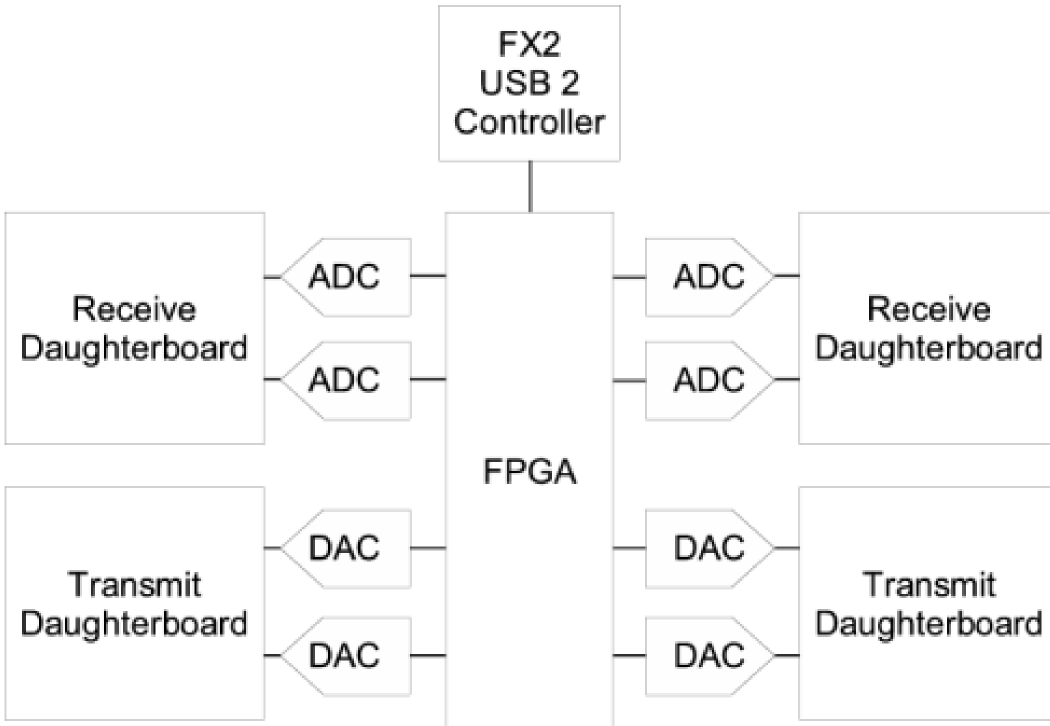


Figure 10: Architectural diagram of USRP [18]

The daughter boards execute the RF front end functions. An antenna can be mounted to these daughter boards to transmit or receive signals. The received signal is directly passed on to the A/D converters for further baseband processing. At the transmitting end, the D/A converter sends the information to the daughter board for transmission. The complete setup of a USRP is given in figure 11.

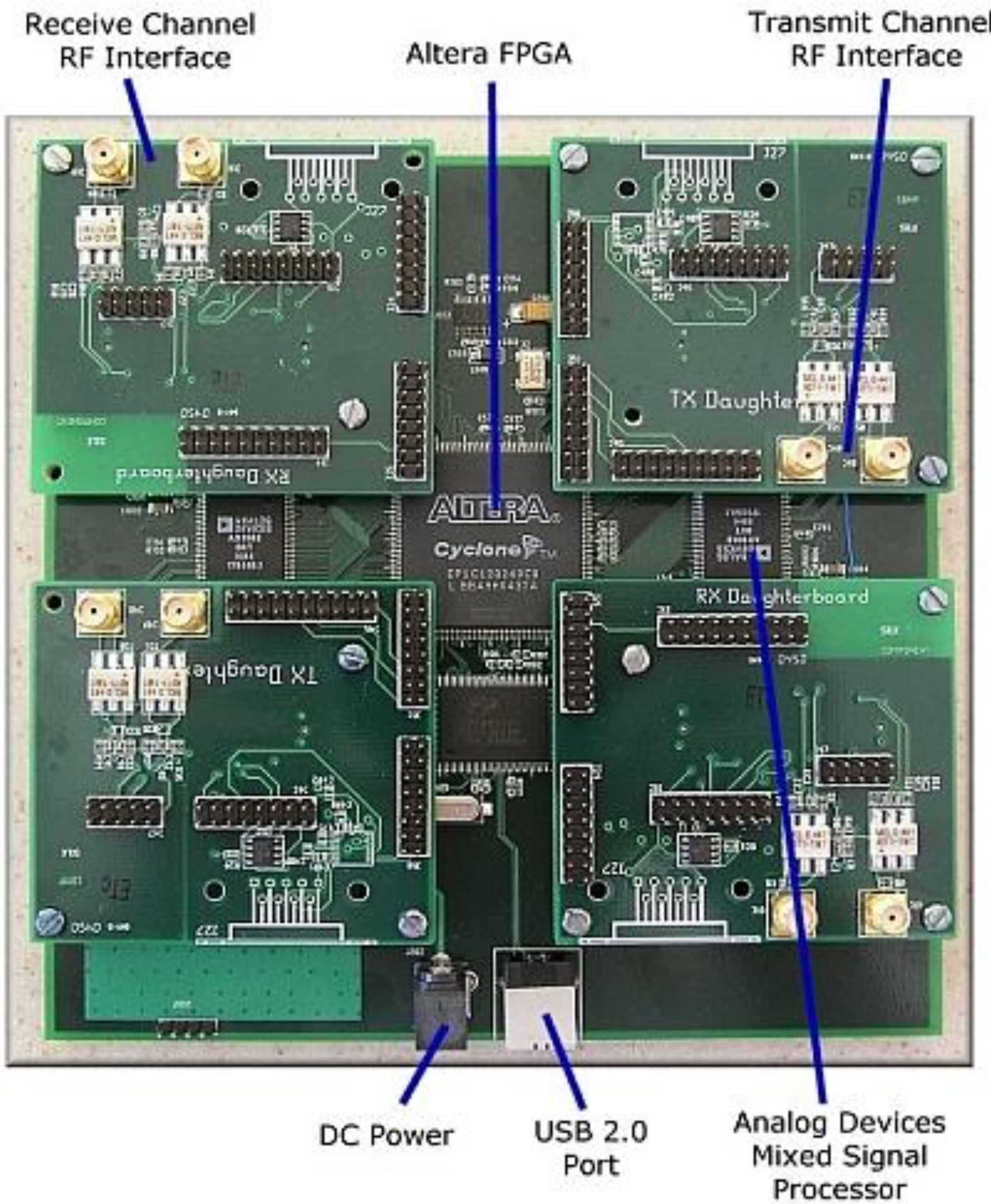


Figure 11: Universal Software Radio Peripheral

CHAPTER IV

DESIGN AND IMPLEMENTATION

It is known that in spatially correlated MIMO channels, the non-distributed Space Time Block Codes (STBC's) offer a reduced Bit Error Rate (BER) [22]. Furthermore, it was shown in [23] that the repetition based cooperative diversity techniques like the Amplify and Forward, Decode and Forward methods reduce the bandwidth efficiency because each relay occupies a finite amount of channel for repetition. Hence, using a distributed STBC can conserve the bandwidth losses occurring due to the multiple relays because all the relays can share the same channel in a distributed manner. We will consider the transmission mechanism of repetition based cooperative techniques for better understanding of the use of distributed STBC.

4.1 Software Setup

4.1.1 First Phase of Cooperative Communication

Though there are a number of repetition based cooperative communication techniques, the most common methods are Amplify and Forward and Decode and Forward [8]. Both these techniques contain two phases of transmission as discussed in [3], [8] and [23]. During the first phase of transmission, the sender transmits the information to the destination as well as the potential relay stations. In the second phase, the sender as well as the relay stations broadcast the information to the destination. The relay stations can either use a Space Time Code (STC) cooperative diversity or they can repeat on orthogonal sub-channels. It was also shown that the Alamouti scheme [21] offers full spatial diversity for space time block codes.

Since the repetitive based protocols send the information twice in different time slots, they require twice the bandwidth required for a single link transmission. To overcome this effect, we use Binary Phase Shift Keying (BPSK) modulation in single link transmission and Quadrature Phase Shift Keying (QPSK) modulation for dual transmission [24]. Since the bandwidth of QPSK is half of BPSK, the overall bandwidth used by both the systems will be same. We must also take into account the latency caused at the relay station for amplifying and forwarding the signal.

Figure 12 represents the implementation of the source node (“source.grc”). The random source block produces a random signal of length 100,000 samples (pre-defined).

The data generated at the random source block is encoded at the packet encoder. We adopt differential binary phase shift keying (DBPSK) modulation which represents data by changes in phase of subsequent symbols. The DPSK Mod block uses gray coding to modulate the encoded bits which are stored in source.dat. Although DBPSK has penalties of BER performance, it enables the simple implementation of the receiver because channel estimation is unnecessary in differential modulation schemes. The modulated base-band signal is saved as “Source.dat”.

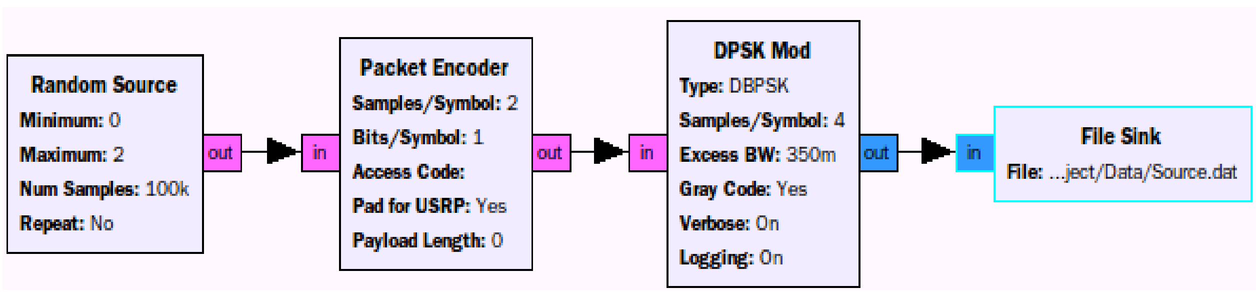


Figure 12: Input signal modulated and saved for transmission (Source.grc)

“USRP_phase1.grc” in Figure 13 describes the signal transmission at the phase 1. The source node (unit #: 1) reads the mapped data saved in “source.dat” and transmits it to the relay and destination. Relay (unit #: 0) and destination (unit #: 2) nodes receive this signal. They are saved as “Relay.dat”, and “Destination1.dat”, respectively. The head count is used as a preamble for the information signal which is later removed before the received data is stored. All the USRP’s operate over the same frequency of 2.45GHz. We use a decimation factor of 128 at the receiving end. After comparing the received signal (at the relay) with the original signal, it is further processed for second phase of transmission.

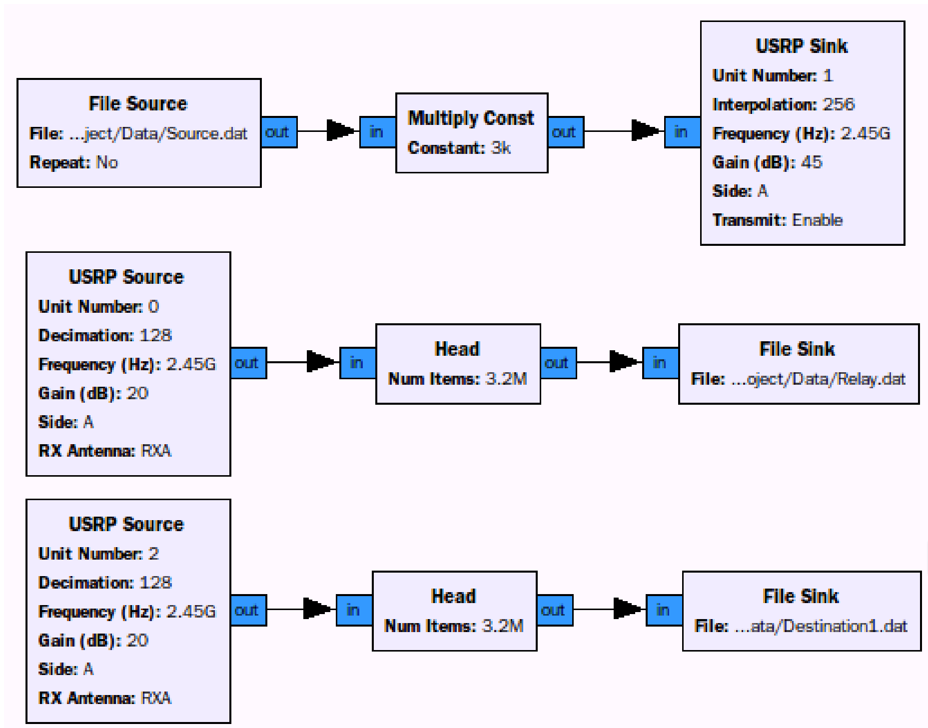


Figure 13: Implementing the communication during first time slot (USRP_phase1.grc)

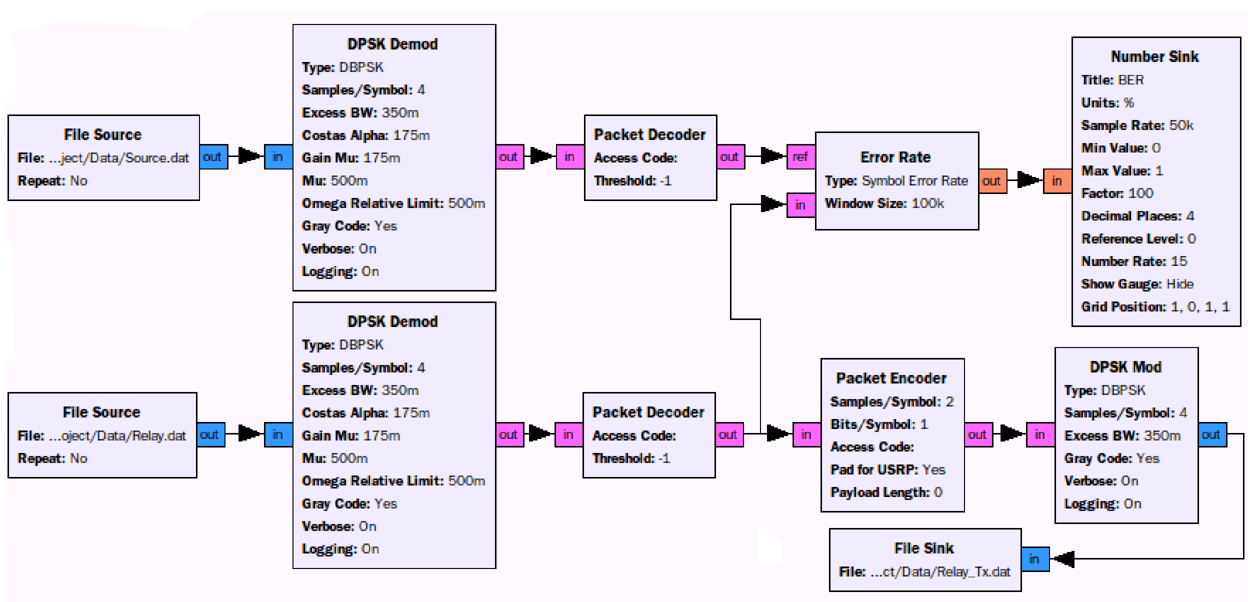


Figure 14: Decoding the relay signal and comparing it with the original input signal

At the relay, relay detects whether error has occurred (Figure 14) by comparing it with the source signal. After comparing the decoded signal to the original input signal, we just discard it if the error has occurred and the relay requests for re-transmission of the signal. If no error is detected at the number sink, we re-encode the message and save the signal in "Relay_Tx.dat". For reality, we should have used CRC during this process. Since we assumed a priori knowledge at the relay for error detection, our implementation is somewhat unrealistic. Anyway, relay finally saves only what it successfully decodes at the "Relay_Tx.dat". In Figure 15, the relay amplifies the signal (which is the primary difference compared with decode and forward) to be transmitted.

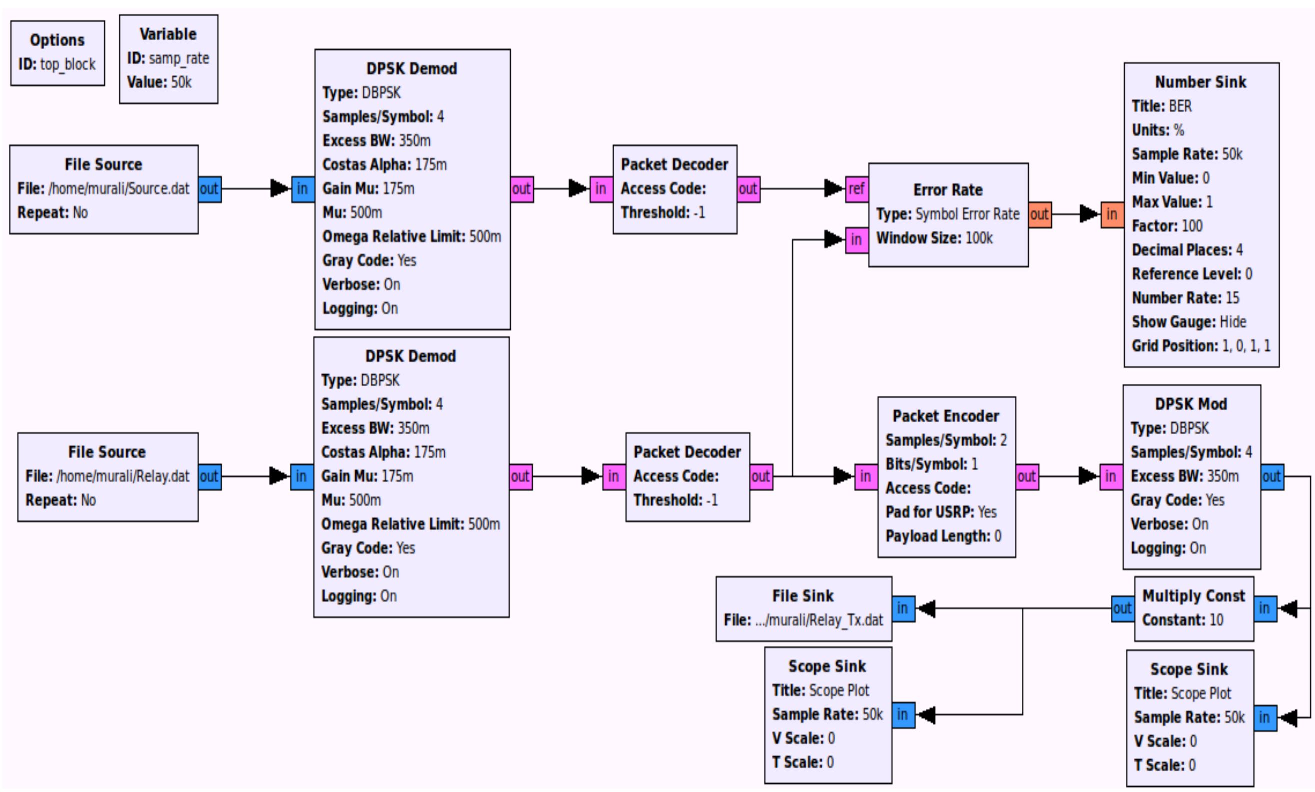


Figure 15: Amplifying the signal to be transmitted at the relay

4.1.2 Second Phase of Cooperative Communication

Figure 16 depicts the signal transmission at the phase 2. Relay node (unit #: 1) amplifies and transmits the re-encoded signal to the destination node (unit #: 0), we save it as "Destination2.dat".

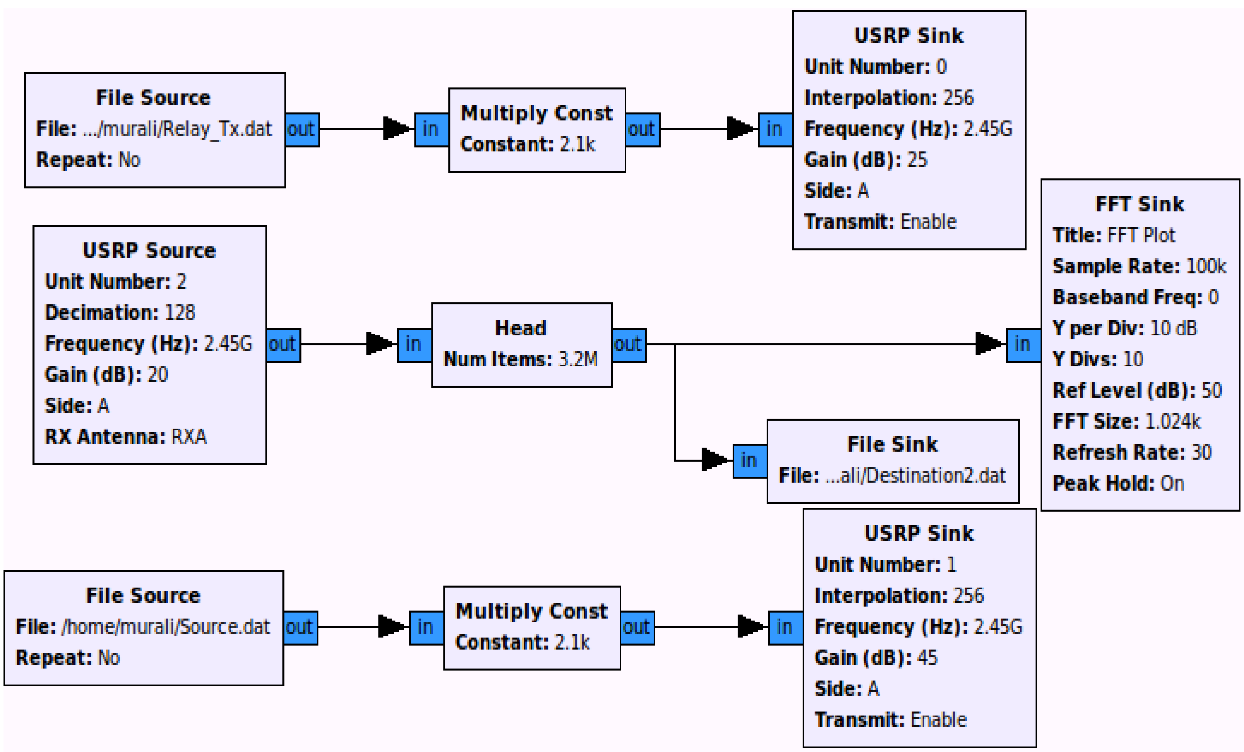


Figure 16: Implementing the communication during second time slot (USRP_Phase2.grc)

During the phase 1 and 2, received signals saved in "Destnation1.dat" and "Destination2.dat" are combined (Figure 17). EGC should be applied in the reference because it can provide the diversity gain without the information of channel. However, we failed to apply EGC in the same manner as in the reference. In the strict sense, the EGC should be performed at the complex-symbol level and it means that we should replace the DBPSK demodulator with other operators. The problem is if we do not employ demodulation blocks, we do not have practical alternatives to correct the different delays observed in received signals. For this reason, we used a trick. We demodulated the complex-level signal, generated the signal again by performing DBPSK modulation. Re-mapped signals are combined and saved in “Combined.dat”.

This type of hard-decision combining has the effect of removing the noise at the output of DPSK Mod again. In case of soft-decision combining, the noise may be cancelled out if they are combined directly and then demodulated. This can be performed using cross-correlation between the two received signals, thereby removing the time delays in each destination file.

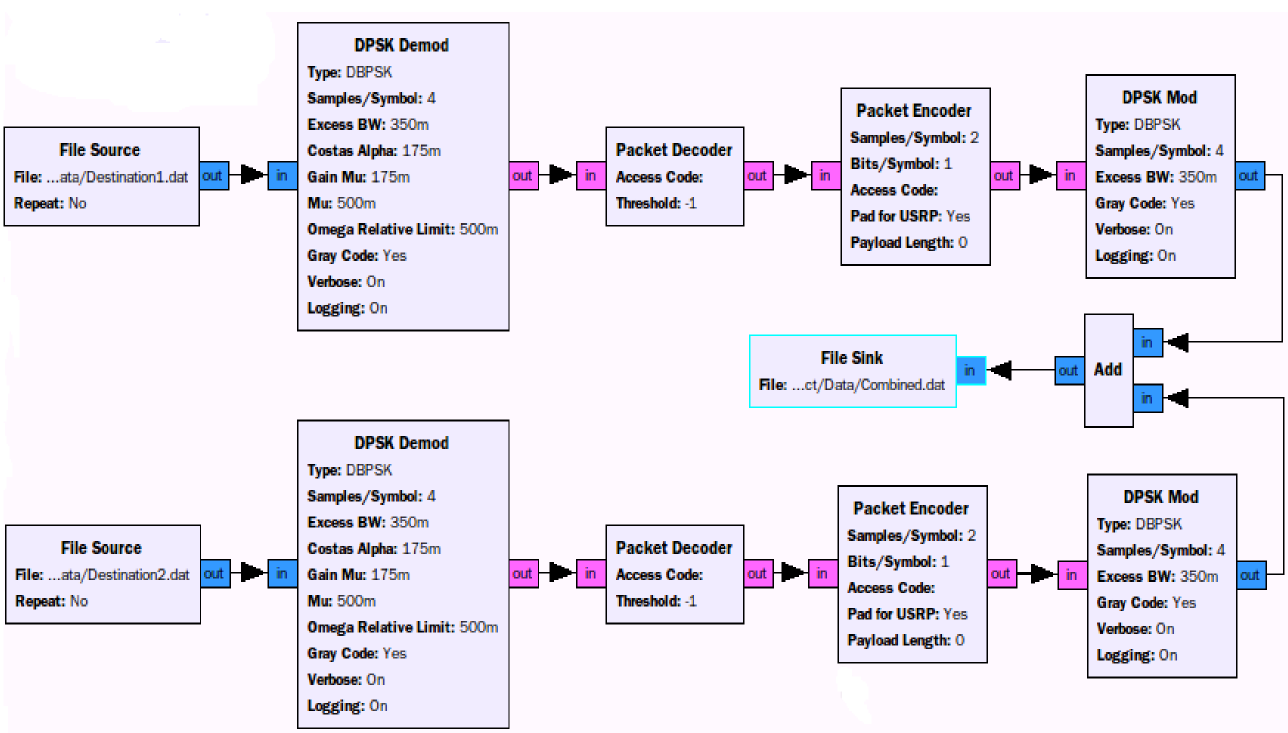


Figure 17: Combination of the received signal in two time slots (Combine.grc)

Figure 18 describes the BER computing part of this program. Combined data (saved in "Combining.dat") is demodulated and compared to the original data. Through this comparison, BER is calculated and displayed. Since we used a finite value of the gain during the transmission, the BER at that respective level is displayed. We repeat the experiment for various values of the SNR gain ranging from 0 to 50dB. Considering the most desirable values, a plot is drawn between the SNR gain and the BER.

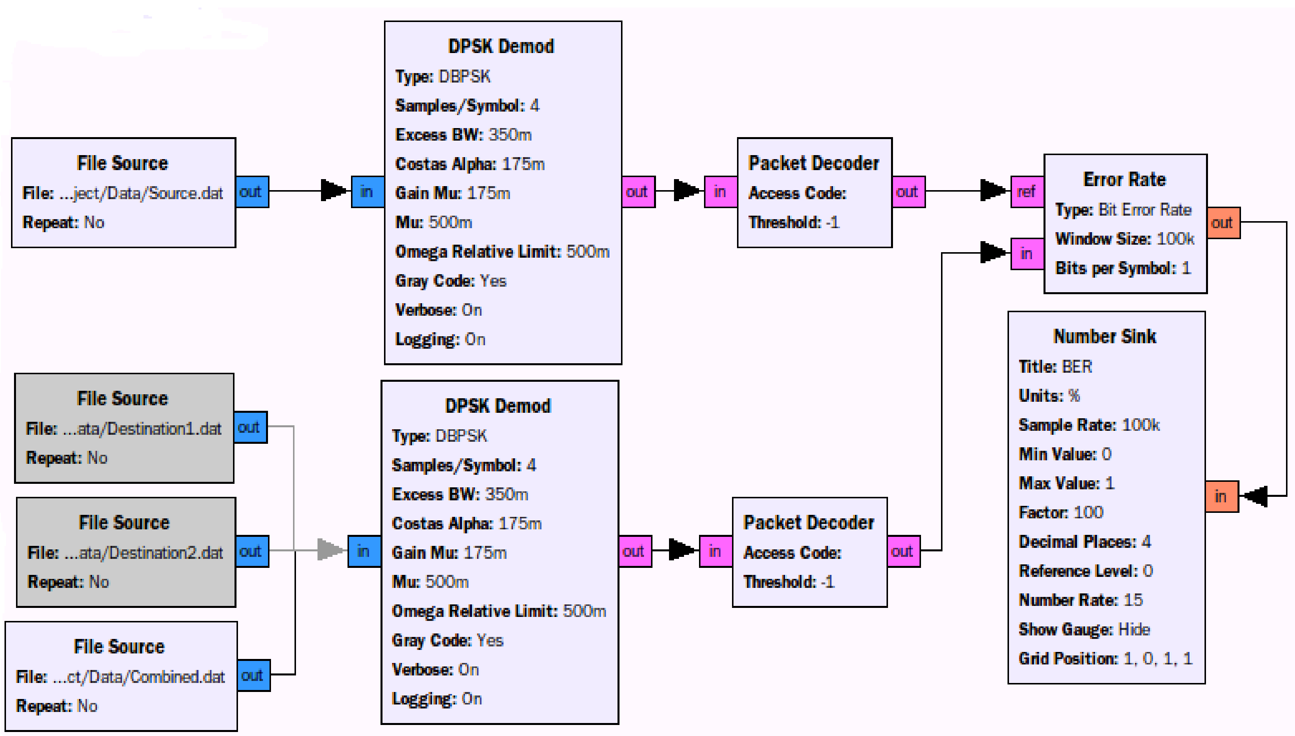


Figure 18: Demodulating the combined signal and comparing it with the input signal

CHAPTER V

EVALUATION

In this chapter, we examine the performance evaluation of the system. We compare the simulation results of amplify and forward, decode and forward, and direct communication with the experimental results. A technique based graph is plotted to clearly understand the difference between the simulation and experimental results. A comparison between the types of cooperative communications is also presented to understand their performance compared with the direct communication. We placed an obstacle close to the destination so as to attenuate the signal. The degradation of the signal due to multi path fading can be observed in the results. A step-by-step procedure of the experimentation is explained in this chapter.

5.1 Hardware setup

We use 3 USRPs in this experiment. They are connected to a computer via USB cables. Each USRP from the right side in Figure 19 acts as source, relay, and destination, respectively. All USRP daughter boards (RFX 2400) support 2.4 GHz carrier frequency whose coherence distances, generally a quarter of carrier wavelength, are about 3 cm. The short coherence distances guarantee the independence between the source-relay and source-relay-destination path with indoor experimental environment (strictly speaking, it does not ensure the independence, but it just provides low correlation between distinct paths).

To attenuate LOS path, an obstacle is placed between source and destination nodes. As the obstacle is close to the receiver, more attenuation can be observed and thus the link quality becomes worse. Under this environment, relay can compensate the performance degradation by forwarding the signal from sources. We compare the experimental results for amplify and forward technique with and without the obstacle. It was observed that the BER performance of ‘no obstacle’ scenario is same as a direct communication. This could be because of no multi path fading and maintaining a short distance between the sender, relay and the destination. In this experiment we setup the sender, relay and the destination node as shown in figure 19. All the USRP’s can also be controlled using a single computer.

Figure 19: Hardware setup for experimentation

5.2 Experimental Results

The major advantage of using GNU Radio companion is that the modulated signal can be saved as a file and can be used any time by the USRP for transmission or for further processing. In this experiment, we used 3 USRP's connected to the host computer for modulating/demodulating the signal. The experiment is investigated sequentially. At first, using Source.grc, the random sequence of which the number of entries is one million is generated. It is modulated to DBPSK symbols, and the symbols are stored in Source.dat. Through USRP_phase1.grc, the symbols are transmitted to the relay node and destination node. At the relay node and destination node, the received symbols are saved in Relay.dat and Destination1.dat, respectively. Figure 20 shows the Bit Error Rate of the demodulated signal with respect to the input signal. The plot shows the signal that will be transmitted by the relay node during the second time slot.

Through Relay.grc, the symbols in Relay.dat are demodulated to bit stream, and this bit stream is compared with the original bit stream. In Figure 20, we can confirm that there is no error at the demodulated bit stream. Hence, the bit stream is modulated to DBPSK. The modulated symbols are amplified and retransmitted to the destination node and stored in Destination2.dat through USRP_phase2.grc.

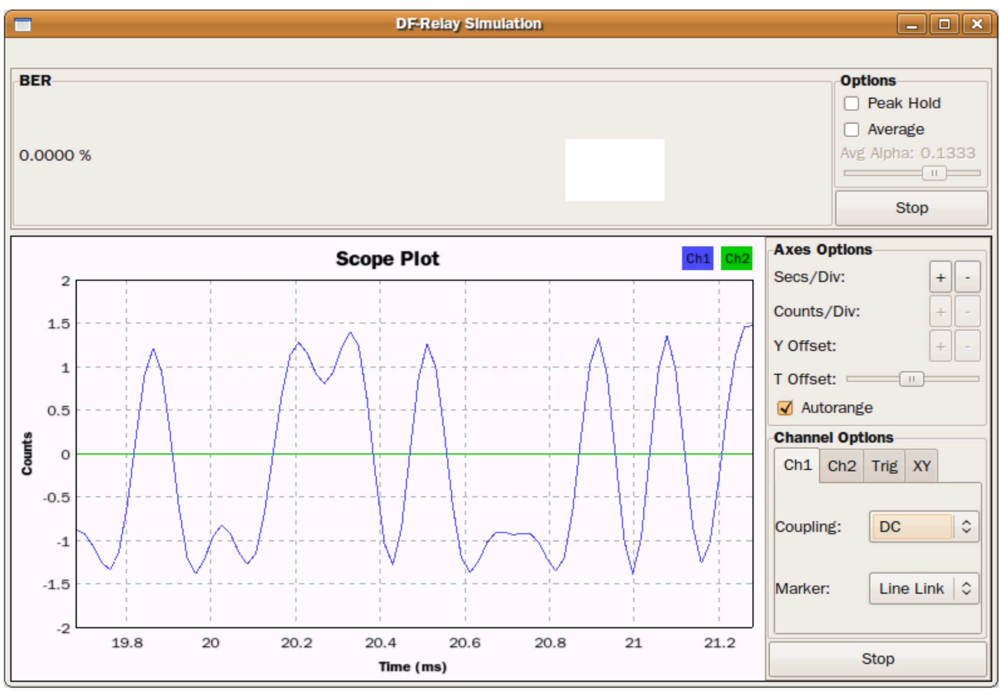


Figure 20: BER of demodulated signal at the relay node and the waveform of retransmitted symbol used in second time slot.

The symbols in Destination2.dat are combined with the symbols in Destination1.dat and stored in Combined.dat through Combined.grc. Figure 21 shows that the symbols in Destination1.dat and Destination2.dat are different. If the symbols in Destination1.dat and Destination2.dat are demodulated and compared with original bit stream, the bit-error-rates are 23.1784 % and 4.7750 %, respectively. Through Combined.grc, it was observed that the BER of the combined symbols is 0.0 %.

Figure 21: The combined symbol at the destination node

During the implementation of the Amplify and Forward technique, assume that the signal is already amplified when received by the relay station due to the noise. Hence, the Amplify and Forward technique offers a degraded SNR performance compared to the Decode and Forward technique. In this method, decoding is not performed at the relay station. The difference between a fixed amplify and forward, and Selective Decode and

Forward is that decode and forward performs well only when the SNR from source to relay SNR_{sr} is greater than the threshold value SNR_{th} [25]. Hence, the hardware implementation of selective decode and forward will be more complicated compared to fixed amplify and forward. Once the signal is received at the destination, the information can be demodulated either with Maximum Ratio Combining (MRC) or using non-MRC. In the case of non-MRC, the destination uses only the received signal from relay station during the second phase of transmission. The noise appended to the received signals at the relay station and the destination is assumed to be AWGN with zero mean and variance N_0.

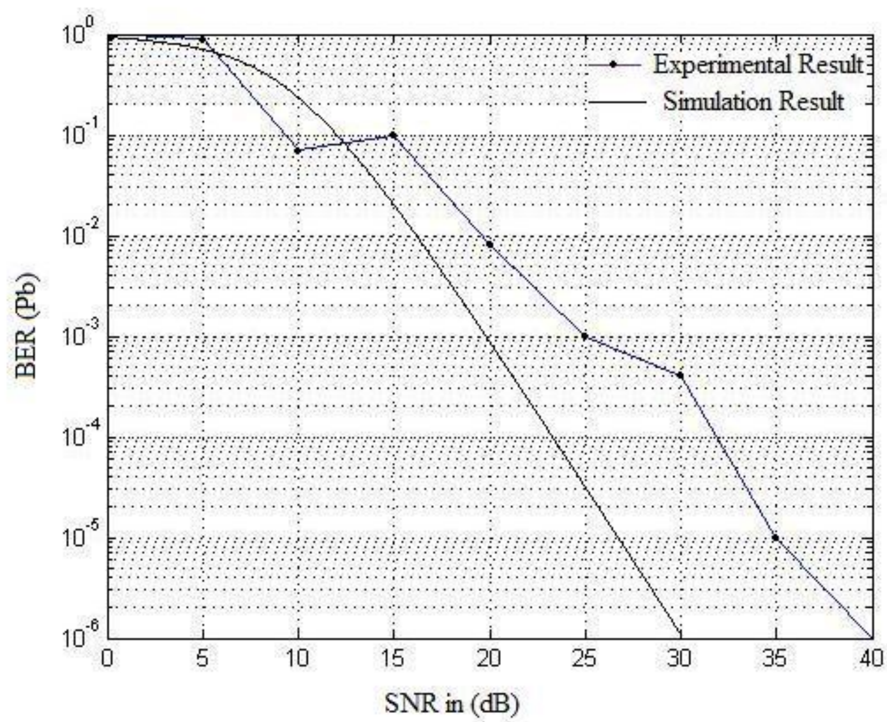


Figure 22: Comparison of BER vs SNR for Amplify and Forward

A graph is plotted between the simulation results obtained from Figure 1 and the experimental results. Figure 22 shows the comparison between the probability of bit error rate and SNR ratio for Amplify and Forward, for the setup we considered. It can be observed that the performance of amplify and forward is worse than the Decode and Forward (Figure 23), because the noise is also amplified at the relay node. Hence, for higher SNR's the performance degrades compared to Decode and Forward technique.

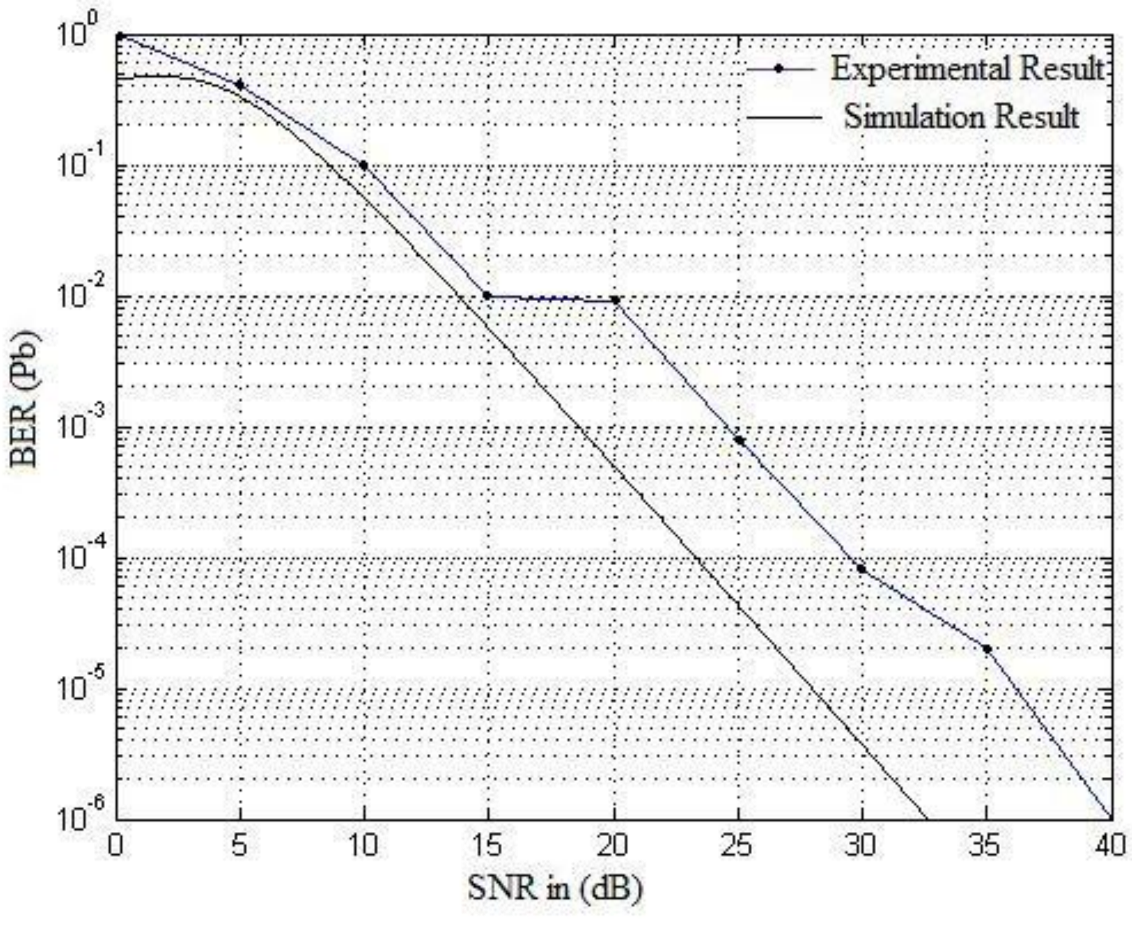


Figure 23: Comparison of BER vs SNR for Decode and Forward

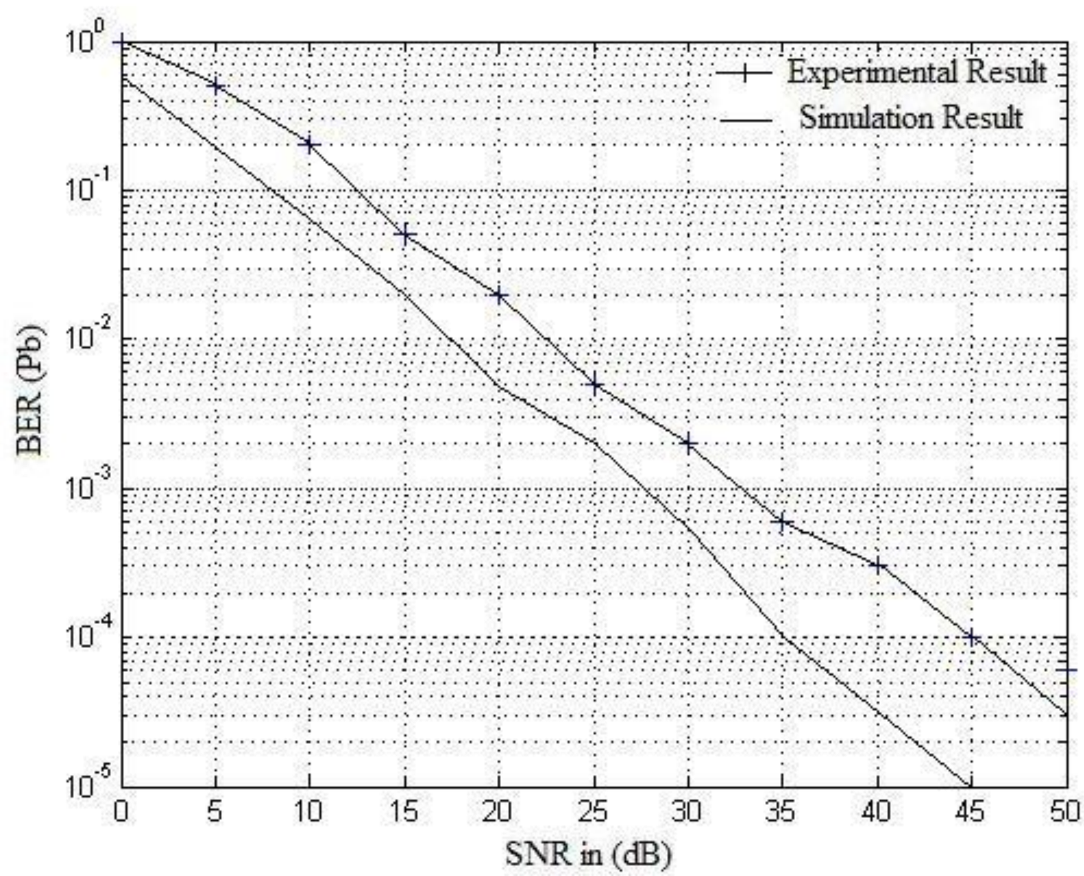


Figure 24: Comparison of BER vs SNR for Direct communication

In our experiments, we placed an obstacle to determine the attenuation offered by it. Without the obstacle, the system performs like a direct communication, i.e. during the first phase of transmission, if the destination receives the signal correctly, there is no necessity for the relay or second transmission. However, we observe the performance of the direct communication is worse than the simulation result as shown in Figure 24. This could be due to the interference caused by Wi-Fi channels in the same frequency range, multi path propagation, etc. A comparison between the experimental results of the cooperative communication is shown in Figure 25.

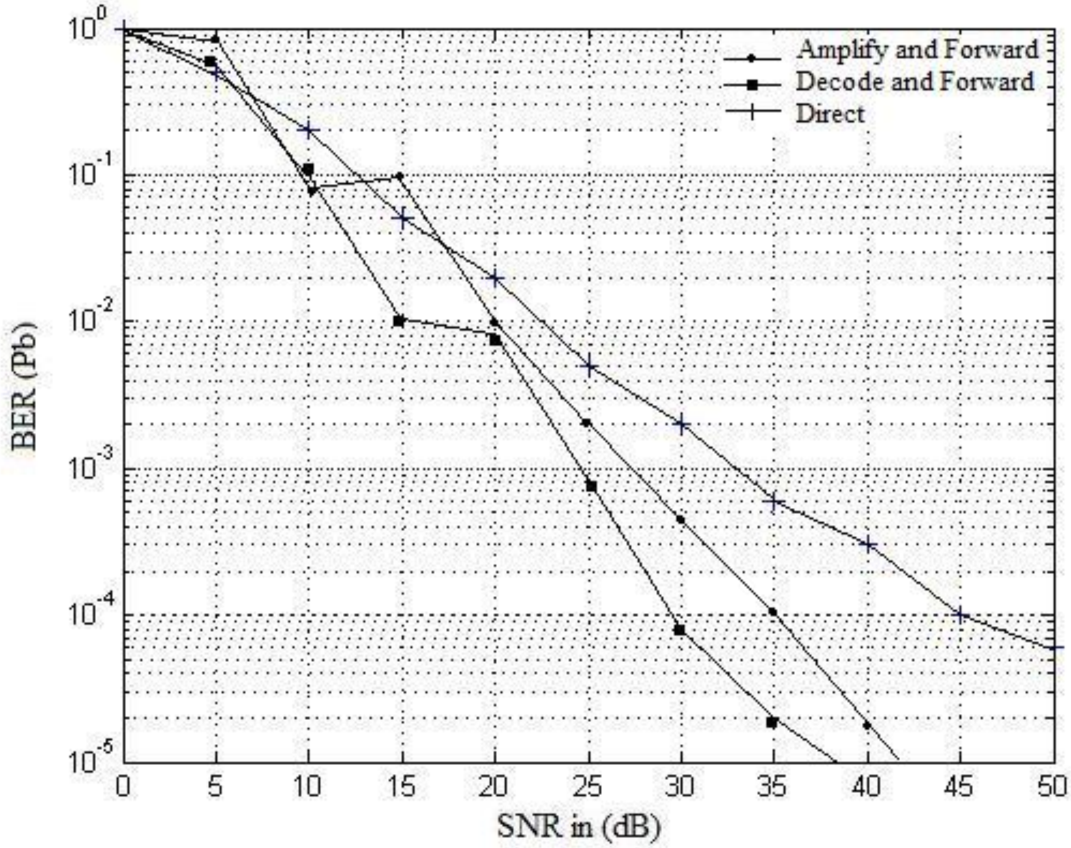


Figure 25: Comparison of experimental results for Amplify and Forward, Decode and Forward, and Direct communication

CHAPTER VI

CONCLUSION AND FUTURE WORK

Since the Amplify and Forward technique amplifies even the noise, the receiver threshold level should be maintained high. Due to this amplified noise, the demodulation becomes more complex. In this thesis work, we have considered some of the fundamental cooperative communication techniques and how to interpret their performance. We have compared the conventional simulation results of amplify and forward with the results of real time experimentation. For implementing this, we made use of software defined radios which are easily reprogrammable and the communication parameters can be modified easily without replacing the hardware. This method of understanding the latest communication techniques is more reliable compared to the simulation results because the simulations are confined to a pre-defined environment where we define all the parameters, including the noise.

For future work, we can also consider the Selective Amplify and Forward [4] technique, as it provides better power levels and also minimizes the BER. The bandwidth limitations caused by USRP are eliminated in USRP 2 which can have the transfer rates in the order of GB/s. Hence implementation of 802.11 is also possible with USRP 2. Another major advantage of USRP 2 is that it uses a Gigabit Ethernet instead of USB 2.0 which provides three times the bandwidth. A bigger FPGA is used for faster computations. To compensate for its speed, a higher resolution A/D and D/A converters are also used. By connecting two or more USRP 2's, a MIMO system can be realized. A set of 8 USRP 2's can be connected as a MIMO system with 4 transmitters and 4 receivers. In this experiment, we considered a hard-decision combining after the second phase of communication. Instead, we can also combine the signals prior to demodulating in order to cancel out the noise appended.

In CDMAC implementation, it is advantageous to implement two-node network compared to a multi-node network. This is because, the data rate reduces with multiple nodes and orthogonality is not possible [11], [13]. Furthermore, the relay selection is simpler in two-node cooperation rather than multi node cooperation [14].

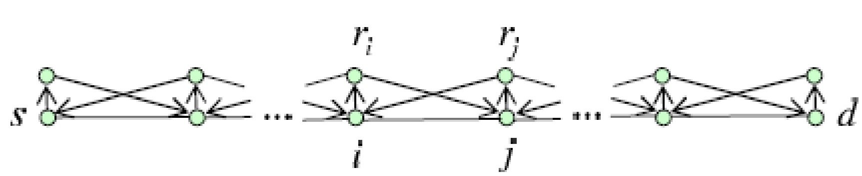


Figure 26: Representation of two-node CDMAC mechanism [14]

In figure 26, the data is to be transmitted cooperatively from the source (*s*) to destination (*d*). Each node including the source and destination is connected to the neighboring nodes. Consider a situation where node i forwards an information packet to the neighboring node j directly. If there is any error in the reception, the node and the relay (i and r_i) re-transmit the packet cooperatively. Similarly, the node j transmits an acknowledgement symbol to the sender and the relay nodes cooperatively with its connected relay r_j [14]. The conventional MAC technique is used if a direct communication can transmit the signals without any error, and the cooperative transmission is disabled. If the direct communication fails, the sender can re-transmit the frame, this time cooperatively with the relay. We can make use of this CD-MAC theory for our future work.

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