DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

COOPERATIVE COMMUNICATION TECHNIQUES WITH PHYSICAL LAYER NETWORK CODING

by
Can Okan SOYLU

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İZMİR

COOPERATIVE COMMUNICATION TECHNIQUES WITH PHYSICAL LAYER NETWORK CODING

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We have read the thesis entitled **"COOPERATIVE COMMUNICATION TECHNIQUES WITH PHYSICAL LAYER NETWORK CODING"** completed by **CAN OKAN SOYLU** under supervision of **ASST. PROF. DR. REYAT YILMAZ** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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Can Okan SOYLU

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ABSTRACT

The main objective of this thesis is to analyze and develop practical cooperative communication techniques with physical layer network coding (PLNC) for wireless communciation systems. It is aimed to show that PLNC is effective and simple techniques for various wireless systems. It provides network throuhgput to be doubled while the BER performance is almost same as one-way traditional network's performance. The first two systems that are discussed and simulated, are PLNC systems in 3-node and multi-node network where each user has symmetric at all angles such as lengths of information, modulation schemes, vice versa. The mapping algorithm is developed and tested for multi-node network where more than one relay exist.The next discussed system asymmetric PLNC system in which users have different length of information so they should use different modulation schemes. The mapping operation at relay is critical for the performance of system so the proper mapping algorithm is found and applied to the system. The simulation results of all systems which are investigated under AWGN and Rayleigh fading channels, show that the network throughput of PLNC system is doubled for acceptable BER performance as traditional network. The last discussed system contains orthogonal frequency division multiplexing (OFDM) technique which is good solution for high data rate transmission. OFDM is added to the proposed PLNC system and it is analyzed and evaluated under Rayleigh fading and Ricean fading channels. The outputs of simulation shows that OFDM can be implemented into PLNC system and the network throughput can be more improved. The different cooperation techniques, Decode and Forward (DF), Denoise and Forward (DNF), Amplify and Forward's (AF) are also discussed and compared in this thesis.

Keywords: Physical layer network coding (PLNC), cooperative communication, orthogonal frequency division multiplexing (OFDM), relay mapping.

FİZİKSEL-KATMAN AĞ KODLAMASI İLE İŞBİRLİKLİ İLETİŞİM TEKNİKLERİ

ÖZ

Bu tezdeki temel amaç, kablosuz haberleşme sistemleri için pratik fiziksel katman ağ kodlaması (FKAK) ile işbirlikli iletişim tekniklerinin incelenmesi ve geliştirilmesidir. Çeşitli kablosuz sistemler içinFKAK'nın etkili ve basit bir teknik olduğunun gösterilmesi hedeflenmiştir. Bu teknik, bit hat oranının tek yönlü geleneksel ağ performansıyla neredeyse aynı olmasına rağmen ağ veri hızının iki katına çıkmasını sağlamaktadır. İlk olarak, her kullanıcının her açıdan (bilgi uzunluğu, modülasyon tipi, vb.) simetrik olduğu 3 düğümlü ve çok düğümlü sistemler incelenmiş ve benzetimi gerçekleştirilmiştir. Birden fazla röle içeren çok düğümlü sistemler için eşlemleme algoritması geliştirilmiş ve test edilmiştir. Daha sonra, bilgi uzunlukları farklı olması nedeniyle farklı modülasyon tekniği kullanan kullanıcıları içeren asimetrik FKAK sistemi incelenmiştir. Eşlemleme işlemi sistem performansını doğrudan etkilediği için uygun eşlemleme algoritması bulunmuş ve sisteme uygulanmıştır.İncelenenen tüm sistemler için yapılan benzetim sonuçları, kabul edilebilir bit hata oranı için FKAK sistemlerinın ağ veri hızının geleneksel ağlarınkine göre iki kat arttığını göstermektedir. Son olarak incelenen sistemyüksek hızlı veri transferi için iyi bir çözüm olan Dik frekans bölümlemeli çoğullama (DFBÇ) tekniğini içermektedir. DFBÇ tekniğinin FKAK sistemine eklenmesi hedeflenmiştir. DFBÇ-FKAK sistemi modellenip, rayleigh ve ricean sönümlemeli kanallarında betimlemesi yapılmıştır. Benzetim sonuçları, DFBÇ'nin FKAK sistemine eklenebileceğini ve ağ veri hızını daha da geliştirebileceğini göstermiştir. Önerilen ve modellenen tüm sistemlerde farklı işbirlik teknikleri incelenmiş ve benzetimler aracılığıyla karşılaştırılmıştır. Bunlar çöz-ilet, sez-ilet ve yükselt-ilet teknikleridir.

Anahtar Sözcükler: Fiziksel-katman ağ kodlaması (FKAK), işbirlikli iletişim, Dik frekans bölümlemeli çogullama (DFBÇ), röle eşlemleme.

CONTENTS

Page

CHAPTER ONE
INTRODUCTION

We encounter some difficulties when we are dealing the wireless communication due to its harsh environment. The transmission over relays are used for better performance,since it creates spatial diversity by node cooperation and broadens coverage without requiring large transmitter powers. Because of these benefits, the relays become popular in cellular, ad-hoc networks and military communications.The one of the areas that the relays are used to enhance transmission, is network coding.

In the recent years,the evolution of network coding isvery rapid. The network coding can be used in a broad spectrum of applications, such as network multicast, distributed information storage, satellite network communications, network security, as well as quantum information (Hu,& Ibnkahla). The topics of researches on network coding changefrom wireline network to wireless networkssince the performance improvement achieved by network coding in wired networks is quite limited. The wireless network is targeted in most network coding researches. The network coding can improve the efficiency of limited-resource usage in wireless networks.

Inspired by traditional network coding, the Physical-layer Network Coding (PLNC)scheme have been proposed, which can further improve the throughput of a wireless network.Despite the idea of PLNC technique is new, there are many researches about PLNC at different angles.

One of the research area is the impact of PLNC on capacity. The one of researches investigated both one-dimensional and two-dimensional random wireless networks andshows that the physical-layer network coding scheme can substantially improve the throughput capacity(Lu, Fu & Qian, 2008). The other research about capacity also reveals thatPLNC can achieve 100% improvement in physical-layer throughput over the traditional multi-hop transmission scheduling scheme, and 50% over the straightforward network coding scheme (Zhang, Liew& Lam, 2006).

The another research area is the BER perforamance of PLNC. The one research discussed theperformance of three-node (one relay) network. The results of this research show that the two time slot PLNC scheme performs worse than the four time slot transmission scheme in terms of sum-BER at high SNR, but better than the four time slot transmission scheme in terms of maximum sum-rate for all SNRs. A three time slot PLNC scheme, which we showed achieves a performance which either lies between, or exceeds, the performance of the two time slot PLNC and four time slot transmission scheme. Moreover, an opportunistic relaying scheme with K relays, and showed that the use of additional relays can significantly increase system performance, and offers a diversity order K times the diversity order when only one relay is used (Louie, Li & Vucetic, 2009). The other research is to find exact BER analysis of PLNC system over Rayleigh fading channels. It is stated that the instantaneous BER of PLNC system is found and it can be applied in many applications (Park, Choi & Lee, 2011).

The securiy is anotherinteresting topic about PLNC. The one research investigates the symbol error performance of a potential eavesdropper in the PLNC system. It is showed that it is difficult for the relay node to decode individual message because the PLNC system tries to send different signals to the same relay node over the same channel simultaneously, which indicates that PLNC can provide security means against passive eavesdroppers (Lu, Fu, Qian & Zhang, 2009).

In this thesis, cooperative communication with Physical Layer Network Coding is discussed for different scenarios. The Bit Error Rate (BER) performances of the proposed systems are investigated under Additive White Gaussian Noise (AWGN), Rayleigh fading and Ricean fading channels. The proposed systems are analyzed for three cooperative methods: Amplify&Forward, Decode&Forward and Denoise&Forward.

1.1 Organization of the Thesis

In chapter one, the reasons why this thesis is written, are stated. The organization of thesis is also explained briefly. In the next chapter, topics of of wireless communication, fading phonemena, fading channels, Phase Shift Keying modulation scheme and cooperative communication are discussed to maintain background of thesis.

In chapter three, idea of physical layer network coding is stated and its main characteristics are analyzed. Transmission schedules of PLNC and traditional network are compared. The practical PLNC system design is also discussed. The working principles of the proposed PLNC system in Alice-Bob-Relay model are studied. Moreover, PLNC system is tested for multi-node network instead of Alice-Relay-Bob model. The mapping algorithm is developed and tested for multi-node network. Finally, the performance of these systems are simulated in AWGN and Rayleigh fading channel for three cooperative methods.

In chapter four, asymmetric PLNC system is discussed. The 'asymmetry' term means that users have different length of information in this chapter. Since the mapping operation is key factor of system, the right mapping algorithm is developed. The modulation/demodulation process of proposed system is studied. Then, the simulation of BER performance of system is made and the simulation outputs are discussed.

In chapter five, Orthogonal Frequncy Division Multiplexing (OFDM) scheme is implemented to the proposed PLNC system to enhance network throughput. The basics of OFDM, the implementationof it to the PLNC system and BER performance of proposed system are analyzed sequantially.

Conclusions about the presented work are given in chapter six.

CHAPTER TWO
FUNDAMENTALS OF WIRELESS COMMUNICATION

2.1 Wireless Communication

The wireless channel environment determines the performance of wireless communication systems. The wireless channel is dynamic and unpredictable as opposed to the wired channel (Cho, Kwin, Yang & Kang, 2010).Since the medium introduces much impairment to the signal, communication through a wireless channel is a challenging task.Noise, attenuation, distortion and interference are the main disturbing factors for wireless transmitted signals (Liu, Sadek, Su & Kwasinski, 2009).

Radio propagation refers the transmission of radio waves from source to destination in wireless communication. There are three main modes of physical phenomena: reflection, diffraction, and scattering which essentially affect the radio waves in the course propogation. Reflection is the physical phenomenon that occurs when a propagating electromagnetic wave collides wtih an object with very large dimensions compared to the wavelength, for example, surface of the earth and building. Diffraction refers to various phenomena that occur when the radio path between the transmitter and receiver is obstructed by a surface with sharp irregularities or small openings. Scattering is the physical phenomenon that forces the radiation of an electromagnetic wave to diverge from a straight path by one or more local obstacles, with small dimensions compared to the wavelength(Cho & Other, 2010). Radio wave's propogation is hard to predict and it is a complicated process that is managed by reflection, diffraction, and scattering, whose intensity depends on environments and instances.

Fading is an other important characteristic of a wireless channel. It refers to the change of the signal amplitude over time and frequency. The fading, modelled as a random process, changes with time, radio frequency or geographical position. Fading causes signal degradation as a non-additive signal disturbance in the wireless channel in contrast to the additive noise. Fading affects the propagation of a radio wave in different ways; multipath propagation (multi-path fading), or to shadowing from obstacles, referred to as shadow fading.

There are two different main types of fading phenomenon: large-scale fading and small-scale fading. Figure 2.1 shows the classificiation of fading channels. Large-scale fading occurs if thetransmitted signal moves through a large distance. The reasons of this type of fading are path loss of signal as a function of distance and shadowing by large objects such as buildings, intervening terrains, and vegetation. On the other hand, small-scale fading means rapid changes of signal levels because of constructive and destructive interference of multiple signal paths when the signalis transmitted between short distances (Tse, Viswanath, 2004). The small-scale fading is divided into two sub categories; multi-path fading and time variance. The first sub category is composed frequency selectivite fading and flat fading and the fading type is set on the relative extent of a multipath. The time variance can also be classified as either fast fading or slow fading.The rapidity of variation of the transmitted signal determines whether the channel acts as slow fading or fast fading. (Cho & Other, 2010).

The relationship between large-scale fading and small-scale fading is illustrated in Figure 2.2. Large-scale fading is affected by the mean path loss that decreases with distance and shadowing that changes along the mean path loss. The received signal strength may be different even at the same distance from a transmitter, due to the shadowing caused by obstacles on the path. Furthermore, the scattering components incur small-scale fading, which finally yields a short-term variation of the signal that has already experienced shadowing. In following part, small-scale fading are discussed in detail.

2.1.1 Flat Fading

The most common type of fading is flat fading which occurs if the signal symbol time duration, T_s, is greater than maximum excess delay, T_m. In other words, the received multipath components of symbol arrive within the symbol time duration.

Narrowband channels term is also used for flat fading channels since the bandwidth of the applied signal, $W \approx 1/T_s$, is smaller than the bandwidth of the fading channel, f_0.

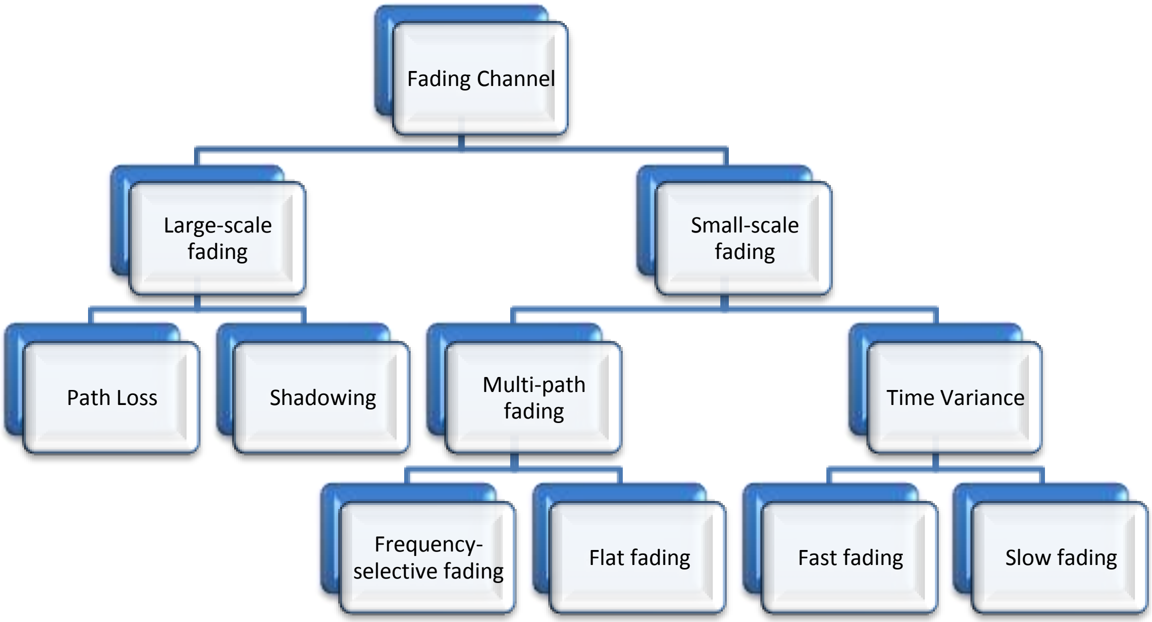

Figure 2.1 Classification of fading channels

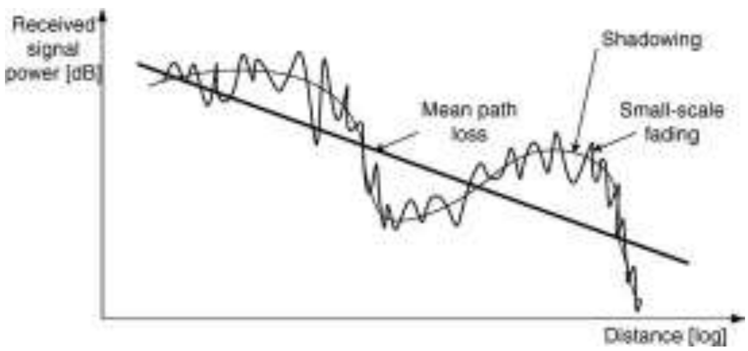

Figure 2.2 Large-scale fading vs. small-scale fading

2.1.2 Frequency Selective Fading

Inter-Symbol interference (ISI) is caused by frequency selective fading. As oppesed to flat fading, the channel is said to be frequency selective when the maximum excess delay of the channel, T_m, is greater than symbol duration, T_s.The frequency selective channel deletes certain frequency components of the transmitted signal. Frequency selective channels are wideband channels since the coherence bandwidth, f_0, is narrow compared to signal bandwidth, *W*.

2.1.3 Slow Fading

If the channel impulse response changes slower than the change rate of the transmitted baseband signal, the channel is said to be slow fading channel. This means coherence time, T_0, of the channel is greater than symbol time, T_s.In this case, Doppler spectral broadening (fading bandwidth), f_d, is narrower than signal bandwidth, W.

2.1.4 Fast Fading

In contrast to slow fading, if the coherence time of the channel, T_0 , is smaller than the symbol duration, the transmitted signal undergoes fast fading.Fast fading increases the Doppler spread of the channel, and the signal bandwidth compared to the fading bandwidth is very small in fast fading case. In practice fast fading occurs for very low data rates.

2.2 Wireless Channels

The performance of wireless devices is evaluatedby considering the transmission characteristics, wireless channel parameters and device structure. The performance of data transmission over wireless channels is well captured by observing their BER, which is a function of SNR at the receiver (Babu & Rao, 2011). In wireless channels, several models have been proposed and investigated to calculate received SNR. All the models are a function of the distance between the sender and the receiver, the path loss exponent and the channel gain. Several probability distributed functions are available to model a time-variant parameter i.e. channel gain. We use the three important and frequently used distributions in this thesis. These are AWGN, Rayleigh and Ricean models.

2.2.1 AWGN Channel

In AWGN channel, the linear addition of wideband or white noise with a constant spectral density (expressed as watts per hertz of bandwidth) and a Gaussian distribution of amplitude is only impairment to communication (Babu & Rao, 2011). Fading, frequency selectivity, interference, nonlinearity or dispersion don’t have influence for this model. But, it lets us to gaininsight into the underlying behavior of a system since it is simple and tractable. The causes of white gaussian noise are shot noise, thermal vibrations of atoms in conductors, black body radiation from the earth and other warm objects, and from celestial sources such as the sun. The AWGN channel is a good model for many satellite and deep space communication links although it is not sutiable for most terrestrial links because of terrain blocking, interference and multipath.

AWGN isalso used to transmit signal while signals travel from the channel and the background noise of channel is simulated. The mathematical expression in received signal can be shown as $r(t)=s(t)+n(t)$ where $s(t)$ is transmitted signal and $n(t)$ is background noise.The white Gaussian noise is added to the signal that passes through AWGN channel. In other words, the transmitted signal gets disturbed by a simple AWGN process.

2.2.2 Rayleigh Fading Channel

Rayleigh fading models assume that the magnitude of a signal that has passed through such a transmission medium will vary randomly, or fade, according to a Rayleigh distribution. The Rayleigh random variable has a radial component of the sum of two uncorrelated Gaussian random variables. Rayleigh fading is a reasonable model when there are many objects in the environment that scatter the radio signal before it arrives at the receiver. The model is suitable for tropospheric andionospheric signal propagation. The Rayleigh fading can also be a useful model in heavily built-up city centres where there is no line of sight between the transmitter and receiver and many buildings and other objects attenuate, reflect, refract, and diffract the signal.

In this thesis, two different rayleigh fading channel models are used. For the systems that are discussed in third and fourth chapter are simulated under fast fading channels however the last proposed system is simulated under frequency selective fading channel. For the fast fading channel, the narrowband rayleigh fading is modelled often as a random process that multiplies the radio signal by a complex-valued Gaussian random function. The spectrum of this random function is determined by the Doppler spread of the channel. Thus one can generate two appropriately filtered Gaussian noise signals and use these to modulate the signal and a 90 degree phase shifted version of the signal.

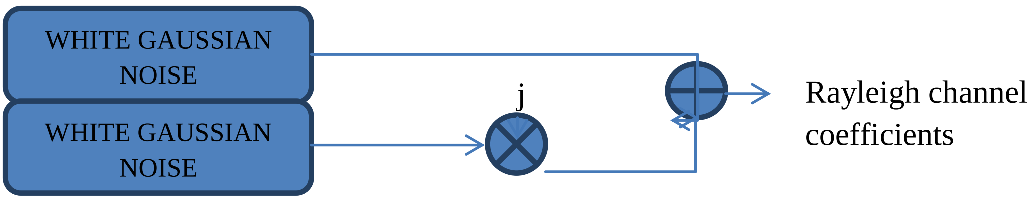

Figure 2.3 Rayleigh fading simulator

For the last system that contains OFDM, Young's model is used for simulating the rayleigh fading channel. The block diagram of Young's model are illustrated in figure 2.4. Rayleigh fading is caused due to multipath reflections of the received signal before it reaches the receiver and the Doppler Shift is caused due to the difference in the relative velocity/motion between the transmitter and the receiver. This scenario is encountered in day to day mobile communications.

According to this model, the steps to simulate Rayleigh Fading + Doppler effect is summarized as :

- ✓ Generate two Independent - Identically Distributed (I.I.D) zero mean Gaussian variates with required variance.

- ✓ Multiply them with the Doppler Filter transfer function in frequency domain .
- ✓ One component is multiplied with '-j' to make it complex and then added as follows: $X_k = F_k A_k - jF_k B_k$.
- ✓ After obtaining Xk its inverse Discrete fourier transform is taken.In Matlab this will be the Inverse Fast Fourier transform (IFFT) and time domain representation will be obtained which is xn.
- ✓ In the last block, the absolute value is taken.

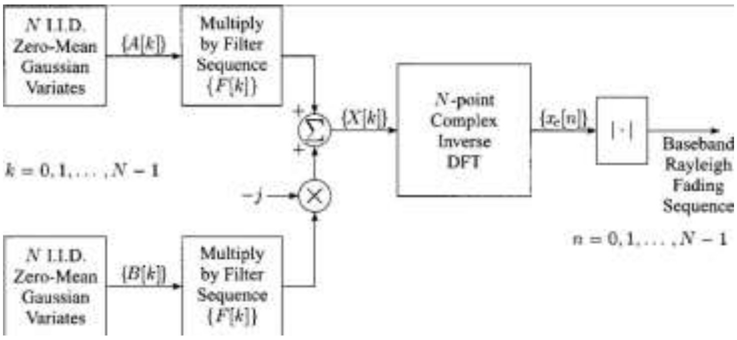

Figure 2.4 Young's model for rayleigh fading channel

2.2.3 Ricean Fading Channel

The Ricean fading model is similar to the Rayleigh fading model, except that in Ricean fading, a strong dominant component of receivde signal is present. This dominant component is a stationary (non fading) signal and is commonly known as the LOS (Line of Sight Component). In Ricean fading, the amplitude gain is characterized by a Ricean distribution (Babu & Rao, 2011).The signal arrives at the receiver by several different and at least one of the paths is lengthening or shortening. If one of the paths, typically a line of sight signal, is much stronger than the others, then Ricean fading occurs.There are two parameters: K and Ω which can describe a Ricean fading channel.K is the ratio between the power in the direct path and the power in the other, scattered, paths. Ω is the total power from both paths, and acts as a scaling factor to the distribution.

The rural area (RA) models are characterized by Ricean fading on the first path, and Rayleigh fading on the remaining paths. The first path has a RICE Doppler spectrum, while the remaining paths have a CLASS Doppler spectrum. The line-of-sight component of the first path has a Doppler shift of 0.7 times the maximum Doppler shift of the diffuse component. By default, a Ricean channel object has a RICE (Jakes + impulse) spectrum on the first path, and a CLASS (Jakes) spectrum on subsequent paths. The ricean channel coefficients can be formulated as

$$H = \sqrt{\frac{K}{K+1}}H(d) + \sqrt{\frac{1}{K+1}}H(s)$$

where H(d) is direct componets and H(s)is scattered components channel which makes like Rayleigh fading.

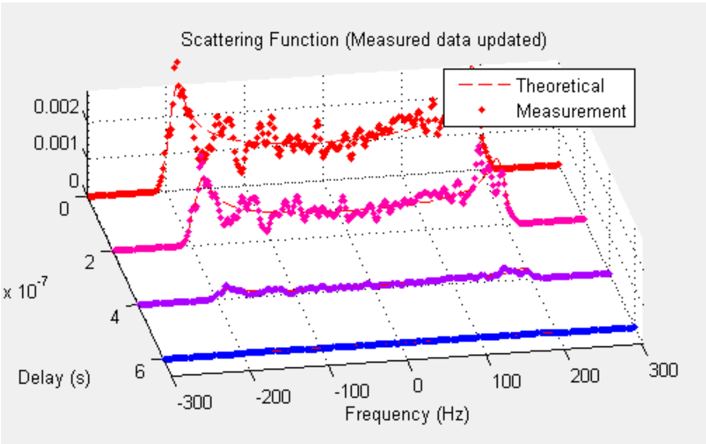

Figure 2.5 Scattering function of ricean fading channel

2.3 Modulation Scheme

The digital data is represented by the number of discrete signals in digital modulation scheme. In Phase-Shift Keying (PSK), finite number of phases, each assigned a unique pattern of binary digits, are used. Each phase generally encodes an equal number of bits and it represents an unique symbol.At the receiver side, the demodulator tries to detect the phase of the received signal and decidescorresponding symbol it represents, to extract the binary digits that aims to be transmitted.

In phase modulation the information bit stream is encoded in phase of the transmitted signal. Specifically, over a time interval of T_s, $K = \log_2 M$ bits are encoded into the phase of the transmitted signal $s(t)$, $0 \le t < T_s$. The transmitted signal over this period $s(t)=s_I(t)\cos(2\pi f_c t)-s_Q(t)\sin(2\pi f_c t)$ can be written in terms of its signal space representation as $s(t)=s_{i1}(t)\phi_1(t)-s_{i2}(t)\phi_2(t)$ with basis functions $\phi_1(t)=g(t)\cos(2\pi f_c t+\phi_0)$ and $\phi_2(t)=-g(t)\sin(2\pi f_c t+\phi_0)$, where *g(t)* is a shaping pulse. To send the ith message over the time interval $\left[kT,(k+1)T\right]$, we set $s_I(t)=s_{i1}g(t)$ and $s_Q(t)=s_{i2}g(t)$. These in-phase and quadrature signal components are baseband signals with spectral characteristics determined by the pulse shape *g(t).* In particular, their bandwidth *B* equals the bandwidth of *g(t),* and the transmitted signal *s(t)* is a passband signal with center frequency f_c and passband bandwidth *2B.* In practice we take $B=K_g/T_s$ where K_g depends on the pulse shape: for rectangular pulses $K_g=.5$ and for raised cosine pulses $0.5\le K_g\le 1$. Thus, for rectangular pulses the bandwidth of *g(t)* is $.5/T_s$ and the bandwidth of *s(t)* is $1/T_s$. Since the pulse shape *g(t)* is fixed, the signal constellation for phase modulation is defined based on the constellation point: $(s_{i1},s_{i2})\in\Re^2,\ i=1,\dots,M$. The complex baseband representation of *s(t)* is

$$s(t)=\Re\left\{x(t)e^{j\phi_0}e^{j(2\pi f_c t)}\right\}$$

where $x(t)=s_I(t)+js_Q(t)=(s_{i1}+js_{i2})g(t)$. The constellation point $s_i=(s_{i1},s_{i2})$ is called the symbol associated with the $\log_2 M$ bits and T_s is called the symbol time. The bit rate for this modulation is K bits per symbol or $R=\log_2 M/T_s$ bits per second (Goldsmith, 2005). There is also differential phase-shift keying modulation scheme that depends on the difference between successive phases. The transmitter decide the phase of transmitted signal by comparing the two adjacent symbols instead of operating with respect to a constant reference wave. In this system, the demodulator determines the changes in the phase of the received signal rather than the phase itself. The implementation of DPSK can be much simpler than ordinary PSK since there is no need for the demodulator to have a copy of the reference signal to determine the exact phase of the received signal. However, it produces more erroneous demodulations.

2.3.1 PSK Modulation Schemes

The basicform of phase shift keying is Binary PSK (BPSK). Two phases are used in BPSK and they are separated by 180° from each other and the position of constellation points does not matter. Since BPSK takes the highest level of noise or distortion to make the demodulator reach an incorrect decision, it is the most robust of all the PSKs. But, only one bit/symbol is modulated so that it is unsuitable for high data-rate applications.

In QPSK scheme, four points are used on the constellation diagram around a circle that distance between points are equal. Two bits per symbol can be encoded with four phases in QPSK.By using Gray coding, the bit error rate (BER) is minimized.

Eight-PSK is usually the highest order PSK constellation deployed because the error-rate becomes too highwith more than 8 phases. 8-PSK encodes three bits per symbol and the distance between the closest points are 45° around a circle. Figure 2.3 shows the three different PSK modulation schemes and BER performance of them is illustarated in Figure 2.4.

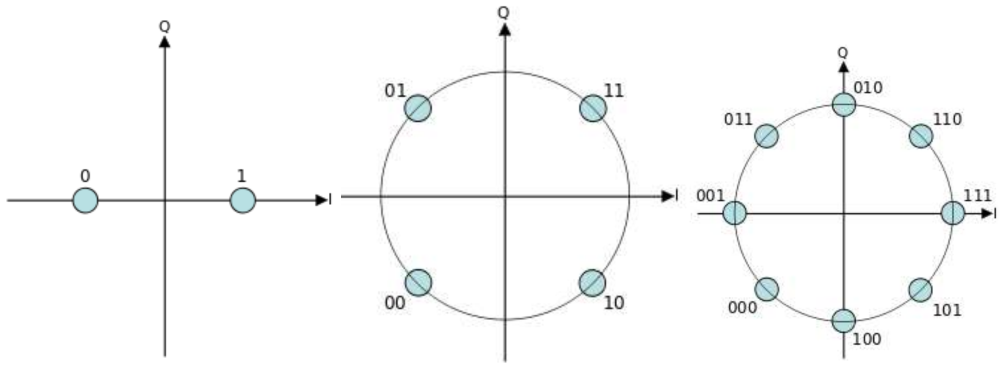

Figure 2.6 BPSK, QPSK and 8-PSK constellation diagram

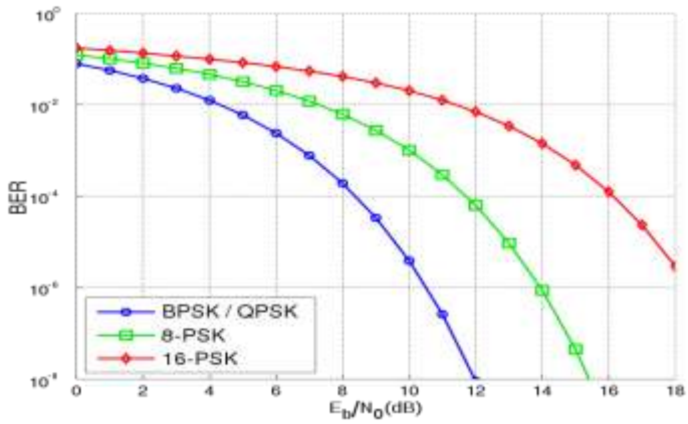

Figure 2.7BER performances of BPSK, QPSK and 8-PSK

2.4 Cooperative Communication

The communication links can be highly uncertain because of multipath fading in point-to-point wireless communications, therefore communication between each pair of transmitter and receiver may not be steady (Su, Sadek & Liu, 2007). To generate diversity and to combat effects of fading, transmitting independent copies of the signal is useful known method. Spatial diversity, one of the most known methods, is generated by transmitting signals from different locations. By this way, independently faded versions of the signal arrive at the receiver. Transmitter should have more than one antenna to create transmit diversity. But in practice, many wireless devices have only one antenna deu to the limitation of size and hardware complexity.To solve this problem, a new method is proposed thatenables single antenna user in a multi-user environment to share their antennas and allows them to achieve transmit diversity and it is called cooperative communication. In other words, it creates a virtual MIMO system (Hunter & Hedayet, 2004).

The broadcast nature of wireless communications suggests that a source signal transmitted towards the destination can be “overheard” at neighboring nodes. The basic idea of the cooperative communications is that all users or nodes in a wireless network can help each other to send signals to the destination cooperatively. Each user’s data information is sent by both the user and the neighbours. Therefore, it is more reliable for the destination to detect the transmitted information because the chance that all the channel links to the destination fail is very low. Multiple copies of the transmitted signals by cooperated users can significantly improve the system performance and robustness (Su, Sadek & Liu, 2007). It also improves communication capacity, speed; reduces battery consumption and extends network lifetime; increases the throughput and stability region for multiple access schemes; expands the transmission coverage area (Liu, Sadek, Su & Kwasinski, 2009).

In cooperative communications, independent paths between the users are created by the help of a relay channel. The relay channel can be thought of as an adjunct channel to the direct channel between the source and destination (Liu & Other). The basic relay channel model, which is shown in Figure 2.5, consists of three terminals: a source, a destination, and a relay which improves communication quality by receiving and broadcasting information between the source and the destination. The fading paths from two users generate spatial diversity since they are statistically independent.

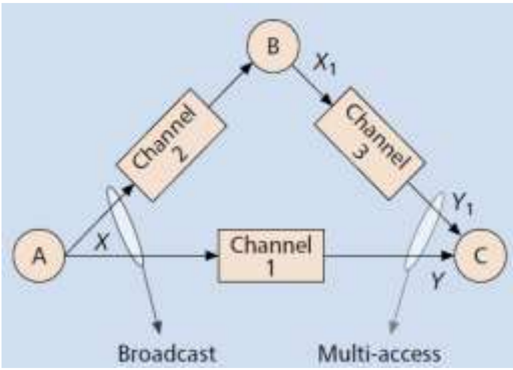

Figure 2.8 Basic relay model

There are two phases in cooperative transmission protocol for wireless networks. In the first phase,all usersbroadcasttheir information to the wireless network, and the destination and other users get the information at the same time. In the next phase, the frames that are received by user in phase 1,are forwarded to their destination by help of other users.TheTime-Division Multiplexing Access (TDMA), Frequency-Division Multiplexing Access (FDMA) or Code-Division Multiplexing Access (CDMA) schemes can be used for transmitting signals through orthogonal channels in both phases.

An important pointin cooperative communication is how the relay nodes process the received signal from the source node. In terms of processing, there are two main categories in cooperative communications protocols; fixed relaying schemes and adaptive relaying schemes. If the channel resources are shared between the source and the relay in a fixed manner, it is called fixed relaying. It provides easy implementation, but the efficiency of bandwidth is low.On the other hand, adaptive relaying schemescan be solution for this problem. The message is processed at the relay if the SNR of received signalexceeds a certain threshold. In the contrary case, the relay does not action on the message (Liu & Other). We will look at the fixed relaying mechanisms in details.

2.4.1 Decode and Forward (DF) Method

The signals transmitted by source are decoded first, then they are broadcasted to the destination by the relay.The multiple copies of user information from sender and the relays are received by the receiver and they are used to extract the related information. We can see that if one cooperating node can't decode the symbols properly, the error is propogated among the nodes. To prevent this, forward error correction (FEC) or perfect regeneration should be used at the relays. However, it is not an option for a delay limited networks.

2.4.2 Amplify and Forward (AF) Method

As opposed DF method, the received signals are not decoded by a cooperating node in this method. These signals are amplified with noise to regain the original amplitude. However, a pilot information is needed for the knowledge of the channel state between source-to-relay links to correctly decode the symbols sent from the source. It results overhead in terms of additional bandwidth.

When the channel link quality between the relay and the destination is much stronger than that between the source and the relay, the performance advantage of the DF cooperation protocol becomes significant. In other words, if the constellation size of the signaling is small, DF protocol is more useful than AF. However, since DF method involves decoding process at the relay, the complexity of the AF method is less than that of the DF method. It means the AF cooperation protocol may be used to reduce the system complexity for high data-rate cooperative communications (Su, Sadek & Liu, 2007).

CHAPTER THREE
COOPERATIVE COMMUNICATION WITH PHYSICAL LAYER NETWORK CODING

3.1 Physical Layer Network Coding (PLNC)

There are different cooperative communication systems based on resource sharing: frequency, antenna, and relay node. Cognitive radio is an example for the first one. For more efficient use of frequency spectrum, different users may temporarily share their resources with others. Frequency bands which are assigned to primary users, are not occupied all the time therefore secondary users may use these unused frequency bands. The next type of cooperative communication is used to create spatial diversity through antenna sharing althoughusersdon't havemultiple antennas. There are two phases in this method.Information flowis from source to relay nodes in first phase, then the flow is from the relay nodes to the destination in a collaborative way. Cooperative communication through PLNC is in the last cooperation methods, which can be defined as a way to share relay nodes. The functions of the relay node are different from the antenna sharing case. Firstly, an arithmetic function is made by relay nodes to combine information received from users, and then they broadcast the result of the function to the network (Fu, Lu, Zhang, Qian, Chen, 2010).

Investigation about network coding started at 2000. Unlike the classic coding techniques such as source coding and channel coding, network coding is implemented at the intermediate nodes of a network instead of end terminals. The functionalities of intermediate (or relay) nodes copy received information from the previous nodes and forwarding the information to the next nodes in traditional network. However, the relaynodes process the information from multiple sources first and then they forward it. It provides larger network throughput.

The relays may manipulate the information over the different OSI layers. If the manipulation is in the physical layer, this technique called Physical Layer Network

Coding. Actually it is easy to work in physical layer because of broadcast nature of signals at wireless network.The information is carried by electromagnetic (EM) waves at the physical layer and it is often received by more than one node. A receiver may also receivemultiple EM signals from different sources simultaneously. This may cause interference in the traditional network so the traditional network should be designed to overcome this interference. However, this type of interence can be used to improve throughput performance in PLNC.

In order to achieve that, two following conditions should be met. Firstly, multiple received signals must be converted into interpretable output signals simultaneously by each relay node. Secondly, a destination should extract the information addressed to it from the transmitted signals by the relay(Fu & Other, 2010). The PLNC meets these conditions through a proper modulation/demodulation technique at relay nodes. It uses Galois Field (2^n) additions to add EM signals so that the interference becomes part of the arithmetic operation.

The selection of relaying mechanism is also most important issues for the relay node. In the AF mode, the relay node just normalizes instead of decoding the received signal and forwards it to next hop. However, In the DF mode, relay nodes first decode the received message and then forward the information to their neighbors in DF method. Since it is hard to detect the individual signals, only the summation of the two signals is interest not separately (Fu & Other, 2010).

3.1.1 Comparison of Traditional Network and Physical Layer Network Coding

The function of relay nodes is important issue in network coding.In traditional network, the relay nodes just copy and forward the received information to their neighbors. However in network coding, received information from different sources will be first combined through a simple bitwise-XOR operation and then the relay nodes forward the summation to next receivers in network coding system (Uysal, 2010). As it may be predicted by its name, PLNCis different from traditional network coding in terms of the layers over which the manipulation of multiple information flow occurs (Fu & Other, 2010).

3.1.1.1 Traditional Transmission Scheduling Scheme

In traditional networks, user 1 and user 3 send their information to user 2 in the different time slot for avoiding interference.As shown in Figure 3.1, four time slots are needed for the exchange of two frames in opposite directions.In the first time slot, user 1 sends its data to user 2. In the next time slot, user 2 forwards the received data to user 3. In the following two time slots, information of user 3 is delivered user 1 by through user 2. In this scheme, only one signal should exist over the channel at each time slots(Uysal, 2010).

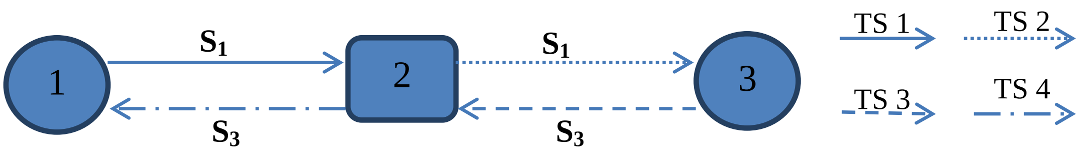

Figure 3.1 Traditional scheduling scheme

3.1.1.2 Straightforward Network Coding Scheme

Figure3.2 shows the straightforward network coding in the three-node wireless network. In this scheme three time slots are needed for exchange information of user 1 and user 3. Firstly, user 1 sends its data (S_1) to relay node (user 2) then user 3 sends its data (S_3) to node 2 in the next time slot. After receiving messages fromuser 1 and user 3, user 2 encodes frame its data (S_2) as follows: $S_2 = S_1 \oplus S_3$, where $\oplus$ denote bitwise exclusive OR operation then it broadcasts S_2 to both user 1 and user 3. The extraction of related information is being made as follows by user 1;

$$S_1 \oplus S_2 = S_1 + (S_1 \oplus S_3) = S_3$$

Using the same method, user 3 can extract S_1. This scheme provides throughput improvement of %33 over the traditional transmission scheduling scheme.

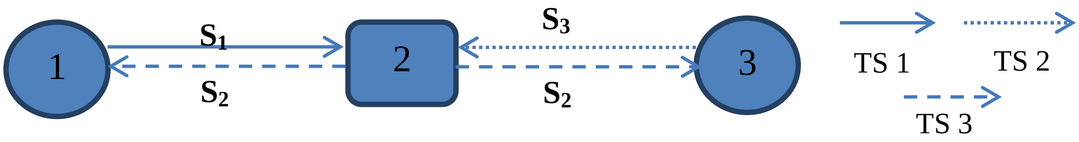

Figure 3.2 Straightforward network coding scheme

3.1.1.3 Physical-Layer Network Coding

The information can be exchanged within two steps in physical layer network coding which provides better network throughput. We can call MAC phase for the first time slot when user 1 and user 3 send their information (S_1, S_3) to relay node user 2. Then, in the broadcast phase, user 2 broadcasts manipulated informationto bothuser 1 and user 3.

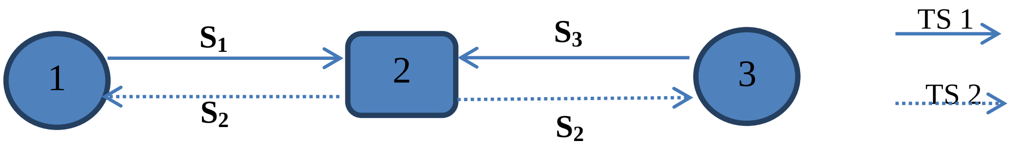

Figure 3.3 Physical layer network coding scheme

In a traditional system, the signals are mixed with the other signals if there is more than one transmission over the same frequency band, and the receiver cannot decode any of them. However, the superposition nature of physical signals actually provides the information combination in a PLNC system so that the receiver can extract the related information by using XOR operation. By using this characteristic of EM signals, the number of time slots is halved in PLNC compared to traditional system.

According to research of Hunter and Hedayet, the channel capacity, which means reliable maximum data rateof the channel between source and destination, is doubled compared to traditional network.

3.1.2 Practical PLNC System Design

There are serious obstacles to use the PLNC scheme inreal life. The main issues are time synchronization, carrier synchronization and power control.In cooperative communications, time synchronization is an important issue since the transmission protocol is implemented through time slots. The time slots have equal length and they are assigned to the even and odd nodes (all these nodes in network are also divided to even and odd nodes). So, the network should be globally synchronized.The researchs shows that the failure of time synchronization causes decrease in desired signal power and ISI. However, it is shown that the performance degradation of 1 to 3dB due to various synchronization errorscan be neglectedto improve the network throughput more than 100%.

Each terminaltransmit messages over the same frequency simultaneously so carrier synchronization should be provided to use benefits of PLNC. When the carrier synchronization is lost, the performance of network aims to degrade. According to Zhang research [7],the average power penalty is less than 1dB when the phase offset is distributed uniformly over $[-\pi/2, \pi/2]$.Even in the worst case, the degradation of pergormance is acceptable in the wireless channels.

The next important issue is power control since the bit error rate (BER) depends on power control. The BER becomes minimal if relay node has the same received SNRs from both users. However, the channels between users and relay are hardly same. The power control mechanism should adjust the power of both user's transmistter for balanced SNRs at relay node. The SNR balance also provides security in PLNC system since the information of users is transparent to the relay node, it interests only the summation.Therefore, nobody from outside extracts the information unless it has the same SNR, which is unlikely.

We can now propose and design PLNC system for different cases. Three-node network will be investigated and simulated first. Then, PLNC is applied for multinode environment.

3.2 System Model & Simulation in 3-node Network

This section investigates issues in the modulation and demodulation techniques for the different scenarios. Since the "Alice-Relay-Bob" model is a fundamental block of the proposed scheme, the analysis of this system is focused.

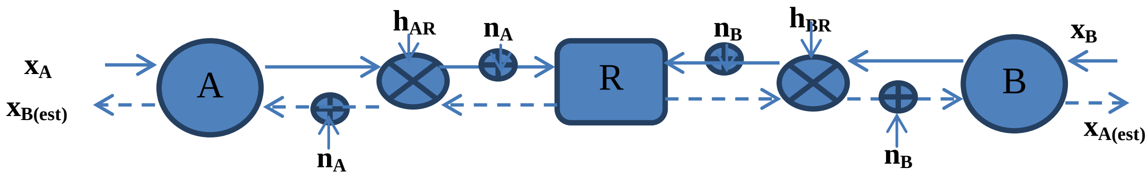

Figure 3.4 Physical layer network coding for the Alice-Relay-Bob model

As previously mentioned, there are practical problems for the implementation of PLNC. To simplify the analysis, the following assumption should be used; symbol-level and carrier-phase synchronization, and the use of power control, so that the frames from A and B arrive at R with the same phase and amplitude, the channel state information is available at the receiver side for both the time slots. These assumptions will be valid for all proposed systems that will be analyzed in this thesis.

In this part, the different scenarios of PLNC system are analyzed and simulated. Firstly, the systems with BPSK modulation and QPSK modulation are considered with AF, DF and DNF (Denoise & Forward) method in AWGN channel. Then, the systems will be simulated in Rayleigh fading channel.

3.2.1 PLNC System in AWGN Channel

In AWGN channel, the channel coefficietns (h_{AR}, h_{BR}) are unityso they don't have effectson the system. The PLNC system in AWGN channel is shown in Figure 3.5.

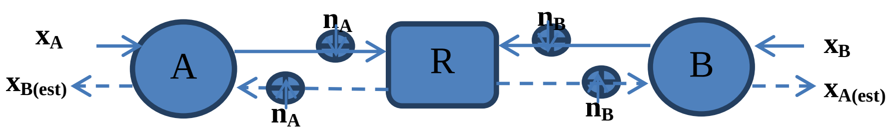

Figure 3.5 PLNC system in AWGN channel

We can portion the transmission in two time slots; MAC phase and BC phase. During MAC phase, A and B modulate their bits and transmit the corresponding signals to the relay. During BC phase, R maps the received signals and broadcasts to both A and B. A (B) estimates the bits of B (A) using the received signal from R and priori information of own bits.

3.2.1.1 PLNC System with BPSK

In this scenario, all three terminals use BPSK modulation technique to send their information. In MAC phase, $\boldsymbol{x_A}$ and $\boldsymbol{x_B}$ {0,1} is modulated to $\boldsymbol{s_A}$ and $\boldsymbol{s_B}${-1, 1}. In AF and DNF methods, the received signal $\boldsymbol{r_R}$ at relay node R can be expressed as

$$r_R = s_A + s_B + n_A + n_B$$

where n_A, n_B represents Gaussian noise with zero mean and variance σ^2 ($N_0 / 2$).

The operations in BC phase are different in cooperation techniques. In AF method, the relay just normalizes the signal with β factor then retransmits to A and B.

$$s_R = \beta r_B \text{ where } \beta = \frac{1}{\sqrt{|h_{AR}|^2 + |h_{BR}|^2 + N_0}}$$

The signals received by A and B are found as

$$r_A = s_R + n_A = \beta r_R + n_A = \beta(s_A + s_B + n_A + n_B) + n_A$$

$$r_B = s_R + n_B = \beta r_R + n_B = \beta(s_A + s_B + n_A + n_B) + n_B$$

A (B) tries to estimate s_B (s_A) from its received signal and knowledge of β with maximum likelihood (ML) algorithm. Then it demodulates $\boldsymbol{x_B}$ ($\boldsymbol{x_A}$) from estimated signal of $\boldsymbol{s_B}$ ($\boldsymbol{s_A}$).

$$\tilde{s}_A = \arg\min_{s \in Q} |r - \beta(s_B + \overline{s})|^2 \quad \tilde{s}_B = \arg\min_{s \in Q} |r - \beta(s_A + \overline{s})|^2$$

In DNF method, the relay does mapping according to the received signal. It doesn't try to decode signals from A and B separately, it only interests the summation of signals. Table 3.1 illustrates the idea of PLNC mapping. If the signals from node A and node B is same, relay transmits the signal '-1', otherwise it transmits signal '1'.

Table 3.1 Mapping and modulation at relay node

MODULATION				MAPPING & MODULATION		
m_A	m_B	s_A	s_B	r_R ($s_A + s_B$)	m_R	s_R
0	0	-1	-1	-2	0	-1
0	1	-1	1	0	1	1
1	0	1	-1	0	1	1
1	1	1	1	2	0	-1

During the BC phase, the relay broadcasts the BPSK signal s_R corresponding to the message m_R both users. The received signal at A and B is given by

$$r_A = s_R + n_A \qquad r_B = s_R + n_B$$

The terminals A and B detect the data transmitted by the relay and estimate the message from the other user by XOR operation. For example let bit of A is 0 and bit of B is 1. Corresponding signal is -1 and 1, respectively. In time slot 1, relay receives summation of signals from node A and B, which is 0. Relay maps the received signal and in time slot 2 broadcasts the signal, which is 1. Node A receives the signal from relay and for extracting the signal of node B, it applies the XOR operation with its transmitted signal;

$$\bar{s}_B = r_A \oplus s_A = 1 \oplus 0 = 1$$

In DF method, MAC phase composes of two sub-phases in which A and B transmit their signals in different time.

$$r_{R1} = s_A + n_{R1} \qquad r_{R2} = s_B + n_{R2}$$

The relay decodes s_A and s_B from its received signals (r_{R1}, r_{R2}) with maximum likelihood (ML) algorithm. Then it broadcasts its signal (s_R) according to table 3.1. The BC phase of DF method is same as DNF method.

3.2.1.2 PLNC System with QPSK

In this case, QPSK modulation technique is used by all three terminals.In AF method, there is no difference between BPSK and QPSK modulated systems. Same process and formulation is valid. Only the degrees of modulation and demodulation are changed at nodes A and B.

In DNF and DF method, MAC phases are same as BPSK case but mapping differs. All possible summations of signals from node A and B are shown (without noise) in Figure 3.6. The relay should maps these nine points to the four signals. The mapping operation must be one-to-one and it gives better performance when the distance between different symbols are bigger. The points in Figure 3.6 that are circled with same color, are mapping the same symbol and mapping table can be seen as in Table 3.2. For example, if the signals of A and B are the same (green color), relay transmits s_3 (00) signal. All combinations are settled in the table.

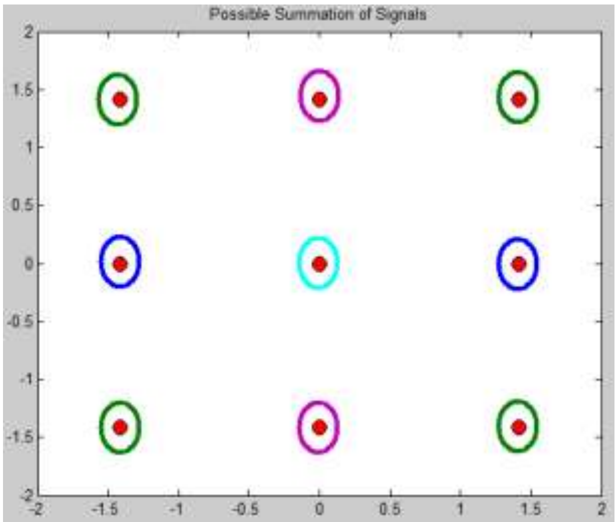

Figure 3.6 Possible summation of QPSK signals

During BC phase, relay transmits its signal according to table 3.2. A and B estimate the received signal and they can extract the needed information using mapping table and priori information of its own transmitted signals. Therefore, mapping table should be known at all terminals.

Table 3.2 Mapping at relay node with QPSK constellation

	s0 (11)	s1 (01)	s2 (10)	s3 (00)
s0 (11)	s3	s2	s1	s0
s1 (01)	s2	s3	s0	s1
s2 (10)	s1	s0	s3	s2
s3 (00)	s0	s1	s2	s3

3.2.1.3 BER Performance

We now analyze the bit error rate (BER) performance of proposed PLNC system in AWGN channel. Suppose the received signal energy for one bit is unity, and the noise is Gaussian white with density N_0 / 2. Simulation results for three different cooperation techniques, AF, DF and DNF, are shown in Figure 3.7. BER performances of systems with BPSK and QPSK are exactly same in AWGN channel so only BER performance of BPSK modulated system is shown.

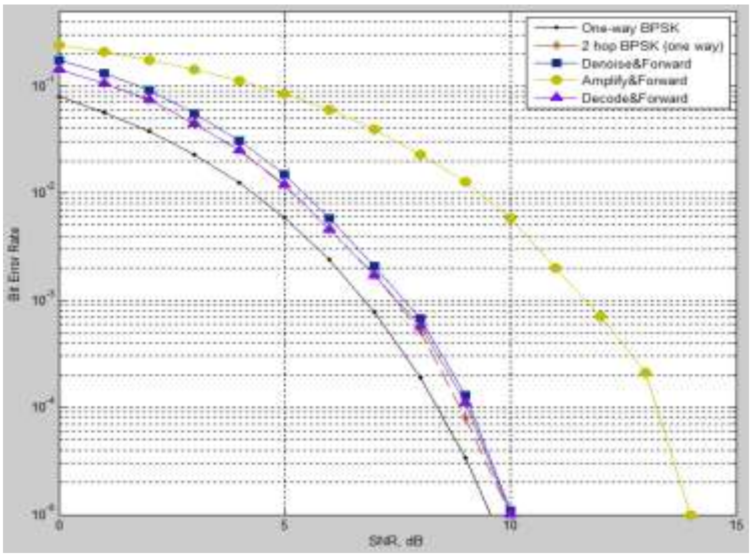

Figure 3.7 BER Performance of PLNC system with BPSK in AWGN channel

Figure 2.7 shows that DF method has slightly better BER performance than DNF method but the difference is getting smaller at high SNR. The BER performances of PLNC systems with DF and DNF method are almost same as 2-hop traditional network's BER performance. For the simplicity, we assume that PLNC system has the same BER performance as the traditional network schemes. The figure also shows that AF method has worst BER performance at all SNR values since the noise is accumulated at every hop in AF method.

In DF method, three time slots are needed for transmitting one frame which gives throughput improvement of 33% over the traditional transmission scheduling scheme. However, in AF and DNF method, only two time slots are needed for one frame which gives throughput improvement of %100 over the traditional transmission scheduling scheme. Therefore, there is a trade-off between network throughput and BER performance.

3.2.2 PLNC System in Rayleigh Fading Channel

We will design and analyze the PLNC system in Rayleigh fading channel. The channel coefficients should be considered in Rayleigh fading channel since they affect the communication.

3.2.2.1 PLNC System with BPSK

The same communication processes are stated as in AWGN channel except that channel coefficients are added in formulas since they deteriorate the communicaton. Including the channel coefficients, the formulas of received and transmitted signals by relay are shown in Table 3.3. Mapping operation was discussed in previous section.

During MAC phase, relay node estimates $\boldsymbol{s_A}$ and $\boldsymbol{s_B}$ using ML decoding algorithm with knowledge of $\boldsymbol{h_{AR}}$, $\boldsymbol{h_{BR}}$. In BC phase terminals (A, B) try to decode $\boldsymbol{s_R}$ using ML decoding algorithm with knowledge of $\boldsymbol{h_{AR}}$, $\boldsymbol{h_{BR}}$. It is assumed that the relay node and A, B nodes have respective channel information.

Table 3.3 Formulation of signals at relay node

	AF	DNF	DF
MAC Phase	$r_R = h_{AR}s_A + h_{BR}s_B + n_A + n_B$	$r_R = h_{AR}s_A + h_{BR}s_B + n_A + n_B$	$r_{R1} = h_{AR}s_A + n_A$ $r_{R2} = h_{BR}s_B + n_B$
BC Phase	$s_R = \beta r_R$ $r_A = h_{AR}s_R + n_A$ $r_B = h_{BR}s_R + n_B$	$s_R = Mapping\left(\hat{s}_A + \hat{s}_B\right)$ $r_A = h_{AR}s_R + n_A$ $r_B = h_{BR}s_R + n_B$	$s_R = Mapping\left(\hat{s}_A + \hat{s}_B\right)$ $r_A = h_{AR}s_R + n_A$ $r_B = h_{BR}s_R + n_B$

3.2.2.2 PLNC System with QPSK

Similar to the system in AWGN, depending on decision areas, mapping is made by relay as shown in Table 3.2. Each user can estimate the other user's signals by using mapping table, channel coefficients and priori information at A and B as in AWGN channel.

3.2.1.3 BER Performance

The same assumption about signal and noise energy is made as in AWGN channel. Simulation results for three different cooperation techniques, AF, DF and DNF, are shown in Figure 3.8. The performance graphs of BPSK modulated system and QPSK modulated system are shown in this case since they are different.

Let us look at the BER performance of BPSK modulated system first. The BER performances of DF and DNF method are exactly the same in Rayleigh fading channel and they are very close to the performance of one-way traditional network. The performance of AF method is worst as in AWGN channel due to cumulative noise.

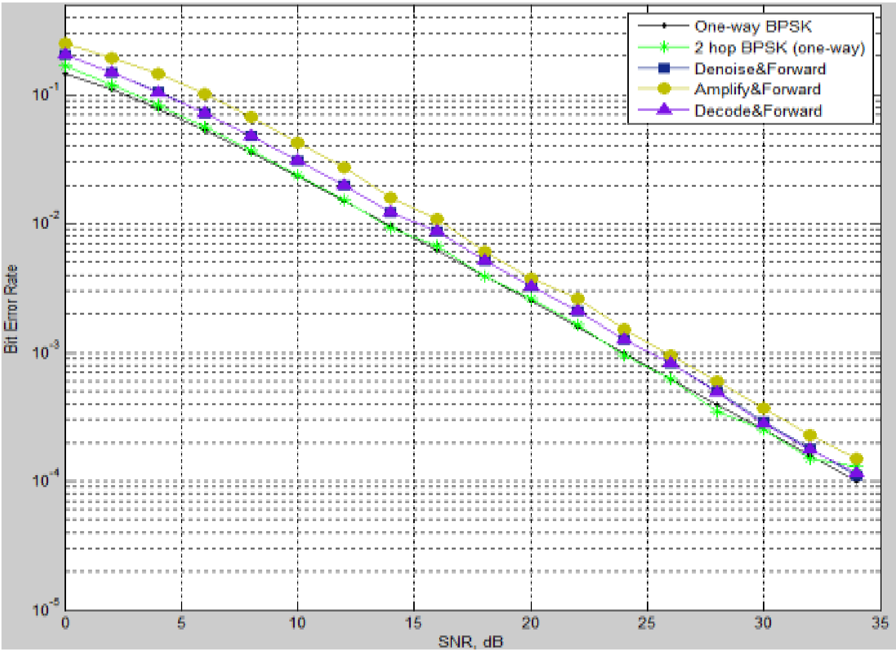

Figure 3.8 Performance of PLNC system with BPSK modulation in rayleigh fadingchannel

On the contrary, in QPSK case, performance of DNF method is worse than DF and AF method since the summation points are more affected in Rayleigh fading channel.The DF method has still the best performance among three cooperation methods.

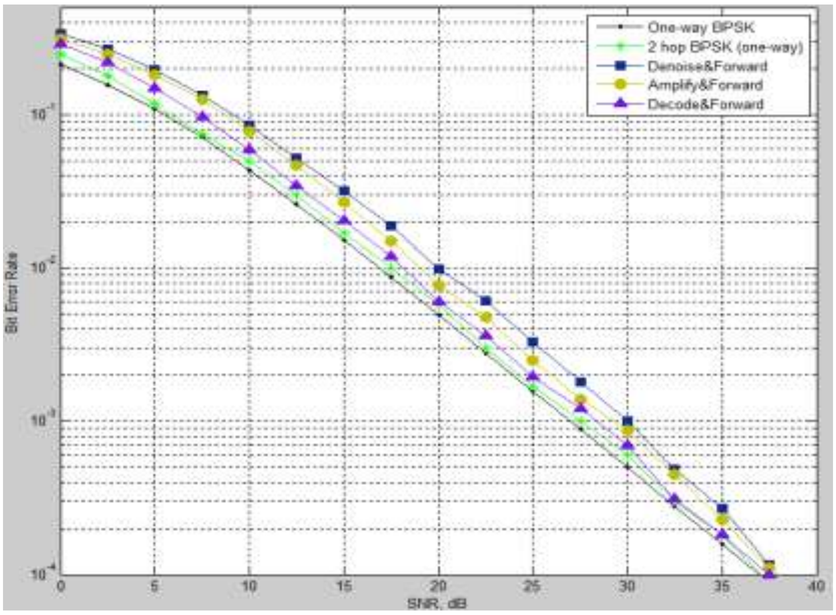

Figure 3.9 Performance of PLNC system with QPSK modulation in rayleigh fading channel

3.3 PLNC System in Multi-node Network

In the previous part, wediscussed the simple 3-node network (Alice-Relay-Bob Model) with bidirectional flow. In this section, the application of PLNC in multi-node networks is analyzed because there are real world applications for the regular network. For instance, access points are positioned along a highway form a regular linear chain in a vehicular network (Zhang, Liew, 2010).

The three-node PLNC model shown above can be extended to an n-node system. Two end nodes and n – 2 relay nodes are equally spaced along a one-dimensional line which is shown in Figure 3.10. Nodes A and B exchange message $\boldsymbol{x_a(t)}$ and $\boldsymbol{x_b(t)}$ through the n–2 relay nodes as in Alice-Relay-Bob model. For successful transmission through node R_i to R_j, the distance between them is less than r, and all the other transmitting nodes are $(1 + \Delta)r$ away from node j, where Δ parameter is used to specify the effect of interference range and $\Delta > 0$. Therefore, the signal transmitted from one node can only be successfully received by its two nearest neighbors on the left and right sides (Fu & Other, 2010).

Time-division multiple access (TDMA) scheme is used for transmission protocol. In this scheme, time axis is divided into equal length time slots, and the nodes transmit signals only at the beginning of a new time slot. As previously mentioned, time slots are composed of odd (solid line) and even (dashed line) segments. The nodes are also divided into odd (empty circle) and even (filled circle) groups, as shown in Figure 3.10. The odd numbered nodes transmit their messages at odd numbered time slots, and all even numbered nodes broadcast at even numbered slots (Fu & Other, 2010).

The relay node forwards the mixed information through either DF or DNF when it receives the messages from neighbour nodes. Figure 3.10 illustrates transmission of the messages without noise error, and the arrows show the directions of transmission. The symbol $\boldsymbol{x_a(t)}$ denotes the t^{th} infomation from left to right (node A to B), and $\boldsymbol{x_b(t)}$ denotes the t^{th} information from right to left (node B to A). For instance, node R_i

stores $\boldsymbol{x_a(t) + x_b(t)}$ and broadcasts this message to nodes R_{i+1} and R_{i-1} in the odd time slot m–1. In the following even time slot m, node R_i receives $\boldsymbol{x_a(t+1) + x_b(t)}$ from its left node R_{i-1} and $\boldsymbol{x_a(t) + x_b(t+1)}$ from R_{i+1}. Since node R_i has the information of $\boldsymbol{x_a(t) + x_b(t)}$ it can decode $\boldsymbol{x_a(t+1) + x_b(t+1)}$ from these received signals. In the following odd time m+1, $\boldsymbol{x_a(t+1) + x_b(t+1)}$ is transmitted to both R_{i-1} and R_{i+1}. Generally, we can use the following equation to explain the process :

$$\{x_a(k+1)+x_b(l)\}=\{x_a(k+1)+x_b(l-1)\}+\{x_a(k)+x_b(l)\}-\{x_a(k)+x_b(l-1)\}$$

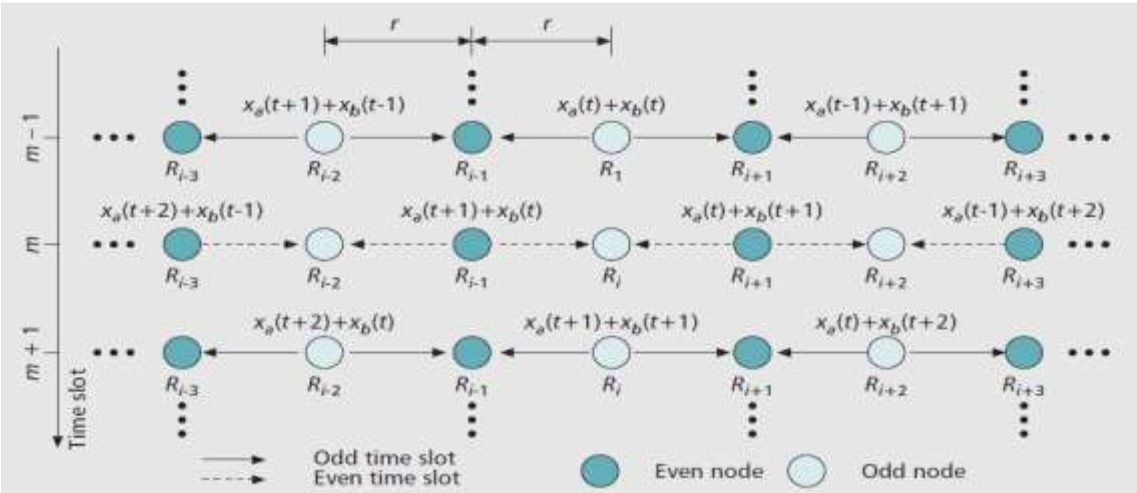

Figure 3.10 PLNC transmission in one-dimensional networks.

3.3.1 System Model & Simulation in Multi-node Network

A regular linear network consists of *N* nodes, node R_1, node R_2, . . , node R_N, which arepositioned equallyspaced. R_1 and $R_N$are source and destination nodes.The transmission schedule in a 5-node network is illustrated in Figure 4.2. At first time slots, R_1 and R_5 transmit their data to their neighbours, respectively X_1,Y_1. In the next time slots, R_2 stores X_1 and R_4 stores Y_1 in their buffer and they transmit X_1 and $Y_1$to R_3 simultaneously. In third time slot, R_1, R_3 and node R_5 transmit their frames to neighbour nodes, X_2, $Y_2$and $X_1 \oplus Y_1$respectively.R_3buffers a copy of $X_1 \oplus Y_1$. R_2 can extract $Y_1 \oplus X_2$ by addingthe stored X_1 to $X_2 \oplus X_1 \oplus Y_1$ received with PLNC detection. As similar, $Y_2 \oplus X_1$ may be obtained by R_4. Then, $Y_1 \oplus X_2$ and $Y_2 \oplus X_1$ are broadcasted by R_2 and R_4. In the same time slot, R_5gets X_1 and R_1gets Y_1. R_3

may extact $Y_2 \oplus X_2$ by adding stored packet $X_1 \oplus Y_1$ to the received packet $X_1 \oplus Y_2 \oplus X_2 \oplus Y_1$ (Zhang, Liew, 2010).

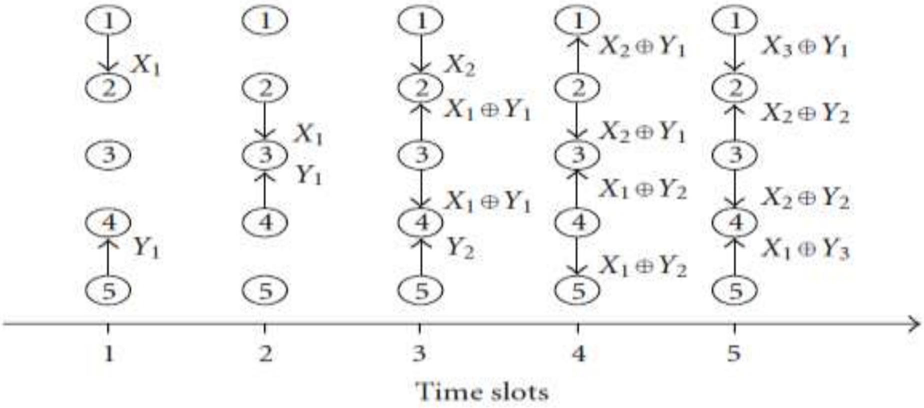

Figure 3.11 PLNC transmission of 5-node network

As it may be understood fromFigure 3.11, the transmitting and receiving operations are made by each node in successive time slots; and when a node transmits, its neighbours receive and vice versa. With reference to Figure 3.11, throughput is 0.5 frame/time slot in each direction which is the maximum possible throughput in half duplex transmission (Zhang, Liew, 2010).

We will investigate this 5-node PLNC system with DF and DNF methods in AWGN and Rayleigh fading channels in the following part.The information is divided into the blocks to prevent error propogation. AF method will not be analyzed for this system since the accumulated noise over four hops can be huge and the BER perforamance of system will become really bad.The proper mapping algorithm which gives best BER performance, is developed and tested.

3.3.2 Multi-node PLNC System in AWGN Channel

Figure 3.12 shows the transmission scheme of 5-node PLNC network. The signals that the nodes transmits at $(t+1)^{th}$ time are also shown. A, B and R_2 transmit their signals in phase 1 and R_2 and R_3 tranmsit in phase 2. We assume that all nodes use BPSK modulation to simplify the analysis. The white Gaussian noise is added to the system and the BER performance of PLNC sytem is examined.

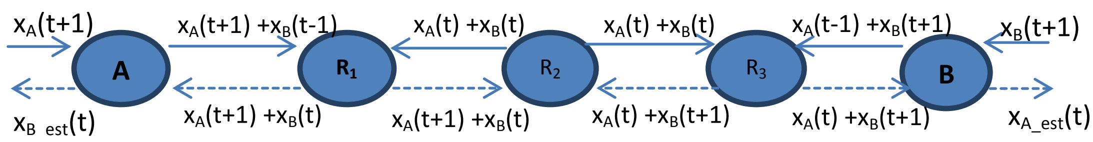

Figure 3.12 PLNC transmission scheme of 5-node network in AWGN channel

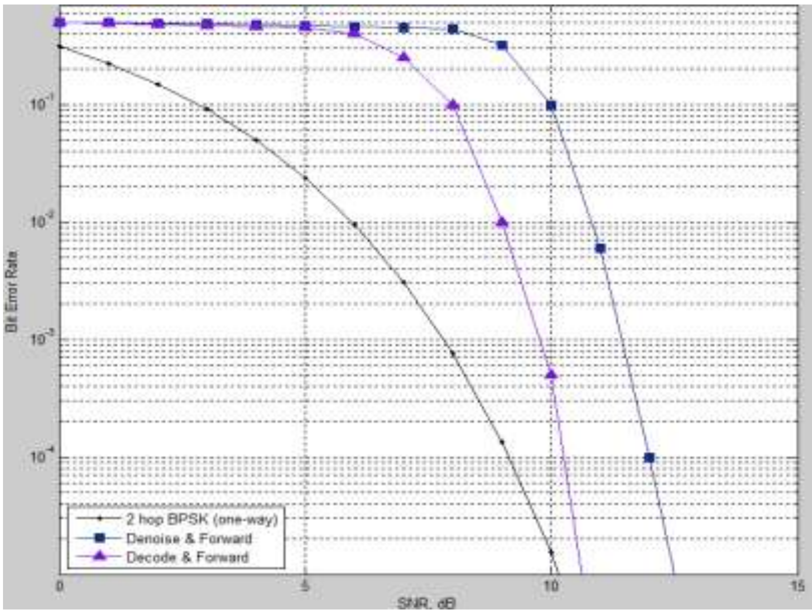

Figure 3.13 Performance of multi-node PLNC system in AWGN channel

Figure 3.13 shows the BER performance comparison between DF and DNF method in multi-node PLNC network. It should be stated that the performances of both methods are really bad at low SNR since the error propogation occurs. The performance of DF method is getting better when the SNR is higher than 6 dB and the performance of DF method is getting better when the SNR is higher than 8 dB. At above 10 dB, the performance of PLNC system is getting closer to the traditional network's BER performance. DF method's BER performance is better than DNF method at all SNR but the throughput of DNF method is 1.5 times of DF method's throughput.

3.3.3 Multi-node PLNC System in Rayleigh Fading Channel

Figure 3.14 shows the BER performance of multi-node PLNC network in Rayleigh fading channel. Similar to the system in AWGN channel, the performances of both methods are really bad at low SNR. The higher SNR, better BER performance for both methods. There is a trade-off between BER performance and throughput to choose the appropriate cooperation methods.

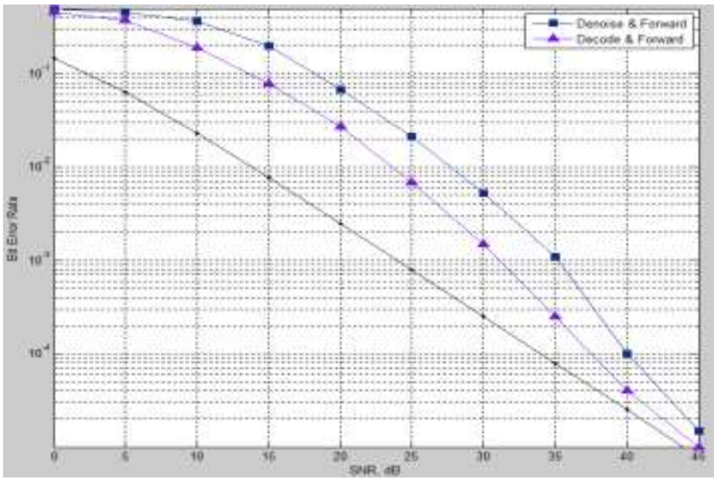

Figure 3.14 Performance of multi-node PLNC system in rayleigh fading channel

CHAPTER FOUR
COOPERATIVE COMMUNICATION WITH ASYMMETRIC PHYSICAL LAYER NETWORK CODING

Although the major part of the researches about PLNC isfor symmetric PLNC systems, this thesis also studies about asymmetric scenarios in a practical PLNC system. The possible asymmetrical cases in Alice-Relay-Bob model are; different lengths of information of Alice and Bob to transmit, the difference in the quality of the channels between Alice and relay and between Bob and relay, the difference of the Alice-relay channel and relay-Alice channel or Alice and Bob have different quality of service (QoS) requirements (Fu & Other, 2010).

In this work, we will examine the situation in which users have different data lengths. The solutions for this system are not unique. For example, when Alice has twice the information of Bob, Alice can transmit with QPSK while Bob can transmit with BPSK modulation. Another approach is that they both use the same modulation, and Alice may use the channel exclusively when Bob completes its transmission (Fu & Other, 2010).Assume that in Alice-Relay-Bob model, Bob's information length is 1.5 times of Alice's information length. We will discuss two different scenarios;

1. Alice uses QPSK modulation and Bob uses 8-PSK modulation,
2. Both Alice and Bob use BPSK modulation

In the second scenario, transmission of information is divided into 3 time slots. At two time slots, Alice and Bob transmit their data but at the third time slots only Bob transmits data. Let us examine both situations.

4.1 Asymmetric PLNC System in AWGN Channel

4.1.1 Transmission Schedule 1: A and B Have Different Modulation Scheme

As shown in Figure 4.1, Node A and Node B use different modulation techniques since they have different lengths of information. When A transmits 3 bits, B transmits 2 bits in one frame.

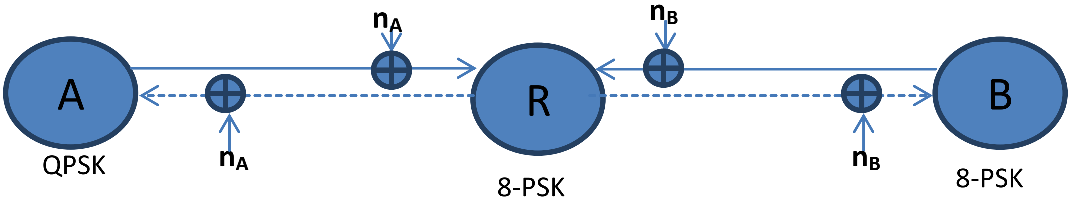

Figure 4.1 Transmission schedule 1 in AWGN channel

During the MAC phase, A and B transmit their data to the relay node. Figure4.2 illustrates the all possible signals at the relay which is summation of signals from A and B. The relay node receives;

$$r_R = s_A + s_B + n_A + n_B$$

In AF method, the relay node just sums the signals from A and B and normalizes (with β factor) the sum then broadcasts. Node A and B receives signals can be formulated as

$$r_A = s_R + n_A = \beta r_R + n_A = \beta(s_A + s_B + n_A + n_B) + n_A$$

$$r_B = s_R + n_B = \beta r_R + n_B = \beta(s_A + s_B + n_A + n_B) + n_B$$

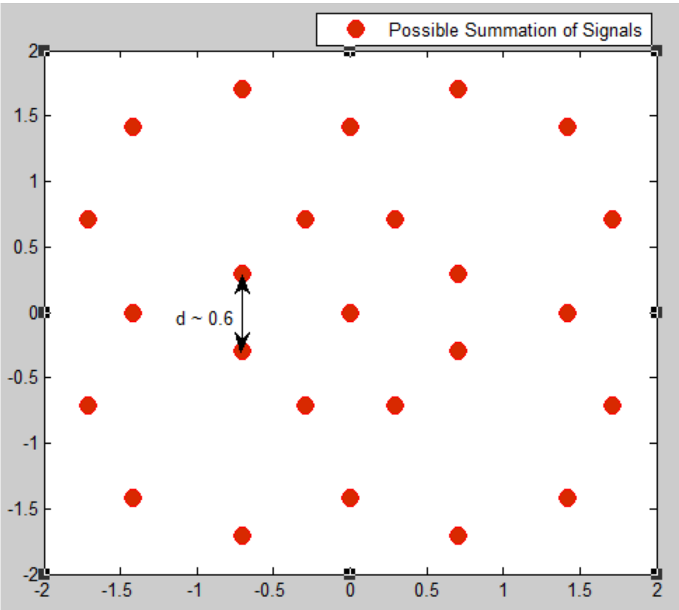

Figure 4.2 Possible summation of QPSK and 8-PSK signals

Since A and B knows the normalization factor and channel information (which is unity in AWGN channel), they can extract the related information using ML decision rule ($\bar{s} \in \{-1,1\}$).

$$\tilde{s}_A = \arg\min_{s \in Q} \left| r - \beta(s_B + \bar{s}) \right|^2 \quad \tilde{s}_B = \arg\min_{s \in Q} \left| r - \beta(s_A + \bar{s}) \right|^2$$

In DF and DNF method, mapping operation is the most important function at the relay since it directly affects the SER performance of the PLNC system. As previously mentioned, mapping function must be one-to-one so that the related information can be uniquely extracted by both A and B. Different mapping functions are analyzed and best SER performance of them, which is shown in Figure 4.3, is discussed in this work. In this mapping functions, the points which are more closed each other are grouped and mapped the same symbol at the relay node aware of mapping function should be one-to-one.

The points in Figure 4.3 that are circled with same color, are being mapped to the same symbol and mapping table can be seen in Table 4.1. $\boldsymbol{a_i}$ represents the QPSK symbol and $\boldsymbol{b_i}$represents the 8-PSK symbol.

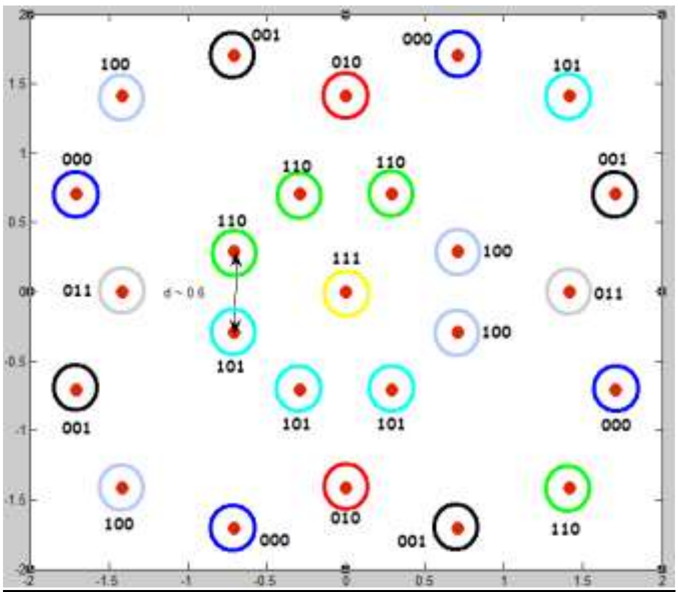

Figure 4.3 Decision areas in asymmetric PLNC system

Table 4.1 Mapping at relay node in asymmetric PLNC

	a0	a1	a2	a3
b0	b6	b1	b7	b2
b1	b2	b5	b4	b0
b2	b5	b3	b0	b4
b3	b7	b6	b3	b1
b4	b4	b0	b1	b5
b5	b3	b2	b6	b7
b6	b1	b7	b2	b6
b7	b0	b4	b5	b3

During the BC phase, relay node broadcasts 8-PSK signals. A and B receive the signals from relay in BC phase can be formulated as

$$r_A = s_R + n_A \qquad r_B = s_R + n_B$$

The nodes A and B decide the received signal by ML estimation method. Then they extract the related information according to mapping functions, as shown in Table 1, and priori information of theirs transmitted symbol. For example if B received *b1* symbol, we can estimate signal of A using the mapping table. There is 4 possible different scenarios;

1. If signal of B is b6 then signal of A is a0,
2. If signal of B is b0 then signal of A is a1,
3. If signal of B is b2 then signal of A is a2,
4. If signal of B is b1 then signal of A is a3.

4.1.2 Transmission Schedule 2: Users Have Same Modulation Scheme

Figure 4.4 illustrates A and B use same modulation techniques (BPSK) although they have different data lengths. In this case, the relay node use 8-PSK modulation.

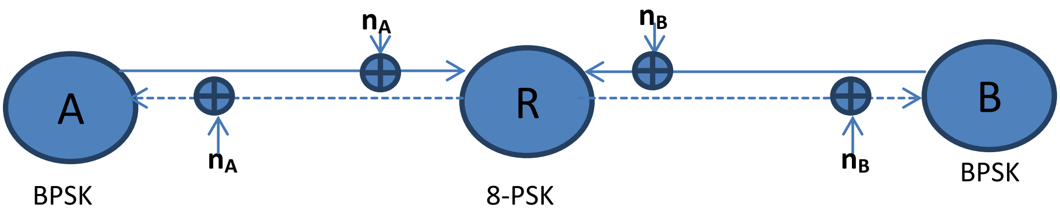

Figure 4.4 Transmission schedule 2 in AWGN channel

The transmission schedule can be explained as follows:

- At first two time slots, A and B transmit their bits
- At third time slot, only B transmits its data since its length of information is 1.5 times of A's.
- At fourth time slot, R transmits its 8-PSK modulated data which are XORed of bits from A and B as shown in Table 4.2.

Table 4.2 Transmission schedule

	S_A	S_R	S_B
Time Slot 1	a_1	-	b_1
Time Slot 2	a_2	-	b_2
Time Slot 3	-	-	b_3
Time Slot 4	-	$(a_1 \oplus b_1, a_2 \oplus b_2, b_3)$	-

Table 4.2 visualizes the above explanation of transmission schedule. At four time slots, A's two bits and B's three bits exchanged. In traditional relay network, only two bits exchanged at the same time, one bit from each node.

This transmission schedule doesn't work with AF method since the relay couldn't decode information from A and B, it just amplifies and forwards. Therefore, XOR operation cannot be done at the relay. Because of this reason, AF method will not be analyzed for this schedule.

Table 4.3 shows the difference between DNF and DF method during MAC phase. MAC phase takes 3 time slots in DNF, however it takes 5 time slots in DF method as shown in Table 4.3.

Table 4.3 Formulas of received signals

DNF Method		DF Method	
Time Slot 1	$r_{R1} = s_{A1} + s_{B1} + n_A + n_B$	**Time Slot 1**	$r_{R11} = s_{A1} + n_A$
Time Slot 2	$r_{R2} = s_{A2} + s_{B2} + n_A + n_B$	**Time Slot 2**	$r_{R12} = s_{B1} + n_B$
Time Slot 3	$r_{R3} = s_{B3} + n_A + n_B$	**Time Slot 3**	$r_{R21} = s_{A2} + n_A$
Time Slot 4	$r_A = s_R + n_A$ $r_B = s_R + n_B$	**Time Slot 4**	$r_{R22} = s_{B2} + n_B$
		Time Slot 5	$r_{R3} = s_{B3} + n_B$
		Time Slot 6	$r_A = s_R + n_A$ $r_B = s_R + n_B$

At the end of the MAC phase, relay receives during three time slots and estimates the received signals using ML decoding algorithm. Then it does XOR operation between corresponding user bits which is shown in Table 4.2. After XOR operation, it broadcasts 8-PSK modulated signals to terminals A and B at BC phase.

Node A and node B estimates the $\boldsymbol{s_R}$, then demodulates 8-PSK signals to BPSK signal. After that they extract the related information according to priori information of theirs transmitted symbol.

For instance, node A has {0, 1} sequence, node B has {1, 1, 0} sequence. At first 3 time slots, A and B transmits their data (B doesn’t transmit at third interval). Relay receives information from A and B and ‘XOR’s of thier data which is {1, 0, 0}. The relay maps the {1 0 0} symbol to the related 8-PSK signal and transmits it at last interval. A and B receives and decodes 8-PSK signal and converts it to three data bits {1, 0, 0}. Node A ‘XOR’s first two of the received bit {1, 0} with its transmitted bits {0, 1}. It extracts the first two bit that node B sends which can be shown as:

$$\tilde{s}_B(1) = r_A(1) \oplus s_A(1) = 0 \oplus 1 = 1$$

$$\tilde{s}_B(2) = r_A(2) \oplus s_A(2) = 0 \oplus 1 = 1$$

$$\tilde{s}_B(3) = r_A(3) = 0$$

Third bit, sent by B, is directly transmitted to the A, The frame transmitted by B, is extracted by A correctly {1, 1, 0}.

4.1.3 BER and SER (Symbol-to-Error Rate) Performance

We now analyze the symbol error rate (SER) performance of transmission schedule 1. Suppose the received signal energy for one bit is unity, and the noise is Gaussian white with power spectral density N_0 / 2. Simulation results for three cooperative techniques are shown in Figure 4.5. We can see that SER performances of A and B are same for DF and DNF method since the mapping is done at the relay node. However, in AF method, SER performance of A is much better than B's because of the relay node just sums the signals from A and B and normalizes the sum then broadcasts. Since modulation of A is lower order than B's, the SER performance of A is better. Throughput of DNF and AF method is higher than DF method. During the same time interval, the number of frames transmitted with DNF and AF method is 1.5 times of DF method's frame and 2 times of number of frames that one-way traditional network can transmit.

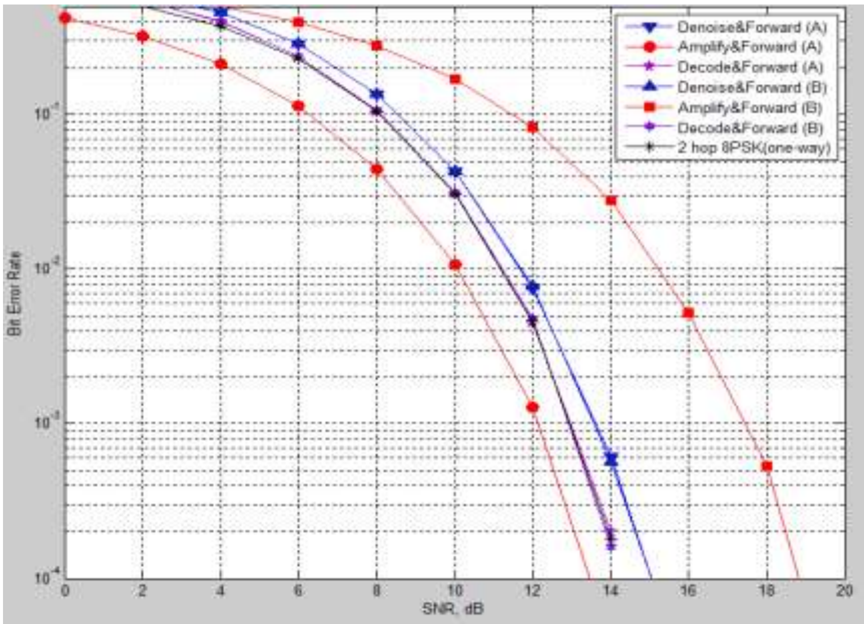

Figure 4.5 SER performance of transmission schedule 1 in AWGN channel

Let us analyze the bit error rate (BER) performance of transmission schedule 2. Simulation results for DF and DNF method are examined in Figure 4.6. We can see that BER performance of B is better than A's for both cooperative methods since at third interval, data from B is directly transmitted over relay without no operation. Although ber performance of DF method is better than DNF method, the throughput of DNF method is 1.5 times of throughput of DF method.

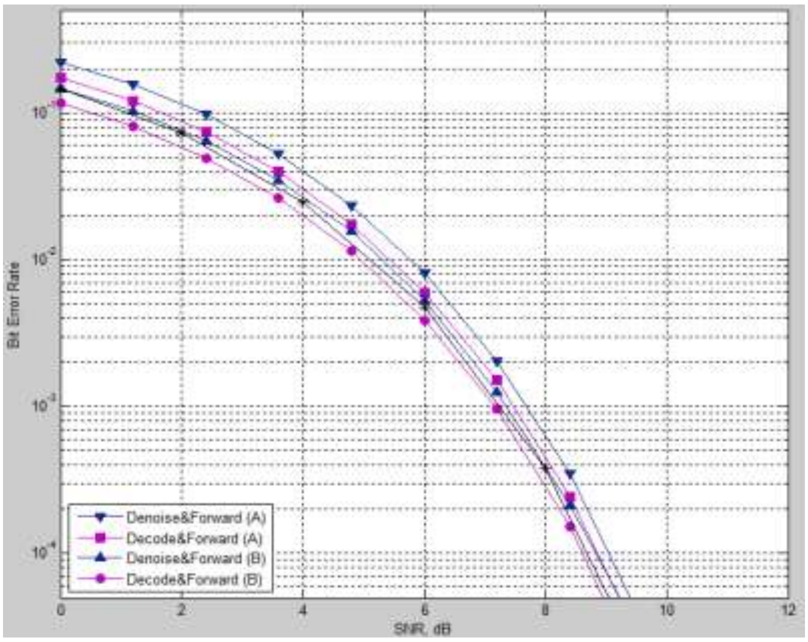

Figure 4.6 Performance of transmission schedule 2 in AWGN channel

If we compare transmission schedules, BER performance of second method is better than first one for all cooperative methods. Because, in the first schedule, terminals A and B use BPSK, however they use QPSK and 8-PSK modulation in second schedule. If modulation is getting higher, the BER performance is getting lower but throughput of system is getting larger.

4.2 Asymmetric PLNC System in Rayleigh Fading Channel

In Rayleigh fading channel, different from AWGN channel, channel coefficients (h_{AR}, h_{BR}, h_{RA}, h_{RB}) should be considered and the system must be configured according to these coefficients as shown in Figure 4.7.

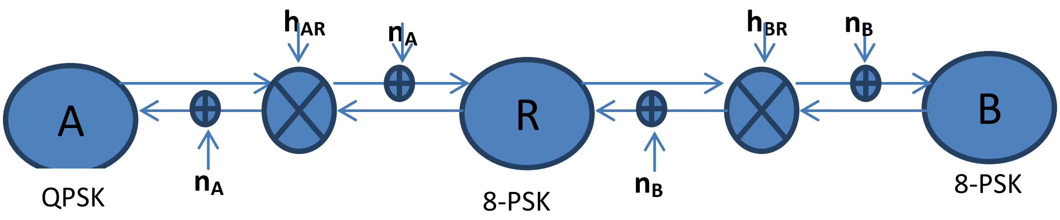

Figure 4.7 Transmission schedule 1 in rayleigh fading channel

4.2.1 Transmission Schedule 1: A and B Have Different Modulation Scheme

There is no big difference between systems in Rayleigh fading and AWGN channel. The operation is exactly same but channel coefficients are added in formulas, stated in Table 4.4.

Table 4.4 Formulas of received signals

	DNF Method	AF Method	DF Method
MAC	$r_R = h_{AR} * s_A + h_{BR} * s_B + n_A + n_B$ $s_R = Map(r_R)$	$r_R = h_{AR} * s_A + h_{BR} * s_B + n_A + n_B$ $s_R = \beta r_R$	$r_{R1} = h_{AR} * s_A + n_A$ $r_{R2} = h_{BR} * s_B + n_B$ $s_R = Map(r_R)$
BC	$r_A = h_{RA} * s_A + n_A$ $r_B = h_{RB} * s_B + n_B$ $\tilde{s}_A = Estimate(r_B, s_B)$ $\tilde{s}_B = Estimate(r_A, s_A)$	$r_A = h_{RA} * s_A + n_A$ $r_B = h_{RB} * s_B + n_B$ $\tilde{s}_A = ML(r_B, s_B, \beta)$ $\tilde{s}_B = ML(r_A, s_A, \beta)$	$r_A = h_{RA} * s_A + n_A$ $r_B = h_{RB} * s_B + n_B$ $\tilde{s}_A = Estimate(r_B, s_B)$ $\tilde{s}_B = Estimate(r_A, s_A)$

4.2.2 Transmission Schedule 2: Users Have Same Modulation Scheme

The system model is shown in Figure 4.8 and formulas at MAC phase can be seen in Table 4.5. The formulas at BC phase are same as above system that is shown in Table 4.5.

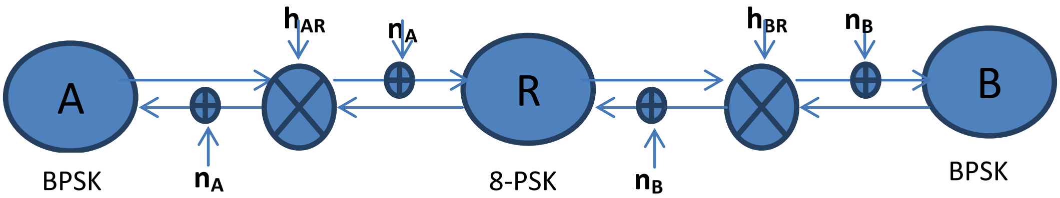

Figure 4.8 Transmission schedule 2 in rayleigh fading channel

Table 4.5 Formulas at MAC phase

	DNF Method	DF Method
MAC	$r_{R1} = h_{AR} * s_{A1} + h_{BR} * s_{B1} + n_A + n_B$ $r_{R2} = h_{AR} * s_{A2} + h_{BR} * s_{B2} + n_A + n_B$ $r_{R3} = h_{BR} * s_{B3} + n_B$	$r_{R11} = h_{AR} * s_{A1} + n_A$ $r_{R12} = h_{BR} * s_{B1} + n_B$ $r_{R21} = h_{AR} * s_{A2} + n_A$ $r_{R22} = h_{BR} * s_{B2} + n_B$ $r_{R3} = h_{BR} * s_{B3} + n_B$

4.2.3 BER and SERPerformance

Figure 4.9 shows SER performance oftransmission schedule 1 in Rayleigh fading channel. Similar to case in AWGN channel, SER performances of A and B are same for DNF and DF method and SER performance of A is better than B's because of relay's function for AF method as similar as in AWGN channel.

If we look at performance of transmission schedule 2 in Rayleigh fading channel, the similar scenario happens. Figure 4.10 shows that the BER performance of A is better than B's performance for DNF and DF method. But the performance of DNF and DF method is almost same in Rayleigh fading channel, unlike in AWGN channel.

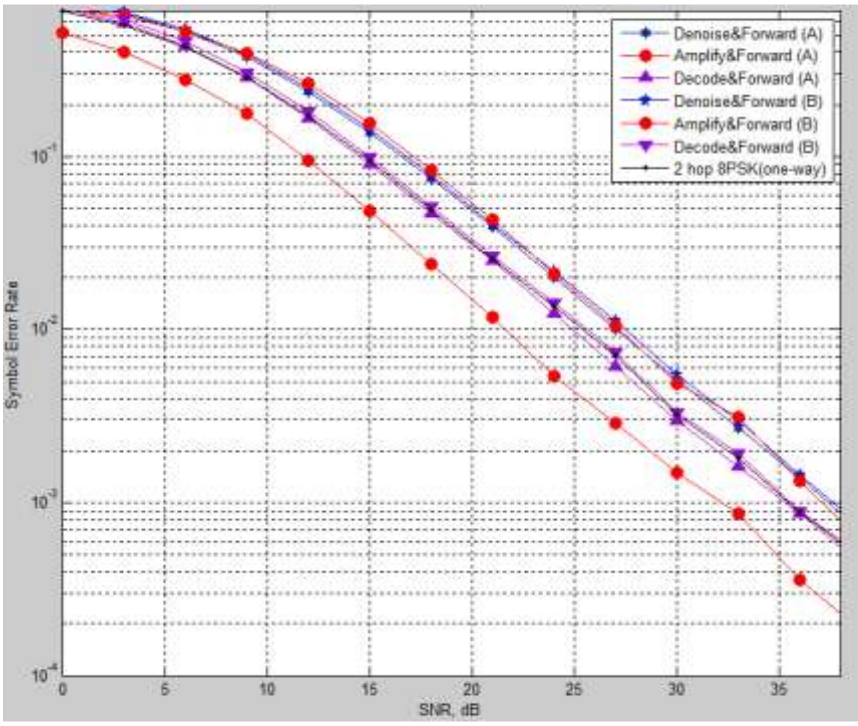

Figure 4.9 SER performance of transmission schedule 1 in rayleighfading channel

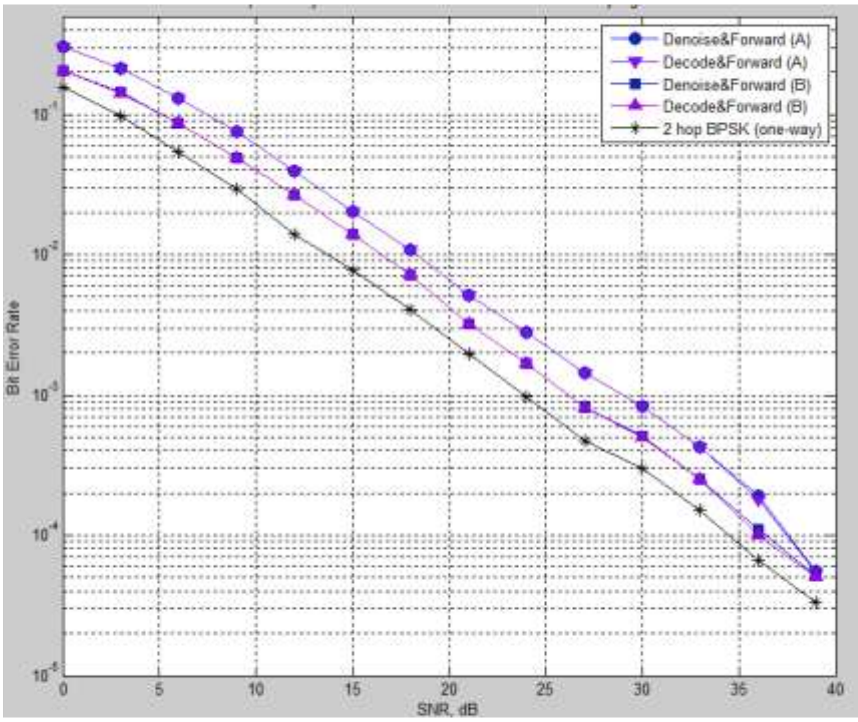

Figure 4.10 BER performance of transmission schedule 2 in rayleigh fading channel

CHAPTER FIVE
PHYSICAL LAYER NETWORK CODING IN FREQUENCY SELECTIVE FADING CHANNEL

5.1 Introduction

Mobile communications will need high data rate wireless transmission in the near future. To realize that, shorter symbol periods that express the higher data rates, are needed. The symbol period (T)and the baseband data rate (R) are inversely proportional (T = 1/R), thereforeincrement of R meansdecrement of T. However, a shorter symbol period may causeISI. ISI occursif a arriving time of delayed version of symbol 'n' overlaps the processing period of symbol 'n+1'. Furthermore, Inter-Carrier Interference (ICI) may be issue if modulated carriers are so close for efficient use of radio spectrum.In optimum case, for no spectrum is wasted, the bandwidth of each carrier would be adjacent to its neighbors. But in practice, a guard band which is wasted bandwidth,should be placed between each carrier bandwidth to provide a space to attenuate an adjacent carrier's signal (Cosby, 2011).

Orthogonal Frequency Division Multiplexing (OFDM)may be solution forISI and ICI problems. OFDM provides a high date rate with long symbol duration to eliminate ISI and it also offers a technique allowing the bandwidths of modulated carriers to overlap without causing ICI. For that reasons, OFDM can be appropriate candidate modulation technique in a broadband, multi-path environment.

5.1.1 Othogonal Division Multiplexing (OFDM) Basics

The modulation technique that a transmitter combines multiple low data rate carriers to form a composite high data rate transmission, is called OFDM (Cosby, 2011).In OFDM technique, frequency spectrum is divided into a number of equally spaced frequency bands that each one carries one user data. Each carrier's frequency is an integer multiple of a base sinusoid frequency. As opposed to frequency divisionmultiplexing (FDM), there are orthogonal subcarriers in parallel in an OFDM system.

Because of the orthogonality of subcarriers, they do not overlap with each other in time domain and the integral of their product, over one period, is equal to zero. Therefore, OFDM converts a frequency selective fading channel into a flat fading channel by using orthogonal subcarriers.

5.1.2 Orthogonality

The subcarriers at $f_k = k / T_{sym}$ can be shown by time-limited complex exponential signals $\left\{e^{j2\pi k f_k t}\right\}_{k=0}^{N-1}$ in the OFDM signal, where $0 \le t \le T_{sym}$. To say that these signals are orthogonal, the integral of the products for their fundamental period should be zero. The formula can be written in the discrete time domain by taking samples at $t = nT_s = nT_{sym} / N$, $n = 0,1,2,\cdots,N-1$.

$$\frac{1}{N}\sum_{n=0}^{N-1} e^{j2\pi\frac{k}{T_{sym}}nT_s} e^{-j2\pi\frac{i}{T_{sym}}nT_s} = \frac{1}{N}\sum_{n=0}^{N-1} e^{j2\pi\frac{k}{T_{sym}}\frac{nT_{sym}}{N}} e^{-j2\pi\frac{i}{T_{sym}}\frac{nT_{sym}}{N}} = \frac{1}{N}\sum_{n=0}^{N-1} e^{j2\pi\frac{(k-i)}{N}n} = \begin{cases} 1, \forall \operatorname{int} k = i \\ 0, otherwise \end{cases}$$

For ICI-free OFDM signal, above orthogonality is amandotary condition.

5.1.3 OFDM Implementation

In practice, discrete Fourier transform (DFT) and inverse DFT (IDFT) processes are useful for implementing the multiple orthogonal subcarrier signals, which are overlapped in spectrum. We can implement DFT and IDFT by using fast Fourier transform (FFT) and inverse fast Fourier transform (IFFT), respectively. In the OFDM transmission system, N-point IFFT is taken for the transmitted symbols $\left\{X_1[k]\right\}_{k=0}^{N-1}$, the result is the samples for the sum of N orthogonal subcarrier signals $\left\{x[n]\right\}_{n=0}^{N-1}$. Let $y[n]$ denote the received sample that corresponds to $x[n]$ with the additive noise $w[n]$ (i.e., $y[n] = x[n] + w[n]$). Taking the N-point FFT of the received samples, $\left\{y[n]\right\}_{n=0}^{N-1}$, the noisy version of transmitted symbols $\left\{Y_l[k]\right\}_{k=0}^{N-1}$ can be obtained in the receiver. Figure 5.1 shows the OFDM transmission structure implemented by IDFT/DFT.As all subcarriers are of the finite duration T, the spectrum of the OFDM signal can be considered as the sum of the frequencyshifted sinc functions in the frequency domain as illustrated in Figure 5.2, where the overlapped neighboring sinc functions are spaced by 1/T (Cho & Other, 2010).

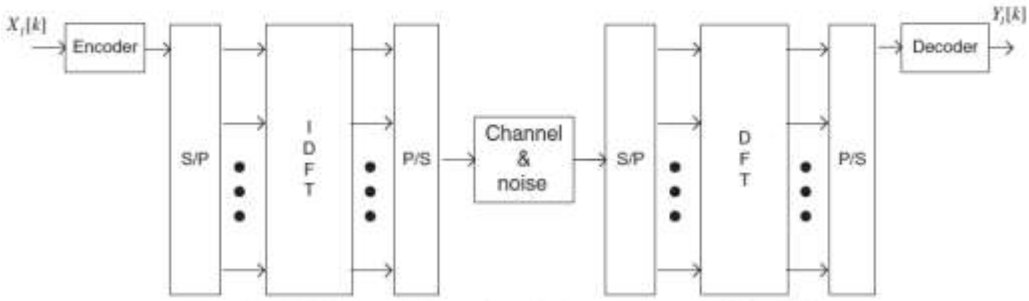

Figure 5.1 OFDM transmission scheme implemented using IDFT/DFT

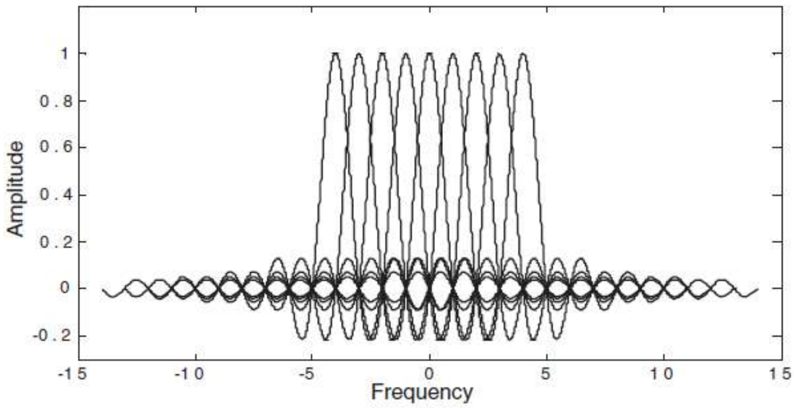

Figure5.2 The spectrum of OFDM signal (linear scale)

An OFDM signal may incur out-of-band radiation, which causes non-negligible adjacent channel interference (ACI) because of time-limited subcarrier signal. Figure 5.3shows that the first sidelobe is not smaller than the main lobe in the spectra. To reduce the out-of-band radiation, OFDM scheme places a guard band around the frequency band at outer subcarriers in OFDM system.The cyclic prefix (CP), a guard interval in the time domain, is also insterted in OFDM scheme. CP prevents the ISI between OFDM symbols (Cho & Other, 2010).

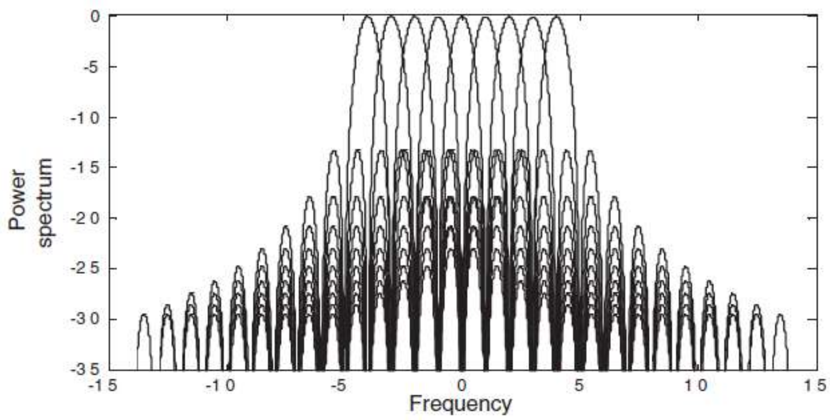

Figure 5.3 Power spectrum of OFDM signal (dB)

5.1.4 OFDM Modulation & Demodulation

The messagebits are modulated with either PSK or QAM symbols first, and then these symbols are converted from serial to N (fft size) parallel streams which are carried by different subcarrier in OFDM transmitter.The duration of transmission time for N symbols is extended to NT_s, which forms a single OFDM symbol with a length of T_{sym} (i.e., $T_{sym} = NT_s$) because of S/P conversion. Let $X_l\left[k\right]$denotes the lth transmit symbol and $\Psi_{l.k}\left(t\right)$ denote the lth OFDM signalat the kth subcarrier $l = 0,1,2,\cdots,\infty$, $k = 0,1,2,\cdots,N-1$, can be formulated as

$$\Psi_{l.k}\left(t\right) = \begin{cases} e^{j2\pi f_k(t-lT_{sym})}, 0 \le t \le T_{sym} \\ 0 \qquad\qquad\quad , \text{elsewhere} \end{cases}$$

Then the passband and baseband OFDM signals in the continuous-time domain can be shown as

$$x_l\left(t\right) = \text{Re}\left\{\frac{1}{T_{sym}}\sum_{l=0}^{\infty}\left\{\sum_{k=0}^{N-1} X_l\left[k\right]\Psi_{l.k}\left(t\right)\right\}\right\} = \sum_{l=0}^{\infty}\sum_{k=0}^{N-1} X_l\left[k\right]e^{j2\pi f_k(t-lT_{sym})}$$

If we sample continuous-time baseband OFDM signal at time instants $t = lT_{sym} + nT_s$ with $T_s = T_{sym} / N$ and $f_k = k / T_{sym}$, discrete-time formula of OFDM symbol becomes

$$x_l\left[n\right] = \sum_{k=0}^{N-1} X\left[k\right]e^{j2\pi kn/N} \quad \text{for } n = 0,1,\ldots,N\text{-}1$$

which can be computed efficiently by using the IFFT algorithm.

The discrete-time received signal $,\{y_l[n]\}_{n=0}^{N-1}$, can calculated from the sample values of the received OFDM symbol $y_l(t)=\sum_{k=0}^{N-1} X_l[k]e^{j2\pi f_k(t-lT_{sym})}$ at $t=lT_{sym}+nT_s$. The receiver can extract the related information, $X_l[k]$, using the orthogonality between the subcarriers in unnoised channel:

$$Y_l[k]=\sum_{n=0}^{N-1} y_l[n]e^{-j2\pi kn/N}=\sum_{n=0}^{N-1}\left\{\frac{1}{N}\sum_{i=0}^{N-1} X_l[i]e^{-j2\pi in/N}\right\}e^{-j2\pi kn/N}$$
$$=\frac{1}{N}\sum_{n=0}^{N-1}\sum_{i=0}^{N-1} X_l[i]e^{j2\pi(i-k)n/N}=X_l[k]$$

The example block diagram of OFDM modulation and demodulation is shown in Figure 5.4. In this case, the number of subcarriers is 6 and their frequencies can be formulated as $f_k=k/T_{sym}$, for $N=6$ (i.e.,$k=0,1,2,...,5$). The receiver can easily demodulate the symbols due to orthogonality of subcarriers.

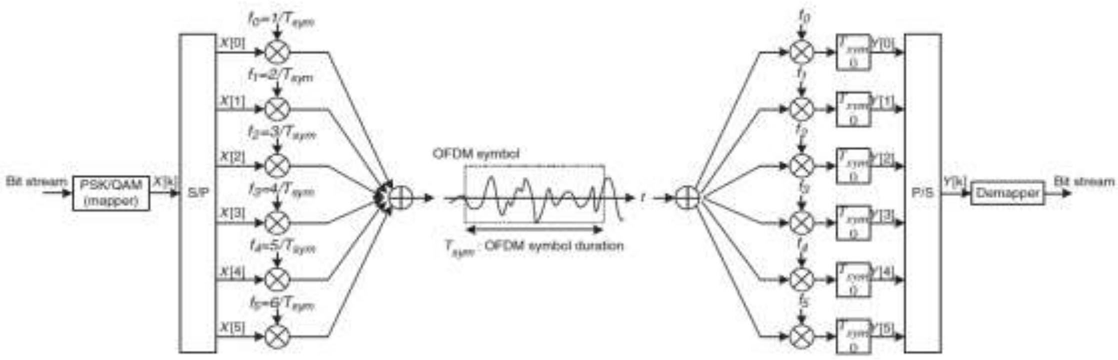

Figure 5.4 Block diagram of OFDM modulation and demodulation

5.1.5 OFDM Guard Interval

ISI occurs in the received signals due to multipath effects of the mobile channel. In other words, the multiple delayed versions of transmitted signals arrive at the receiver at different time instants. To eliminate ISI between symbols which belongs to same block, the spectrum is divided into subchannels, and a block of symbols are transmitted with different subcarriers. However, ISI still occurs between the last part of the first transmitted block, and the first part of the second transmitted block (Cho & Other, 2010). Moreover, ISI will occur if the synchronization is loss since information will be decoded and combined for 2 adjacent symbol periods. Furthermore, ICI will occur because orthogonality will be lost (Cosby, 2011).

A guard interval is introduced to solve these problems, and it is added to each OFDM symbol period. It solves ISI problem since it makes the symbol period longer, so that the demodulator does not have to be so precise in picking the period beginning and end, and decoding is always done inside a single period. However, ICI problem still occurs.

To prevent both ISI and ICI, the guard period must be formed by a cyclic extension of the symbol period. The process is; taking symbol period samples from the end of the period and adding them to the front of the period. The resulting time sample sequence becomes periodical when the IFFT is taken for a symbol period (during OFDM modulation) sinceIFFT is extension of the Fourier Series for periodic waveforms. The period is the number of samples used. The symbol period is longer, the symbol period represents the same frequency spectrum however it becomes longer with the cyclix extension. Suppose that symbol duration is T ,the number of subcarriers is N, and the time span of the channel is G, then the OFDM signal duration becomes

$$T_{OFDM} = NT_S + GT_S$$

Both ISI and ICI are eliminated because orthoganality is kept with this method (Cosby, 2011).

The receiver also uses cyclic prefix time for syncronization so that cyclic prefix provides the receiver carrier syncronization. By this way, no need extra data transfer for synchronization.

5.2 Model of PLNC System with OFDM

We will implement OFDM technique into PLNC system as shown in Figure 5.5. For simplicity, 3-node network is examined. All nodes use BPSK modulation and FFT size is selected 128 and tap delay is 5.

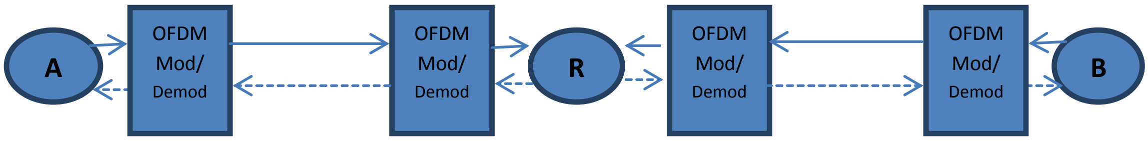

Figure 5.5 Block diagram of OFDM-PLNC system

Evey node converts its data from serial to parellel form and modulate with OFDM subcarriers then tranmits. Receiving of data is made similarly. The system is examined in Rayleigh fading and Ricean fading channels for DF and DNF methods.

In MAC phase of the system, binary data of user's information is modulated with BPSK modulation and each data in every block is carried with 128OFDM subcarriers and 4 bit cyclix prefix are added to mitigate ICI. Then the each block data is processed with inverse fourier transform and transmitted to the relay.

In BC phase, the relay demodulate the signals from users with ML decoding algorithm and it decides the transmitted symbol according to the summation of received signals. The mapping is done at relay node and then OFDM modulation is processed. OFDM signals are broadcasted to the users and they extract the related information through OFDM demodulation and ML decoding algorithm.

5.2.1 The System in Rayleigh Fading Channel

The proposed system is simulated in Rayleigh fading channel and its BER performance is shown in Figure 5.6. The figure shows that effect of frequency selective channel is removed by using OFDM technique so PLNC technique can be implented into wireless systems in frequency selective fading channel. The BER performance of system is very closed to the traditional network but the transmission data rate is enhanced significantly. DF method's performance is slightly better than DNF's method however DNF' method promises higher data rate transmission.

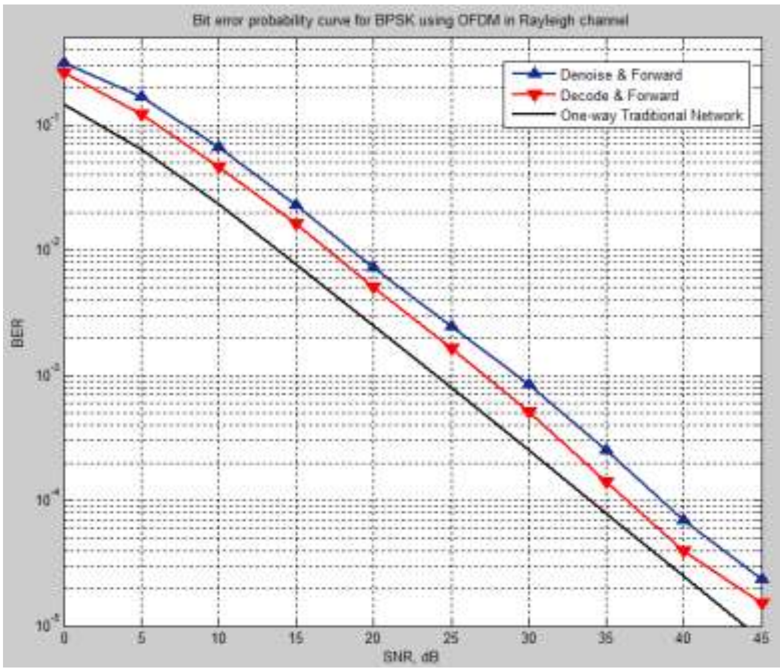

Figure 5.6 Performance of OFDM system in rayleigh fading channel

5.2.2 The System in Ricean Fading Channel

The system is simulated in Ricean fading channel for different K-factor values. The BER performances of simulated systems are shown in Figure 5.7 and Figure 5.8. We can see that the Ricean fading channel characteristics become like AWGN channel as the K-factor is getting bigger. On the contrary, if the K-factor is approached to zero which means there is no dominant LOS signal between terminals, the channel characteristics are close to the rayleigh fading channel. We also analyze that performance of DF method is better than DNF method and it is close to the performance of traditional one-way network.

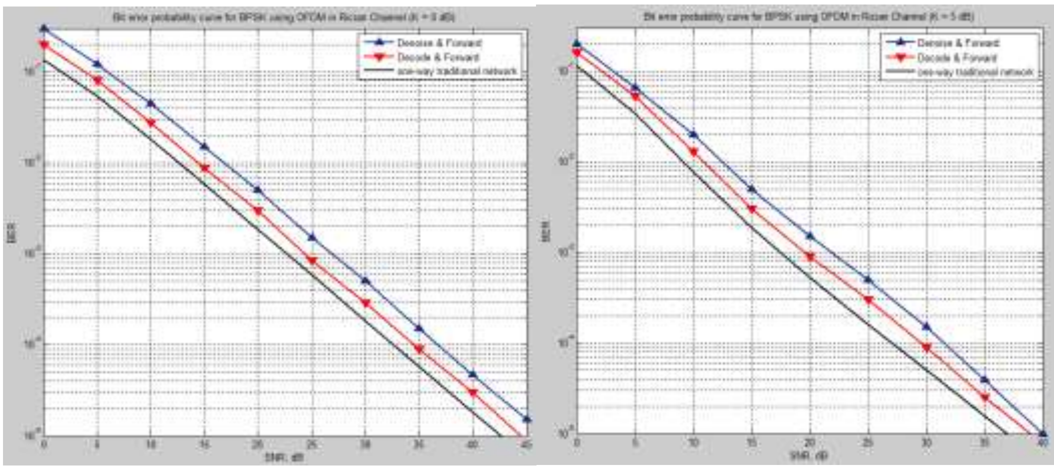

Figure 5.7 Performance of system in ricean channel (K = 0-5 dB)

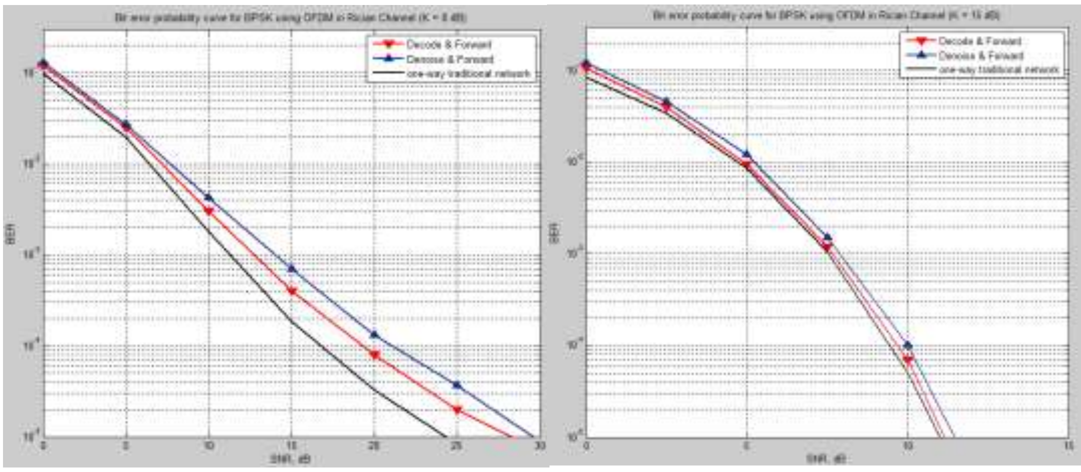

Figure 5.8 Performance of system in Ricean channel (K = 8-15 dB)

CHAPTER SIX
CONCLUSIONS

The broadcast nature of wireless network is getting apart from wired network with broadcasting feature. The signal transmitted by a node may be listened by several other nodes, and a node may capture signals from several other nodes at the same time. Although this characteristiccreates an interference in most wireless networks (e.g., IEEE 802.11), it may be useful when it is used through right way such as network coding. The network coding can be implemented at the physical layer to use the broadcast property for improving the capacity in wireless networks. It is called a PLNC scheme which coordinates transmissions among nodes. This thesis's purpose is to apply PLNC system into the relay node network for different scenarios.

There are four main scenarios that are discussed. The systems in all scenarios are investigated under AWGN and Rayleigh fading channels. In the first scenario, symmetric PLNC system in 3-node network is investigated. It's bit error rate performance is simualated and it is stated that, BER performances of PLNC system and traditional network are nearly same however PLNC with DNF or AF system gives throughput improvement of 100% over the traditional transmission scheduling scheme. In the next scenario symmetric PLNC system is expanded from three-node network to one-dimensional multi-node network. The mapping algorithm for multi-node network is developed and applied to get the best BER performance.

In the third scenario, asymmetric PLNC system is analyzed. In this case, the source nodes have information with different length therefore they use different modulation schemes. The critical and most important part of system design is to use proper mapping algorithm. Therefore, the different mapping algorithms are tested and the one of them is selected for the best BER performance. The simulation results show that the network throughput is doubled while the BER performance of asymmetrical PLNC system is close to the performance of traditional network.

In the last scenario, PLNC system is discussed under frequency selective channel fading. OFDM scheme is added to the PLNC system in order to cope frequency selective fading channels. In order to transmit high data rates, short symbol periods must be used. In a multi-path environment, a shorter symbol period leads to a greater chance for ISI. OFDM mitigates this problem. With OFDM implementation, proposed OFDM-PLNC system is investigated in Rayleigh fading and Ricean fading channel for DF and DNF. The BER performance of propose system is acceptable when the data rate is getting higher.

In conclusion, this work shows that PLNC scheme is easy, effective and promising method and it can be implemented for the various wireless communication systems.It enhances throughput of the applied systems significantly for the nearly same BER performance as traditional network. It is also shown that there is trade-off between cooperative methods. When DNF and AF method provides faster transmission then DNF, the BER performance of DF method is better than other at every discussed systems.If we want to compare AF and DNF about BER performance, DNF is superior. However, if the simplicity of implementation is an issue, AF method is the right solution for the system.

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APPENDICES

LIST OF FIGURES

LIST OF TABLES