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COOPERATIVE RELAY PROTOTYPE DEVELOPMENT AND PERFORMANCE MEASUREMENT

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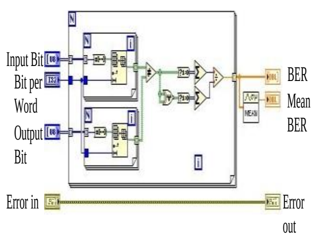
Graphical abstract



Abstract

To meet the demand for high data rate, the wireless cellular system technology has grown in a steady pace in recent years. However, due to multipath fading, shadowing effects and path loss, the wireless communication links are prone to errors. To improve the communication link, at the cell edge and shadowed environment, cooperative relaying scheme has been proposed. In cooperative relaying, an additional node is placed between the source and destination terminals, to provide redundant path for data transmission. However, existing literature on cooperative relaying only investigates the system performance through theoretical simulations. The real world performance remains unknown because of the lack of prototypes for field testing and measurement. This work focuses on the development of an amplify-and-forward (AF) cooperative relaying prototype. The prototype is developed using the LabVIEW system development platform and the implementations are carried out on Universal Software Radio Peripheral (USRP). The performance of the AF based cooperative relaying prototype is measured in terms of the bit error rate (BER) and compared with the direct communication link without relay. The measured results show that cooperative relay assisted communication achieves significant improvement in terms of signal reliability, coverage distance and power efficiency.

Keywords: Cooperative relay, universal software radio peripheral, amplify-and-forward, BER

Abstrak

Untuk memenuhi permintaan untuk kelajuan data tinggi, teknologi sistem selular wayarles telah berkembang dalam kadar yang stabil pada tahun kebelakangan. Walau bagaimanapun, isyarat wayarles masih terdedah kepada kehilangan pelbagai arah, bayang dan kehilangan laluan, mengakibatkan ralat dalam laluan komunikasi. Geganti koperasi telah dicadangkan untuk membaiki laluan komunikasi di penghujung sel dan kawasan yang dibayangi. Geganti koperasi adalah teknik untuk meningkatkan kebolehpercayaan isyarat dengan memperkenalkan nod tambahan antara terminal sumber dan terminal destinasi untuk menyediakan laluan berlebihan untuk penghantaran data. Walau bagaimanapun, kerja sedia ada berkenaan geganti koperasi menyiasat prestasi melalui simulasi secara teori sahaja. Prestasi dunia sebenar masih tidak diketahui kerana kekurangan prototaip untuk ujian lapangan dan pengukuran. Oleh itu, tumpuan kerja ini adalah untuk membangunkan prototaip geganti koperasi dengan cara menguatkan-dan-hantar (AF). Prototaip tersebut dibangunkan dengan menggunakan platform pembangunan sistem LabVIEW dan dilaksanakan dengan Periferal Radio Perisian Universal (USRP). Prestasi prototaip geganti kooperasi AF diukur dari segi kadar ralat bit (BER) dan hasilnya dibandingkan dengan laluan langsung tanpa geganti. Hasil ukuran menunjukkan bahawa geganti koperasi meningkatkan kebolehpercayaan isyarat secara ketara, memanjangkan jarak liputan dan mengurangkan penggunaan tenaga.

Kata kunci: Geganti kooperasi, periferal radio perisian universal, menguatkan-dan-hantar, kadar ralat bit

1.0 INTRODUCTION

The growing demand of data applications has led to significant development in wireless communications. However, when wireless signal are propagated through space, the power attenuates exponentially with increasing distance. Therefore, improving the signal reliability and enhancing system capacity of the user at the cell edge or in a shadowed environment, remains a challenge due to various propagation effects such as, path loss, shadowing, multipath fading and interference [1].

Cooperative relaying scheme can be used to mitigate the effect of path-loss, shadowing and multipath fading [2]. The path-loss and shadowing effect observed in cooperative network may be less than that of a direct link, due to the redundant path provided by the relay link, and this is known as cooperative diversity [3]. Performance benefit of cooperative diversity or spatial diversity can be achieved from either the medium access layer or physical layer. The physical layer enables throughput gain, power saving, interference reduction and cell extension [3]. In addition, wireless relay terminal offers improvement of signal reliability and it is cost efficient because its deployment is not relying on wired backhaul [4, 5].

Cooperative relaying can be implemented with amplify-and-forward (AF), decode-and-forward (DF) and the hybrid of the AF and DF. In the AF technique the received signals at the relay is amplified by an amplification factor with a minimum delay and the amplified signal is forwarded to the destination [6, 7]. Although AF relays are less complex to implement, they amplify the desired signal as well as the noise, which could lead to decoding errors at the destination. However, in achieving the maximum diversity gain, the AF cooperative scheme is more beneficial compared with the DF relaying scheme [8]. Furthermore, physical layer network coding can be implemented at the AF relay, to achieve a higher throughput with a lower complexity [9].

Orthogonal frequency division multiplexing (OFDM) is a technique that enables high data rates in digital broadcasting, WiFi and 4G mobile communications [10]. The development of OFDM is motivated by the growing demand of data rates, especially in multimedia application and services. In OFDM, a single data stream is divided into multiple streams of lower rate subcarriers, to enhance robustness of the system against fading [11]. Each subcarrier is orthogonal to each other, where it enables overlapping of subcarrier without inter-symbol interference. The modulated subcarriers can make use of modulation schemes such as, quadrature amplitude modulation (QAM) or phase shift keying (PSK) to maintain high data rate and high capacity in wireless system [10].

Most of the existing works on cooperative relaying investigate the performance through theoretically simulation. In [12] the authors proposed CoopMAC protocol implemented based on 802.11 devices. However, the testbed is based on the off-the-shelf wireless cards, whereby the hardware cannot be simply customized at the MAC layer and it is not programmable at the physical layer. In [13], the authors studied the effect of relay location in LTE, for coverage extension using DF and AF relays. Reference [14] proposed an enhanced cooperative DF relay scheme by using bit rearrangement technique at the relay. However, the real world performance remains unknown because of the lack of relay prototype for field testing and measurement.

The performance established in simulated and theoretical works may vary with the real-world scenario, as the real-world environment is quite complicated to model. To properly evaluate a protocol in actual propagation environment, the use of experimentation becomes needful. Hence, a prototype or testbed can be used to evaluate the performance benefits of cooperative relaying schemes.

The inability of simulated and theoretical works to realistically capture the real world wireless signal propagation effects, has motivated the need for a testbed. In [15], a relay testbed was developed to determine the performance of the cooperative relaying scheme in real environment. The author proposed a USRP cooperative testbed for both single and multiple relays using Gaussian minimum shift keying (GMSK) modulation with different scenarios such as blockage, distance and fading. It uses DF technique with SISO configuration at the relay. However, the testbed does not support OFDM and higher order modulation which are used in modern communication system such as 4G Long Term Evolution and WiMAX.

In this paper, we propose to develop a practical AF and OFDM based cooperative relaying prototype to access the performance of relaying network in actual environment. Universal Software Radio Peripheral (USRP) and LabView platform are used in the prototype development. The real-world performance is measured and evaluated in terms of the bit error rate (BER). The performance of the cooperative relaying scheme is compared with the direct communication scheme without relay, in an indoor environment with line-of-sight (LOS) and non-line-of-sight (N-LOS) settings. The measurements justify that cooperative relay assisted communication delivers significant improvement not only in terms of signal reliability, but also in terms of coverage distance and power efficiency

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2.0 SYSTEM DESIGN

This paper intends to evaluate the performance of cooperative relay communication scheme in real wireless environment, by developing a relay prototype based on LabVIEW system development platform and NI USRP 2922. The design consists of two phases. The first phase starts with the development of direct link communication, which is used as the baseline scheme for comparison. The second phase is the development of cooperative relay prototype where the relay is introduced into the network to provide redundant path for the transmitted signal, to mitigate the effect of fading and bit errors at the destination node.

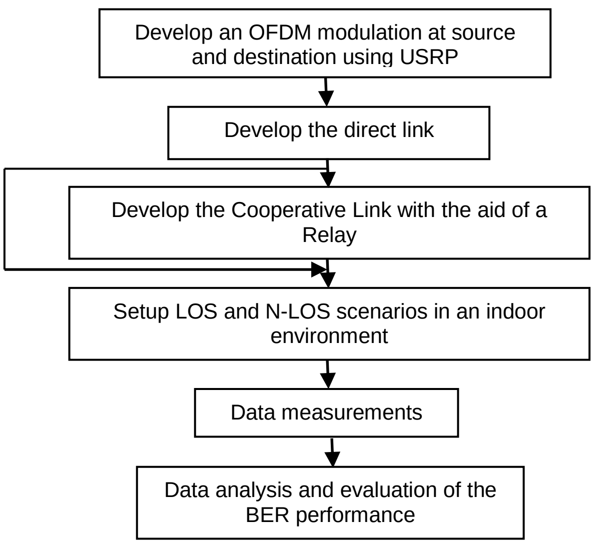

Figure 1 Flowchart of the design

The flow of the designed model is shown in Figure 1. OFDM block is developed by using 4-quadrature amplitude modulation (4-QAM) at the source terminal. At the destination terminal, symbol timing recovery, matched filters and 4-QAM demodulation are constructed. In the second phase, the cooperative relay is introduced. The deployment setup is implemented in a LOS and N-LOS environment. All nodes are equipped with single antenna.

2.1 Hardware Configuration

The hardware tools used in the experiment consists of a single PC host, three NI USRP's 2922 (source, destination and relay nodes) for direct link (without relay) and cooperative link (with relay). The USRPs are connected to the PC host through an Ethernet switch. An external clock generator, OctoClock is connected to the NI USRP 2922 for frequency and timing synchronization. This enables the synchronization of the source and destination terminal. The setup is deployed with a dipole antenna supporting 900 and 1800 MHz band with omnidirectional radiation pattern and 3 dBi gain. Table 1 shows the specification of the hardware used while Table 2 shows the indoor measurement parameter setup.

Table 1 Hardware's specification used for this project

Hardware	Specifications
Single PC host	a) Intel Core i7 1800GHz b) 8GB DDR3 L Memory
3 NI USRP 2922	Frequency range 400MHz to 4.4GHz
Ethernet cables	Category 5 enhanced (cat5e)
Single Ethernet switches	Tp Link-SG1016, 16 port gigabit switch
A single external clock	OctoClock provide 10 MHz/1 pulses per second (PPS)
3 antennas	VERT900 antenna dual band (824-960MHz,1710-1990 MHz)

Table 2 Indoor measurement parameter setup

Indoor parameter	Setting Values
In-band frequency	850 MHz
Out-of-band frequency	850-915 MHz
Transmits power	-16dB
Bandwidth	100 kHz and 200kHz

2.2 First Phase: Direct Link Development

In the first phase, the source and the destination nodes are designed for the direct communication scheme.

2.2.1 Design of the Source Terminal

The source block diagram is presented in Figure 2. The source is initialized by calculating the pilot tones based on the OFDM parameters such as fast Fourier transform (FFT) size, cyclic prefix, and length of the null tones. In this paper, one pilot tone is added after every twelve data tone. Furthermore, to avoid inter carrier interference, guard period or also known as cyclic prefix is inserted into the OFDM symbols. To understand the importance of the guard period, assume at time t the following symbols are transmitted from the source $\psi_n(t) = e^{(jn2\pi t/T)}$ and $\psi^{\delta}_{n+m}(t) = e^{(j2\pi(n+m)t/T)}$.

Assuming the offset δ is less than 0.5 then the reception pulse at the destination can be expressed as

$$\psi^{\delta}_{n+m}(t) = e^{(j2\pi(n+m+\delta)/T)}. \quad (1)$$

Let us further assume that there is a loss of orthogonality and hence, there is maladjustment between two consecutive symbols at time τ, then the received symbol can be computed as

$$X_k = v_0 \int_{-\frac{T}{2}}^{-\frac{T}{2}+\tau} \psi_n(t)\psi_i^*(t-\tau)dt + v_1 \int_{-\frac{T}{2}+\tau}^{\frac{T}{2}} \psi_n(t)\psi_i^*(t-\tau)dt. \quad (2)$$

X_k can be as approximated provided $T \gg \tau$ as

$$\frac{X_k}{T} \approx \frac{2m\pi\frac{\tau}{T}}{m\pi} = 2\frac{\tau}{T}, \quad (3)$$

which is independent of the numbers of carriers. The interfering power in any carrier can be obtained by taking the expectation of (3) as follows

$$ICI = 20\log\left(\sqrt{2}\frac{\tau}{T}\right). \quad (4)$$

To combat the inter carrier interference, cyclic prefix are used. In the generate bits block, the data length consisting of the FFT size, length of pilot tones and length of null tones are calculated and the required numbers of bits are generated. The generated symbols, the calculated pilot tones position and the parameters from the front end panel are fed into the transmitter to obtain the QAM OFDM modulated symbols. System parameters such as the number of transmitting antennas and the number of receiving antennas, training and synchronization sequence are configured in the virtual instrument (VI) program "ofdm_tx.VI". The signals then undergoes symbol mapping using pulse shaping filter, where a continuous-time waveform is generated from the discrete valued input symbols. The signals are finally being transmitted by the writes_tx data block.

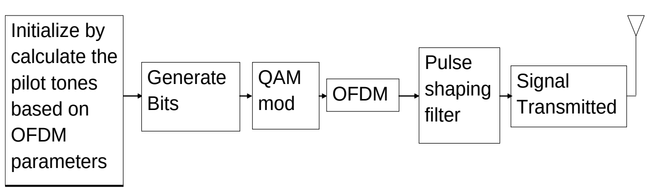

Figure 2 Block diagram of source terminal

2.2.2 Design of the Destination Terminal

The receiver block diagram at the destination terminal is shown in Figure 3.

At the destination terminal, the VI "mod_classifier_RX.vi" initializes the USRP by calculating the position of the pilot tones from the received OFDM parameters, the USRP are then configured based on the calculations. The received samples are captured and compared with the threshold value to detect the source signals. When the received signal at the destination exceeds the threshold values, the samples pass through the fetch block and the indicator of packet found is switched on, which indicates that the received signals have been fetched from the source terminal, the fetched signals are then passed through the match filter and over the sampling operation block where the samples are matched with the pulse shaping filter, similar to the filter used in the source terminal. The processed signals from the match filter along with the calculated pilot tones and training parameter are passed into the VI "ofdm_rx.VI" to perform the demodulation process of OFDM channel. The final output data stream and constellations diagrams are presented in a waveform display on the PC host to determine if the destination terminal successfully receives the signals from the source terminal.

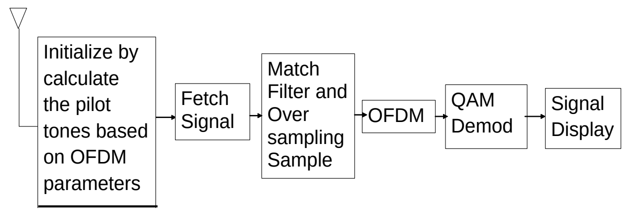

Figure 3 Block diagram of destination terminal

2.3 Second Phase: Cooperative Relay Development

In the second phase where there is no line of sight, the system performance degrades due to path loss and shadowing. As the source signal travels in space, the power decays exponentially with the distance. To improve the received power at the destination, a cooperative scheme can be introduced as shown in Figure 4, where S, R and D denote source, relay and destination respectively. In the cooperative scheme, a relay is inserted into the network. In this design, a third NI USRP 2922 node is placed in the network to act as a relay.

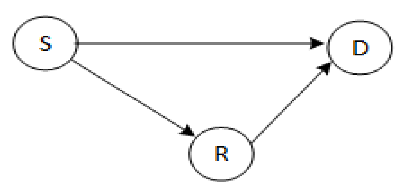

Figure 4 Cooperative scheme scenario

2.3.1 Design of the Relay Terminal

AF technique is implemented at the relay terminal, where the signals received from the source terminal is amplified by an amplification factor. The amplified signal is then forwarded to the destination terminal. Figure 5, shows the block diagram of the relay terminal. First the relay configures the receiver and transmitter parameters setting, such as the IP address for NI USRP 2922, clock source, frequency source, sample rate, carrier frequency, active antenna ports, number of samples per fetch and gain. The signals are fetched by the relay receiver using the fetch block, the received signal is then amplified and forwarded to destination terminal using the write block. In order to perform the relay function, the operation of fetching and the operation of writing signals are performed in an alternate time slots as the relay operates under half duplex constrains, i.e. the relay can only receive or transmit in one time slot.

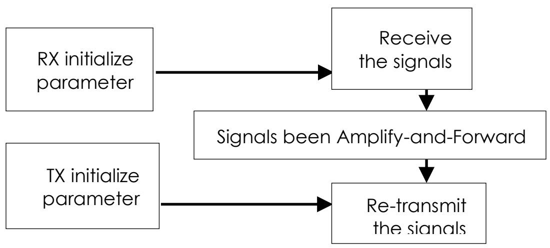

Figure 5 Block diagram of relay terminal

2.3.2 Destination Terminal Aided by a Cooperative Relay Link

In this paper, we consider in-band and out-of-band AF based relays. In the in-band AF relay, all the nodes operate in the same frequency band. In order to utilize the cooperative relay link, the destination terminal has to capture the signals from the direct link and the relay link. These two signals are combined together to perform the cooperative communication. Figure 6 shows the block diagram of the cooperative communication where the signals from the source and relay terminals are received and stored in buffer for further analysis at the destination. However, the received signal at the destination from the source and the relay can add up constructively or destructively. To minimize the effect of destructive signaling, the out-of-band AF relay can be implemented. In the out-of-band AF relaying, the source transmitter and the relay receiver implement the same frequency of 850MHz while the relay transmitter and destination terminal frequencies are set to 915MHz. Hence, the destination can only receive from the relay terminal, as such the ambiguity at the destination is eliminated.

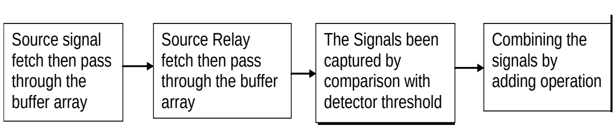

Figure 6 Block diagram of cooperative relay assisted communication at destination terminal

2.4 Indoor Measurement Setup

An indoor environment, which consists of rooms and halls, is used for the experiment in order to emulate a rich scattering scenario. In addition, LOS and N-LOS scenarios for the direct link and cooperative relay link are considered.

Figure 7 shows the measurement setup. The source terminal is located inside the room while the destination terminal is placed outside the room. The line-of-sight (LOS) distance from source to destination terminal is 6m(from source) while the non-line-of-sight

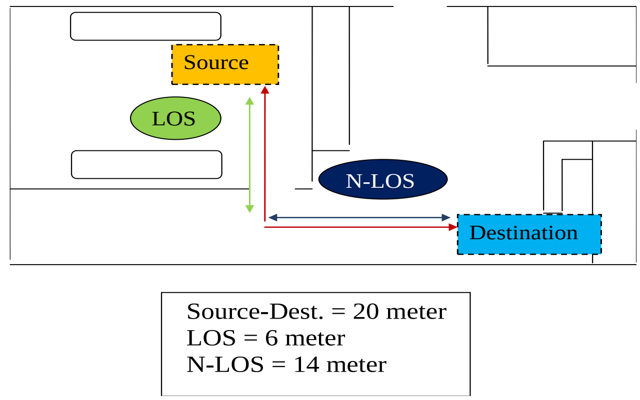

Figure 7 The layout of direct link

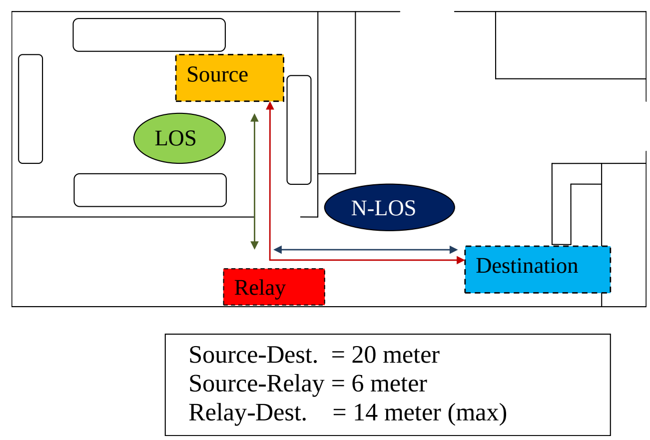

Figure 8 The layout of cooperative relay link

(N-LOS) distance varies from 7-20m (from source). The longest total distance from the source terminal to the destination terminal is set to 20m.

In Figure 8, the relay is introduced into the network. The AF relay is placed between the source and the destination. The distance from the source terminal to the relay terminal is fixed at 6m. The distance from the relay to the destination terminal is varied from 1-14m (or the destination is 7-20m from source).

2.5 Performance Measurement

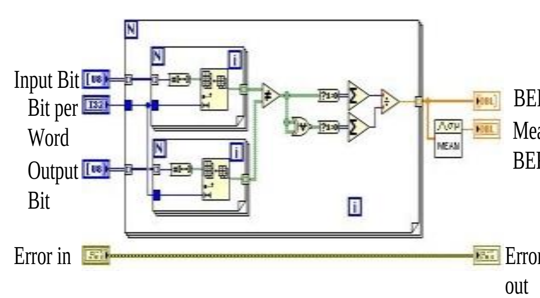

Figure 9 Virtual Instrument (VI) block diagram of computing BER

The BER measurement is performed by comparing the input bit stream transmitted from the source terminal with the output bit stream received at the destination terminal as shown in Figure 9.

3.0 RESULTS AND DISCUSSION

In this section, the field measurement results of the direct transmission and the cooperative communication are presented.

3.1 Direct Transmission Link

In the direct transmission link, the source transmits to the destination without the aid of a relay. Measurements are carried out for both LOS and N-LOS paths. From the PC host display, it can be observed that the BER is approximately close to 0% in the LOS case. Recall that the LOS distance is set to 0-6m. Hence, with the distance of about 6m and with a direct link between the source and the destination, the destination can completely recover the transmitted 4QAM OFDM symbols without errors. The effect of blocking and path loss can be observed at the NLOS path.

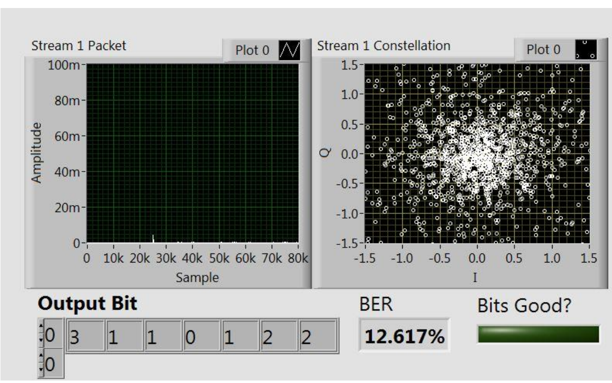

Figure 10 The direct link result at 20 meter from source terminal

As the distance between the source and destination increases in the NLOS path, the BER performance starts to degrade. In this experiment, the maximum NLOS distance is set to 20m. From Figure 10, it can be observed that, the destination terminal cannot completely recover the signals from the source terminal. A scattered constellations diagram of the transmitted 4QAM OFDM symbols can be observed from the display. Furthermore, the BER value increases significantly to about 12.6%. To improve the performance of the wireless link at the destination, there is a need to introduce a third node which can help to forward the source symbols to the destination. In this case, the third terminal is the relay node.

3.2 Relay Assisted Cooperative Link

As in Figure 4 and Figure 8, the performance of the destination node can be enhanced by placing a relay between the source and the destination. For the cooperative scheme, the LOS path measurement is omitted because network has already presented a good BER performance. However, we note that, relays can still be used in the LOS part to improve signal reliability in terms of diversity gain. We therefore proceed to the N-LOS path, where the BER performance of the direct link starts to degrade. By introducing a relay terminal between both source terminal and destination terminal, the BER can be improved as shown in Figure 11, where the BER close to 0% can be achieved and four distinct constellations points can be observed.

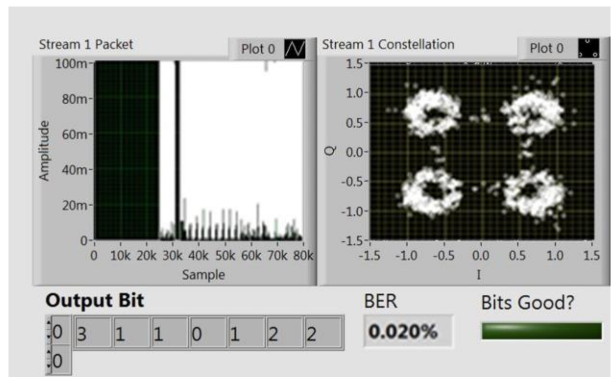

Figure 11 The cooperative relay link result at 20 meters from source terminal

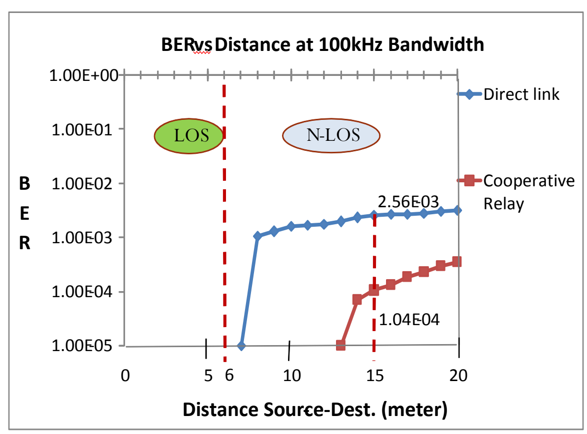

Figure 12 Comparison of direct link and cooperative relay link using in-band frequency of 850MHz at 100 kHz bandwidth

In Figure 12, the BER versus the distance is plotted for both the direct transmission link (without relay) and the relay assisted cooperative link. The figure shows that the BER versus distance for in-band relay with 100 kHz bandwidth. The results shows that the cooperative relay is able to reduce the BER significantly. As an example, at 15 meters the BER for the direct link is 2.56 $\times10^{-03}$. By introducing an in-band relay to the network, the BER performance is improved to 1.04 $\times10^{-04}$. Furthermore, the result shows that by placing a relay in the network, the coverage distance can be extended. Suppose the system BER performance is fixed at 1.00 $\times10^{-04}$, without a relay in the network, the direct link distance is about 7m. In contrast, by placing a relay in the network, the distance can be extended to up to 15m. In short, the cooperative relay scheme is able to improve the coverage distance by about 47%.

Figure 13 shows the BER performance versus distance for the out-of-band cooperative relaying scheme. In this scheme, frequency isolation is implemented where the signals propagate through two orthogonal channels. The first channel carries the signals from source terminal to the relay terminal while the second channel carries the signals from relay terminal to the destination terminal.

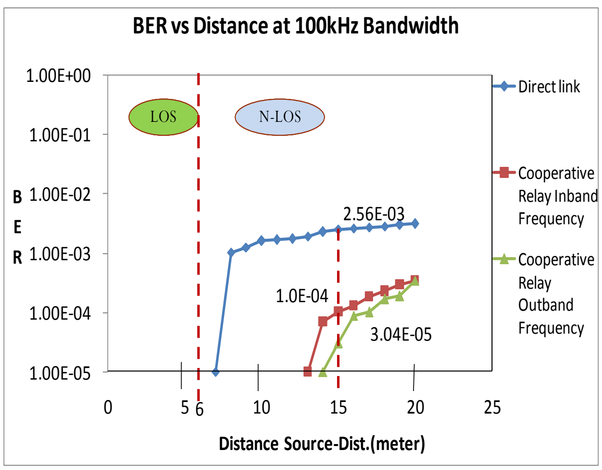

Figure 13 Cooperative relay link using out-of-band frequency at 100 kHz bandwidth

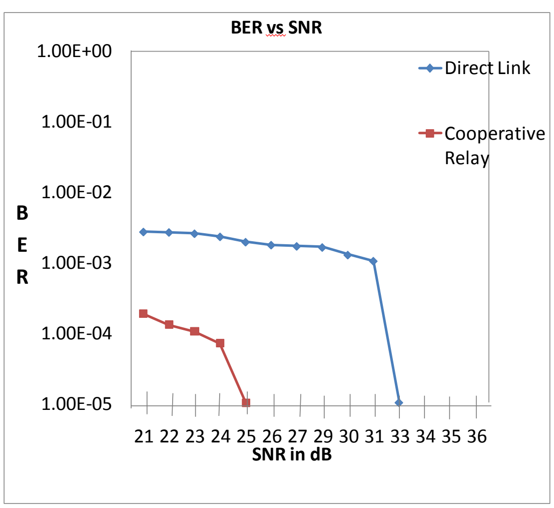

Figure 14 Comparison BER vs SNR for cooperative relay link with direct link

In Figure 13, the results obtained from the out-of-band relaying scheme is compared with the direct link (without relay) and the in-band cooperative scheme in Figure 12. It can be observed that the out-of-band scheme is slightly better compared to the in-band relaying scheme. As earlier noted, in the in-band cooperative relaying scheme, the signal received from the source and relay terminal can add up constructively or destructively. However, in the out of band relaying scheme, the destination only receives signals from the relay node, because the signals from the source are isolated using orthogonal frequency channels.

Finally, the BER versus signal-to-noise-ratio (SNR) graph is presented in Figure 14. The plot shows the comparison between the cooperative relay link and direct link. Although the BER improves with SNR for both schemes, it can be observed that the cooperative relay link gives better performance compared to the direct link. The cooperative relay link also requires less signal energy (or lower SNR) to achieve the same target BER when compared to the direct link.

4.0 CONCLUSION

The prototype implementation of a direct communication and a cooperative communication scheme using NI USRP 2922 and LabVIEW platform has been developed. The measurement is conducted in an indoor environment with LOS and N-LOS paths. The results show that the BER performance is severely degraded in N-LOS environment for the direct communication scheme. By placing a relay prototype in the network, the BER performance is significantly improved especially in the N-LOS environment. The results also justify that the cooperative relay can extend coverage distance and improve network transmit power efficiency.

As a future work, the implementation of cooperative relay testbed can be further improved by implementing higher order modulations techniques such as 16-QAM or 64-QAM to emulate the 4G Long Term Evolution technology for high speed data transfer. The testbed development using a multiple input multiple output (MIMO) and also multiple relays can also be further investigated.

Acknowledgement

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