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USING AMPLIFY-AND-FORWARD RELAY FOR COVERAGE EXTENSION IN INDOOR ENVIRONMENTS

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ABSTRACT

Cooperative communication is a promising method for increasing the capacity and extending the coverage between a base station (BS) and a mobile user (MU) by using relays to exploit cooperative diversity. However, the existing literature mainly focuses on theoretical performance evaluation without experimental validation and, thus, fails to address the effects on real-world radio signal propagation. This research, therefore, aims to develop a prototype amplify-and-forward (AF) relay using software-defined radio (SDR) to evaluate the real-world performance of such a relay in improving coverage. The proposed relay is developed using the LabVIEW software and programmed on a National Instruments-Universal Software Radio Peripheral 2922 (NI-USRP 2922) SDR platform. The major merit of this entire communication setup is less expensive as the system uses a reprogrammable hardware. The measurements are performed indoors, and the signal strength or received power at the MU in cases with and without the relay is recorded. The results show that the received power performance and signal-to-noise ratio (SNR) at the user improve significantly when the AF relay is deployed compared to when direct link point-to-point transmission without the relay is used.

Keywords: *Cooperative communication, Amplify-and-forward Relay, Software-defined-radio, GNU radio, SNR*

1. INTRODUCTION

The demand for high data rates in wireless mobile communications has increased drastically in recent years [1], and the growth of the customer demand has exceeded that of the available capacity. To enhance the data rate and spectral efficiency, cooperative communication is a promising method, and a relay can be implemented to satisfy the increasing customer demands, extend cell-edge coverage, increase capacity and reduce the power transmission at the BS [2]. The concept underlying the relay is based on that of the repeater. The main function of a relay is to forward point-to-point signals from a BS to a mobile user (MU) and vice versa. By using a relay, the system's cell edge coverage can be extended and reliable data rates and lower transmission powers can be achieved [3]; for these reasons, relays were applied in the 4G IMT-Advanced system [4]. From the business perspective, the use of relays can avoid incurring the additional costs of building another BS in the network because relays have less-complex hardware and can be installed conveniently on top of an existing lamp post or building, thereby reducing the capital expenditure (CAPEX) and operating expenditure (OPEX) [5].

There are two major types of relay: the amplify-and-forward (AF) relay and the decode-and-forward (DF) relay. As shown in Figure 1, the AF relay receives the signals from the BS and then amplifies the signal received by the MU. In contrast, a DF relay decodes the received signal and re-encodes it before forwarding it to its destination [3].

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AF relays offer good spectral efficiency and are much less complex than DF relays. AF relays use linear relaying techniques, which are less resource intensive, and the signaling overhead is generally lower than those of its nonlinear counterparts, such as DF relays. AF relays are simple, and they are able to recover the throughput loss resulting from the extended coverage [6]-[9]. Therefore, we focus on AF relays in this paper.

This paper is organized as follows. Section 2 provides the literature review. In Section 3 we give an idea about our proposed scheme vs conventional scheme, Section 4 discussed the hardware setup configuration. The .methodology is presented in Section 5. The numerical results and discussion are given in section 6. Finally, the conclusions are drawn in section 7.

Figure 1: A downlink scenario in an AF relay network

2. LITERATURE REVIEW

The existing literature on relaying mostly focuses on numerical simulation results, and real performance measurements are lacking. To evaluate the real-world performance of a communication system, prototype testbeds are often used. Software-defined radio (SDR) has been used in wireless communication system prototyping because of its configuration flexibility and low development costs. Programmable radios can be realized using SDR with the help of system development software, such as GNU Radio and LabVIEW [10]-[11]. Reference [12] implemented LabVIEW and NI USRP 2920 SDR for railway communication services, but the system performance was limited to a point-to-point scenario, and relaying was not considered. Reference [13] proposed a MIMO SDR-based network for long-distance robotic control applications, but such a network does not support data applications, and relaying was not considered. A relay prototype was demonstrated in [14] to measure the real performance gain in terms of both data rates and coverage. However, the scope of the measurements in [14] was limited to the outdoor environment. The real-world performance of a relay in improving the coverage in indoor and non-line-of-sight environments has not been investigated to date.

Reference [15] assumes a fixed gain in each clusters of L AF relay such that each whole relay's cluster is satisfied by a transmit power constraint. They showed how the capacity scales with the number of links and transmit power as the number of MEs, BSs and relays tend to infinity. In contrast, our paper deals with only L=1 and study how the distance or SNR behaves in terms of received power from direct and relay links.

Mostly, all of these papers evaluate their performances through computer simulation and analysis. In contrast, this research aimed to develop an AF relay prototype using a SDR platform (NI USRP 2922) and LabVIEW software and to measure the received power in cases with and without relays in an indoor environment. The received power is used as a metric to assess the effectiveness of the relay in extending the coverage in an indoor environment.

With an implementation of a simple single antenna relay based on received power versus either distance or SNR. We show that the single antenna relay link outperform it is counterpart point-to-point link.

3. CONVENTIONAL VS PROPOSED SCHEME

Conventional setup implements a large number of hardware, which used for digital and analog communication experiments. Therefore, the processing time is long as well as the cost is high. For instance, in conventional lab setup consist of 20 hardware components with 40 users, only one half can access the lab at a time and the others have to be waiting (idle). Moreover, it is costly and time consuming.

The proposed hardware setup using USRP can substitute all the hardware components such as Oscilloscope, signal generator, etc. The cost of USRP is less and it is system is upgradable, when compared to other hardware. If we place a switch between the users and the USRP, all users can access the USRP in a time manner without any delay as depicted in Figure 2. Each user accesses the resources, at a certain time slot.

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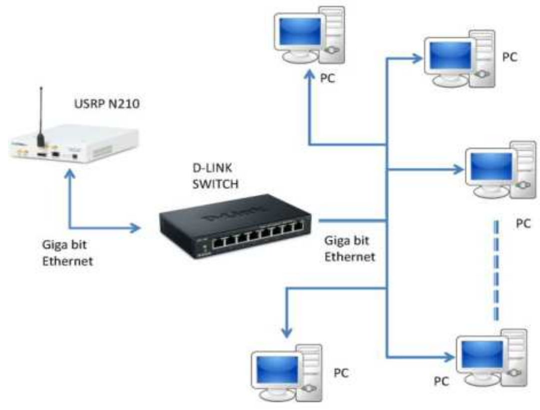

Figure 2: A Switch Is Placed Between The USRP And Users, All Users Access The USRP At A Certain Time Slot

4. HARDWARE SETUP CONFIGURATION

In this research experiment, we used three NI USRP's 2922 for source, destination and relay nodes for point-to-point link (without relay) and cooperative link (with relay) controlled by a single PC host. The PC host connected to the USRP'S through an Ethernet switch. The time and frequency synchronization of source and destination is achieved through an external clock generator (OctoClock). A dipole omnidirectional antenna with 3 dBi gain is deployed in this setup.

The hardware setup specification is given in Table 1, while the indoor parameter setup is given in Table 2.

Table 1: The Hardware Setup Speciation

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:The Indoor 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

5. METHODOLOGY

5.1 BS (Source) Prototype

The flow chart in Figure 3 shows that the USRP is configured so that the signal can be transmitted from the BS prototype. Then, pilot tones are calculated based on the Orthogonal Frequency Division Multiplex (OFDM) parameter. One pilot tone is added to the 12 data tones, and the positions of the null tones are simultaneously calculated. Subsequently, the data length or number of bits is calculated using the fast Fourier transform (FFT) size formula, which is the difference between the length of the pilot tones and the length of the null tones. All of these calculations are performed carefully to generate bits for the SISO single-input and single-output (SISO) OFDM transmission system. Then, the signal moves to the 4-Quadrature Amplitude Modulation (4-QAM) system to be modulated. The modulated signal is then sent to the SISO OFDM transmission. In this block, the OFDM signal with additional training and synchronization training sequences facilitates the transmitter operation [16]. In SISO OFDM, the data are converted from serial to parallel and subjected to Inverse Fast Fourier Transform (IFFT). A cyclic prefix is added before converting the parallel data back to serial data [17]. The signal after SISO OFDM will then undergo symbol mapping to map the true information bearing signal to the output symbols. Finally, the signal is transmitted using the Write Tx (transmitter) data block diagram [18].

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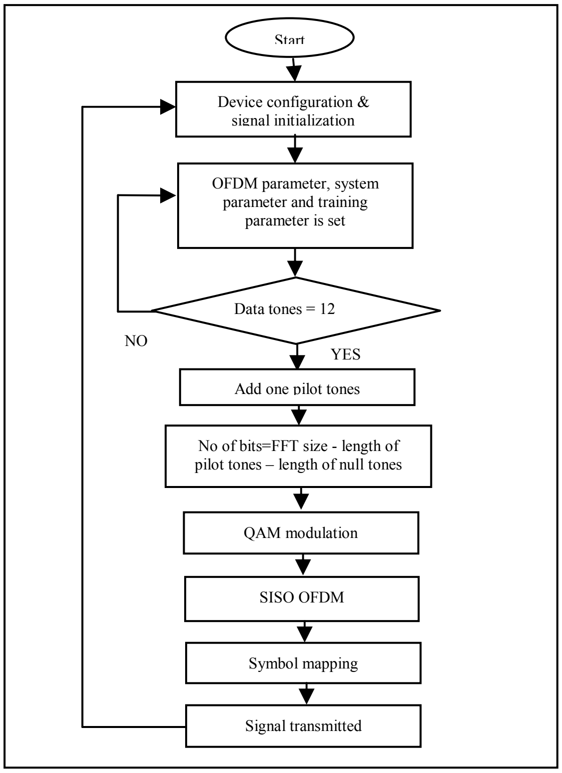

Figure 3: Flowchart of BS (source) prototype development link scenario in an AF relay network

5.2 AF Relay Prototype

The flowchart in Figure 4 describes the AF relay development. First, the device transmitter (Tx) and receiver (Rx) ports are configured. Then, the signals from the source are received as Rx Fetch Data. The received signal is amplified and retransmitted as Tx Write Data. The received and transmitted waveforms are also displayed.

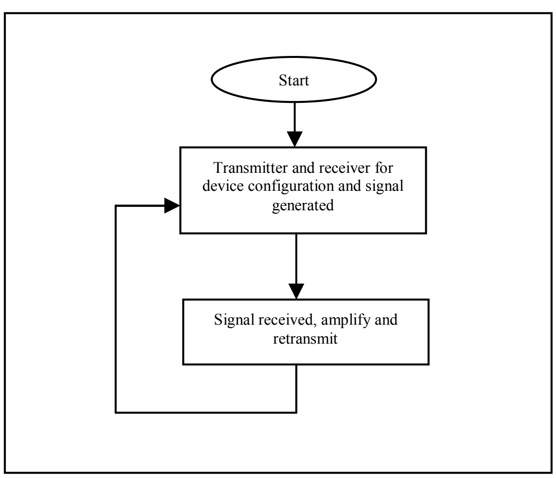

Figure 4. Flowchart of AF relay prototype development

5.3 MU (Destination) Prototype

Figure 5 shows the destination node (MU) flowchart in the LabVIEW program. The working principles are as follows: First, the device is configured, and the signal is initialized by calculating the positions of the pilot tones according to the OFDM parameter. The block diagram called usrp rxrf trigger and capture.vi then fetches the sample number [19]. This block diagram captures the sample number, which is compared with the threshold required to detect the transmitted signal. If the received signal is above the threshold, In-phase and Quadrature component (IQ) samples are returned. The IQ samples then pass through a matched filter and oversampling block. Subsequently, the samples pass through SISO OFDM and 4-QAM, producing the demodulated signal. In the SISO OFDM block, the serial data are converted to parallel data. The cyclic prefix is removed, the signal undergoes FFT, and the data are converted from parallel to serial data. Finally, the receive packet streams and QAM constellation are displayed.

5.4

5.5 Deployment in a Network Scenario using NI-USRP

After developing the LabVIEW program, the program was deployed on NI-USRP2922, as shown in Figure 5. The test was repeated several times to ensure that the program is capable of indoor measurements. First, three USRPs, which were used as the source, relay and destination, were placed on the racking system in the WCC Laboratory. The testing was conducted using only the SISO configuration.

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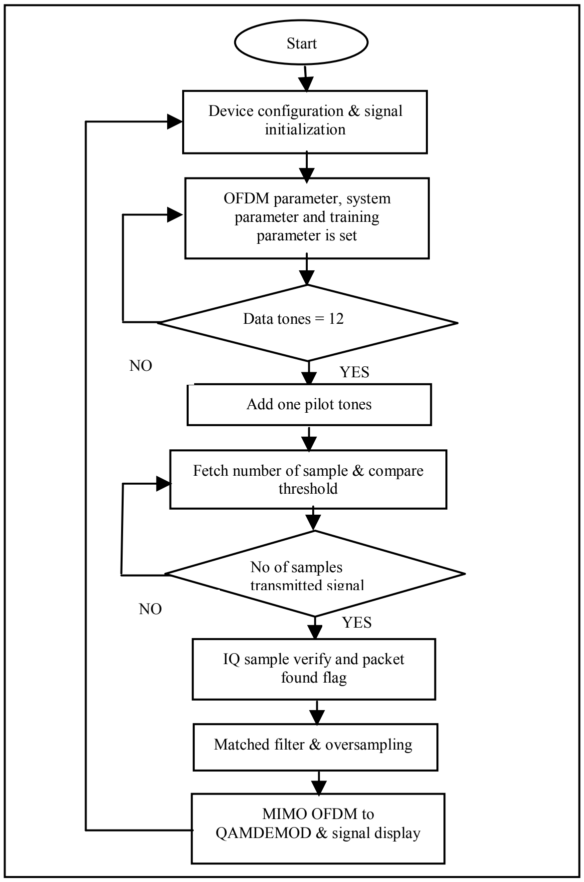
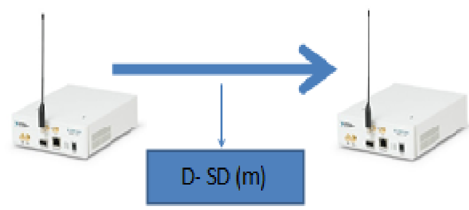
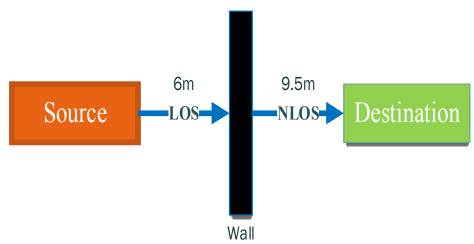


Figure 5 Flowchart of Destination Programming

Figure 6: On-the-rack setup



(a)



(b)

Figure 7: The point-to-point direct transmission setup: (a) actual setup (b) layout design

5.6 Indoor Measurements at Various Separation Distances to Determine the Received Power Level

5.6.1 Point-to-Point direct Transmission

The actual setup and layout design for point-to-point transmission are shown in Figure 6 and Figure 7. The source was located inside the WCC laboratory and was thus surrounded by a wooden wall, whereas the destination was placed at variable distances between the source node and 15.5 m away. The LOS area was at a distance of 6 m (at the laboratory door), and then, the Non-Line-of-Sight (NLOS) condition was applied. The distance between the source and destination is denoted as D_{DS}.

5.7 AF Relay Network Setup

The setup of the AF relay network is shown in Figure 8. The source and destination are located at fixed positions while the relay is moving from the source toward the destination. The distance between the source and the relay is denoted as D_{SR}, and the distance between the relay and destination is denoted as D_{RD}.

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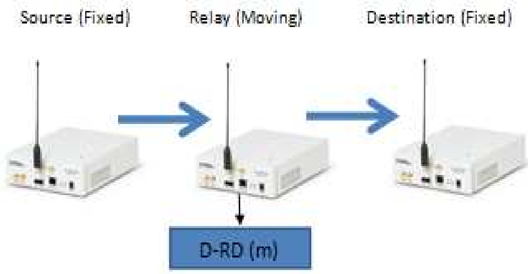

Figure 8: AF Relay Network Setup

5.8 Scenario 1

Case 1: LOS for both relay-to-destination and relay-to-source signals.

The optimal LOS distances were 6 m from relay to source and 9.5 m from relay to destination Figure 9 shows the first scenario, where the source was fixed at 0 m, the destination was fixed at 15.5 m, and the distance between the relay and destination was varied from 2 m to 15.5 m. The received power at the destination was measured at each of the relay positions.

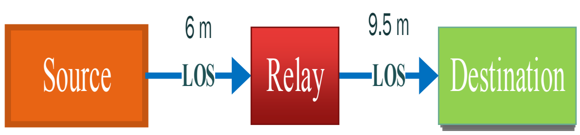

Figure 9: First Scenario Measurement Setup For AF Relay Network

5.9 Scenario 2

Case 2: From the destination NLOS scenario at the source and the LOS scenario at the relay (relay and destination outside the WCC Lab and source inside the WCC Lab)

Figure 10 shows the second scenario, in which the source-relay link was in NLOS and the relay-destination link was in the LOS. The source was positioned in the WCC laboratory, whereas the relay and destination were located outside the laboratory, as shown in Figure 10. Measurements were only collected indoors because of the limitation of the short coaxial cable connected to the USRP and Clock Synchronizer.

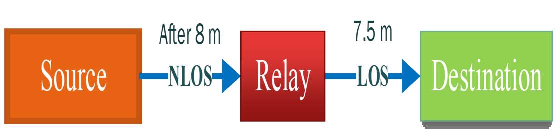

Figure 10: Second Scenario For Measurement Setup Of AF Relay Network.

6 MEASUREMENT RESULTS AND DISCUSSION

The graphs of the received power versus distance for point-to-point direct transmission and AF relay-assisted transmission are discussed below.

6.1 Received Power Versus Distance

Figure 11 shows the received powers for the point-to-point direct transmission and AF relay network versus distance. The theoretical received power versus distance is also shown. Before discussing the graph, the theoretical received power was simulated using the log-distance path loss model. The equations for path loss are shown below:

$$P_L(dB) = P_L(d_0) + 10n\log(d/d_0) \quad (1)$$

The path loss, *PL*, was calculated using the free space loss assumption, and *n* was taken from the environment factor where $n = 1.428$ for indoor LOS (2 m to 6 m) and $n = 4.053$ for obstructed in-building or indoor transmission (6.5 m to 15.5 m).

The indoor LOS included the wooden wall, and the obstructed in-building scenario in this research involved a concrete wall [7], [20]. The path loss must include the reflections from the walls that contribute to the received power. The graph that the theoretical received power is higher than those of both the relay-assisted transmission and the point-to-point direct transmission. This is because the theoretical result is for an ideal case. The received power for the relay-assisted transmission was better than that of the point-to-point direct transmission because of the diversity gain [21]. For the LOS case (D_{SD} < 6m), the average improvement was approximately 5 dB, whereas for the NLOS case (D_{SD} > 6m), the average gain was approximately 15 dB. The slope described in subsection. 5.5 was the same because the LOS involved distances from 2 m to 6 m, and the NLOS scenario spanned 6.5 m to 15.5 m. In [22], using two-way relaying improved the received power by 12%. In comparison, in this research, the received power improvement was 23%, almost double.

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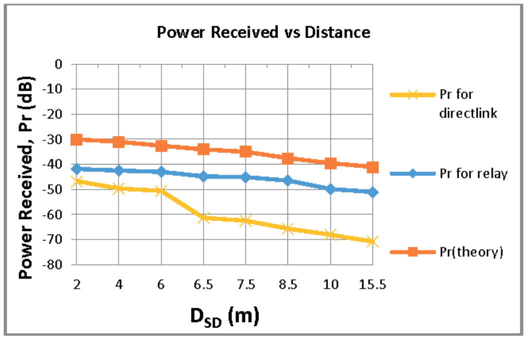

Figure 11: Received Power For The Direct Link And Relay Versus Distance.

6.2 Received Power Versus SNR

Figure 12 shows the received powers using point-to-point direct transmission and AF relay-assisted transmission versus SNR. Generally, the received power of AF relay-assisted transmission was higher than that of point-to-point direct transmission, and the theoretical received power overestimated the measured performance. For example, when the SNR value was 50 dB, the *Pr* for the AF relay was -45 dB, whereas for point-to-point direct transmission, the received power was -50 dB. Thus, a 5 dB gain is achieved when the relay is used to assist the transmission. When the SNR value was low, the gain was more significant. For instance, at SNR = 42 dB, the relay provided a gain of approximately 20 dB relative to point-to-point transmission.

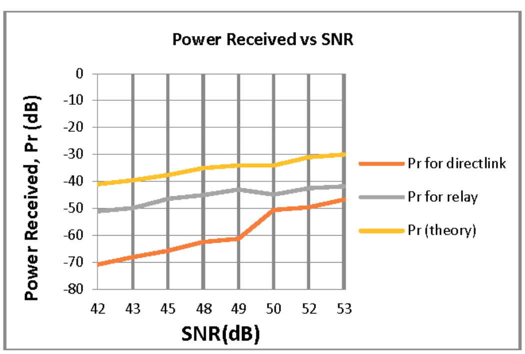

Figure 12: Received Power For The Direct Link And AF Relay Versus SNR

6.3 Power Ratio Versus Distance

Finally, Figure 13 shows the power ratios for point-to-point direct transmission and AF relay versus distance. The power ratio is the ratio between the transmitted power and the received power, and higher power ratios are related to higher path losses. For point-to-point direct transmission, the power ratio increased significantly as the separation distance increased, whereas in the AF relay-assisted case, the power ratio increased gradually as the separation distance between the source and destination increased. The maximum difference between point-to-point direct transmission and AF relay transmission was approximately 20 dB. Thus, the relay could provide a significant gain in signal strength at the destination to compensate for the path loss between the source and destination. In other words, the relay extended the coverage of the source BS.

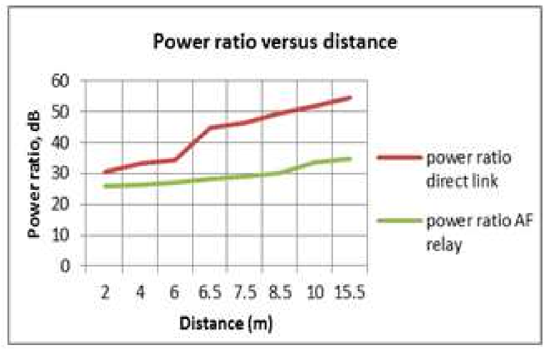

Figure 13: Power Ratios For Direct Link And AF Relay Versus Distance

7 CONCLUSION

An AF relay prototype using the NI USRP SDR platform and LabVIEW software was developed in this work, and indoor measurements of the downlink received power of an AF relay network and point-to-point direct transmission were conducted. The overall received power performance of AF relay-assisted transmission was found to be significantly better than that of point-to-point direct transmission. The SNR for AF relay was also improved compared to that of point-to-point direct transmission. Finally, the power ratio achieved using the AF relay also improved by approximately 20 dB compared to that of point-to-point direct transmission. These results explain that the cooperative relay can improve network transmit power efficiency and extend coverage distance. In the future, the proposed relay could be further studied in outdoor environments and using the MIMO antenna configuration to determine the coverage performance.

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