Multimedia SDR-based Cooperative Communication

Ahmed Prince*, Ahmed E. Abdalla*, Hisham Dahshan†, Alaa El-Din Rohiem †
*Department of Electronic Engineering
†Department of Communication Engineering
Military Technical College, Cairo, Egypt
Email: ahmed.prince@ieee.org, elsaid_a@mtc.edu.eg, hdahshan@mtc.edu.eg, alaa_rohiem@yahoo.co.uk

***Abstract*—Wireless communication systems are challenged to attain the demands of multimedia applications for high data rates and power efficiency. However, multipath fading affects the wireless channel which may cause degradation of the system performance. Cooperative communication emerged as an effective diversity technique to resist the multipath fading and to enhance the system performance. In this paper, an improved Signal to Noise Ratio combining (improved SNRC) is proposed. The proposed testbed of cooperative communication system is based on using NI USRP 2920 devices, single board computer (ODROID XU4), and open source software (GNU Radio) with FFmpeg which is a complete open source multimedia solution. The implemented experiments include voice communications and video streaming using GMSK modulation transmission to exploit cooperation benefits for multimedia communication. The relay terminal utilizes two different cooperative relaying techniques (Amplify and Forward (AF) and Selective Decode and Forward (SDF)). Performance analysis of the improved Signal to Noise Ratio combining (improved SNRC) is evaluated in comparison with the Equal Ratio Combining (ERC) in terms of bit error rate (BER) for voice communication and frame error rate (FER) for video streaming. The experimental results declare that improved SNRC outperforms ERC.**

***Keywords*—cooperative communication,software defined radio, USRP, ODROID, AF, SDF, ERC, improved SNRC.**

I. INTRODUCTION

Wireless communication systems are challenged to attain the demands of multimedia applications for high data rates and power efficiency, whereas wireless channels are not reliable and bandwidth limited. Additionally, the real-time of various multimedia applications affects the possibility of the re-transmission. So, the key to improve wireless multimedia transmission is to increase the reliability of channel and error flexibility without sacrificing the bandwidth efficiency [1]. The multi-input multi-output (MIMO) technique brings improvements for robustness to channel fading by supplying diversity in the spatial field. As a substitute to multiple antenna structures when the equipments are restricted to only one antenna (due to the limitations on the equipment size, and/or the extra antennas cost), wireless cooperative relaying is now strongly researched to offer spatial diversity. In cooperative communication schemes, wireless communication started from a source terminal is caught by other terminals (called relay transceiver terminals). These terminals process the received data then send it to the intended destination terminal, where various signal copies are combined for reliability improvement. Many researchers are using different available platforms to analyze the cooperative communication networks. A cooperative communication framework using Universal Software Radio Peripheral (USRP) device and GNU Radio software is implemented in [2] to evaluate the performance of cooperative communication. The relays use decode and forward relaying technique. In [2], authors compare between direct communication, single-relay, and multi-relay cooperation utilizing GMSK modulation. Maximum ratio combining (MRC) technique is utilized at intended destination terminal. A cooperation framework using USRPs and MATLAB platform is implemented in [3]. A relaying selection technique is proposed which is able to change between AF and DF relaying techniques based on redundant error estimation coding to calculate BER estimate values. A combining technique at the destination is proposed which weighs signals using the corresponding BER estimate values. The experimental implementation for cooperative communication is built using USRPs, GNU Radio and single board computer (ODROID) in [4]. GMSK modulation scheme is used to transmit text message. The relay terminal uses multihop SDF relaying technique. The experimental setup for cooperative communication is built using USRPs and LabVIEW in [5]. Various Phase Shift Keying (PSK) modulation techniques are used to transmit a text message. AF relaying technique is used at the relay terminal. The combining technique utilized at the destination terminal is MRC technique. The experimental performance of cooperative communication over direct transmission is evaluated by the analysis of channel capacity. Furthermore, analysis for optimal position of the relay terminal is performed by changing of the relay location. This work aims to verify the performance analysis via experimental implementation of various cooperative communication techniques. The experimental setup is developed using open source SDR software GNU Radio, USRP devices and single board computer (SBC) called ODROID which serves as a processing unit for relay terminal which enable portable standalone SDR framework implementation. In this work research, an improved Signal to Noise Ratio Combining (SNRC) technique is proposed in order to enhance and improve the performance of cooperative communication. Estimation of Signal to Noise Ratio (SNR) for each received signal is performed using M2M4 technique that calculates the second-order and fourth-order moments for incoming complex samples. Improvement in the performance for the proposed technique is shown in experimental results.

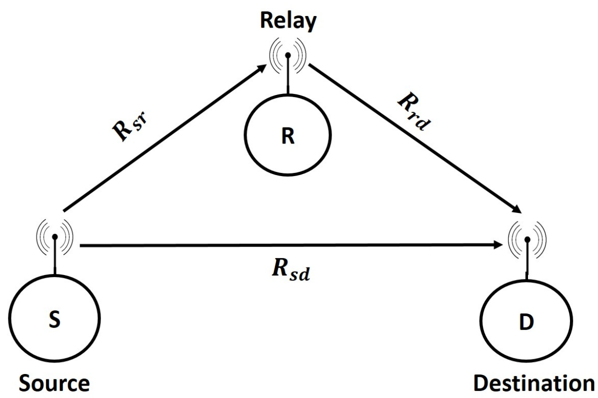

Fig. 1: Cooperative single-relay communication system model.

Experimental implementations for cooperative relaying and combining techniques using GMSK transmission for voice communications and video streaming are developed to exploit the cooperation benefits for multimedia communication.

II. System Model

A half-duplex cooperative communication system model with single-relay is presented in Fig.1. Each terminal in the system is unable to simultaneously transmit as well receive data at the same time. The network is composed of a source terminal (S), a single relay terminal (R), and a destination terminal (D). In Phase I, source terminal transmits data signal directly to destination terminal as well to relay terminal. The received data signals Y_{sd} and Y_{sr} at the intended destination terminal and relay terminal, respectively, can be expressed as

$$Y_{sd} = R_{sd}\ X_s + a_{sd} \tag{1}$$

$$Y_{sr} = R_{sr}\ X_s + a_{sr} \tag{2}$$

Where: R_{sd} is gain coefficient of S-D channel link, X_s is the transmitted data signal, a_{sd} is noise added over S-D link, R_{sr} is gain coefficient of S-R channel link, and a_{sr} is noise added over S-R link.

In phase II, for AF cooperative relaying technique, the relay terminal simply amplifies the incoming data signal then re-transmits it to intended destination terminal. The incoming data signal to the intended destination terminal from relay terminal can be expressed as

$$Y_{rd} = \alpha R_{rd} X_s + a_{rd} \tag{3}$$

Where α is amplification relaying factor which is the inversely proportional to the channel S-R fade $1/R_{sr}$ to equalize its effect, R_{rd} is gain coefficient of R-D channel link and a_{rd} is noise added over R-D link. Amplification relaying factor in AF technique is calculated as follows

$$\alpha = \sqrt{\frac{\psi}{|R_{sr}|^2\,\psi + 2\phi_{sr}^2}} \tag{4}$$

Where: $\psi = E[|X_s^2|]$ is the energy of transmitted data, $2\phi_{sr}^2 = E[|a_{sr}^2|]$ is additive noise variance.

For SDF cooperative relaying technique, the relay terminal receives the sent data signal from the source terminal and decodes it so additive noise is not amplified. SDF relay terminal is able to detect if the received data contains errors and it will only transmit the correct data. The incoming data signal to intended destination terminal from relay terminal in this case is expressed by

$$Y_{rd} = R_{rd}\ X_r + a_{rd} \tag{5}$$

Where: X_r is transmitted data signal by relay terminal.

For any used cooperative relaying technique, received data signals for each phase can be combined by maximum ratio combining (MRC) technique [6] to improve BER performance. However, for both AF and SDF relaying techniques, MRC requires knowledge of the exact channel conditions for S-R and R-D paths. Equal ratio Combining (ERC) technique can be used which is the simplest combining technique. It can be used if there is no available knowledge about the channel characteristic [7], in which the incoming data signals are equally weighted in the combination at destination terminal. In this case the combination can be expressed by

$$Y_d = \frac{1}{2}(Y_{sd} + Y_{rd}) \tag{6}$$

Signal to Noise Ratio Combining (SNRC) technique is another attractive combining technique that can be utilized at destination terminal. SNR estimation value based on estimated BER value is used to characterize the channels characteristic which is used to weight the incoming data [8],[9]. The main advantage of SNRC over MRC is that it does not require explicit knowledge of the channel conditions. But an additional bit sequence has to be sent to estimate the channel quality in terms of SNR estimate value. This results in a assured loss in bandwidth [10]. As a solution, we propose an improved SNRC combining technique which estimates SNR value for each received data signal using M2M4 technique which is based on calculations of the second-order and fourth-order moments of the complex samples. The M2M4 SNR estimator can be expressed as [11]

$$SNR_{estimation} = \frac{\sqrt{2M_2^2 - M4}}{M_2 - \sqrt{2M_2^2 - M4}} \tag{7}$$

Where $M_2 = E[y_n y_n^*]$ is the second order moment of complex samples and $M_4 = E[(y_n y_n^*)^2]$ is the fourth order moment of complex samples. The improved SNRC technique can be expresses as

$$Y_d = (SNR_{sd} + SNR_{rd})^{-1}(SNR_{sd}Y_{sd} + SNR_{rd}Y_{rd}) \tag{8}$$

where SNR_{sd} and SNR_{rd} denote SNR estimations for data signals from source and relay terminals, respectively. The fundamental merit of improved SNRC over traditional SNRC is that no allocating bits are so and no wasting in the bandwidth.

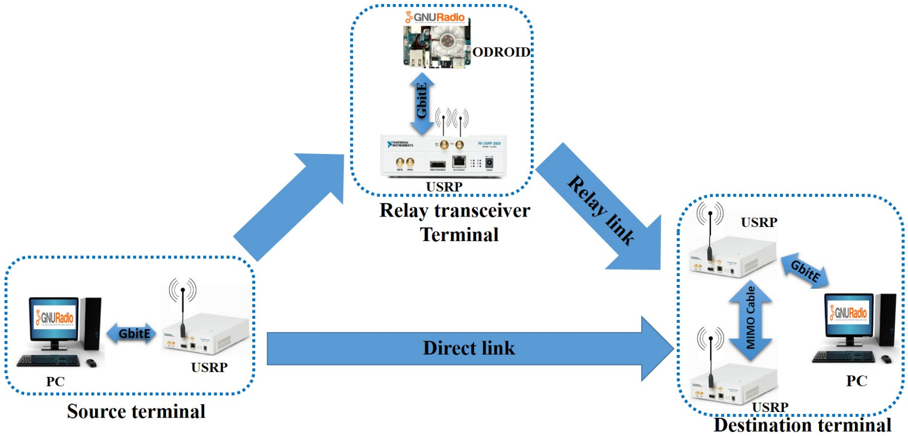

Fig. 2: Cooperative single-relay communication system implementation.

III. PROPOSED COOPERATIVE COMMUNICATION FRAMEWORK

In this part, details of experimental implementation for SDR-based cooperative communication system based on GNU Radio , Single Board Computer "ODROID XU4" and USRP 2920 is provided which is shown in Fig. 2.

A. Source terminal

First discussion of preparing voice and video data before performing channel coding, framing and modulation is presented. For the voice source terminal shown in Fig.3, audio source used is a microphone that is attached to a PC with installed GNU Radio. Audio source block enables to capture audio from the audio input hardware (microphone) to the designed GNURadio flow graph. File Sink block is used to save the incoming float stream out to a binary file to be used for further analysis. The conversion of analog audio form into digital form is usually called audio coding. A main advantage of using audio coding is the ability to compress the signal that will reduce the digital audio bit rate. In other words, audio codec can represent audio with the possible fewest bits, while preserving an audio quality that is appropriate. The GSM Full Rate Vocoder uses Linear Predictive Coding with Regular Pulse Excitation [12]. The GSM Full Rate Audio Encoder block corresponds to an encoder voice-oriented audio signal that samples a 13 Kbits/sec. This block has been included considering the available processing capabilities, since a voice coder can greatly reduce the computational load. The used GSM full-rate audio encoder block encode short audio samples so a float to short block is used to convert float samples output from audio source block to short samples. Vec Length parameter assigns the length of each output stream from this source Scale parameter is used to adjust output signal sampling required for the next block.

For the video source terminal shown in Fig. 4, a web camera is used to capture live video which is connected to a PC with installed GNU Radio and FFmpeg. FFmpeg performs the processes of the real-time video capturing by webcam and the video streaming compression and encoding in H.264 format. As one of the most popular media software in Linux system, FFmpeg is able process most media files [13]. In order to connect the GNU Radio Python code and FFmpeg, a pipeline is needed. In this case, a Python module "socket" is used to enable the H264 packets to transfer from FFmpeg to GNU Radio Python code by using the UDP protocol. A UDP source block is used for the video data source in the flow graph which specifies IP address of the sending host and the receive data port number.

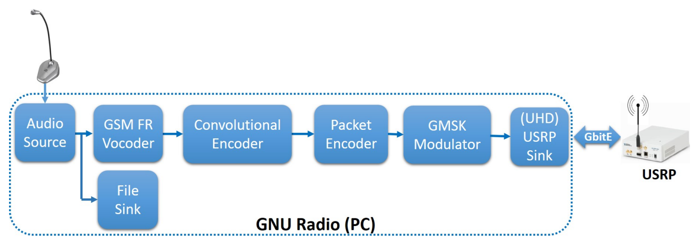

Fig. 3: Voice source terminal architecture.

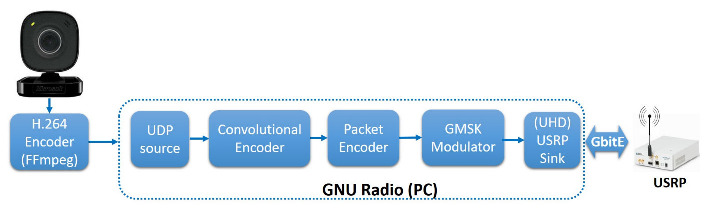

Fig. 4: Video source terminal architecture.

After the preparation of voice and video data to be processed with GNU Radio, they are passed to half rate convolutional coding with constraint length seven. Then the coded data stream is passed to packet encoder block. After framing, the packetized data stream is modulated by GMSK Modulator. Then a USRP Sink block is used to connect the GNURadio flow graph of source terminal with USRP hardware device. It up converts the incoming complex samples to be sent by USRP device.

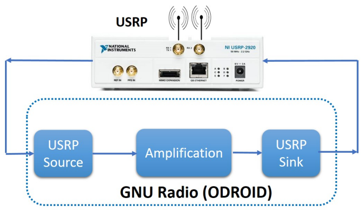

Fig. 5: AF relay terminal architecture.

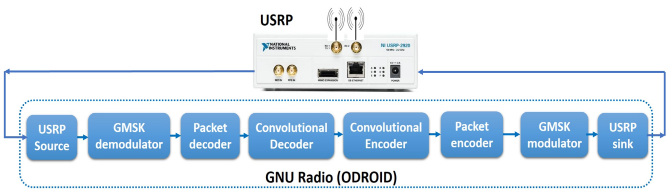

Fig. 6: SDF relay terminal architecture.

B. Relay terminal

The Amplify and Forward (AF) relay simply amplifies received data then re-transmits it to destination terminal. The AF relay setup is shown in Fig.5. AF relay first receives signal from source terminal then performs fixed gain relaying (blind relaying) [14] which uses a fixed amplification gain of value 1. Finally, the relay sends the amplified data to destination terminal.

The DF relay can first demodulate and decode the incoming data signal, then re-encode and re-modulate. Finally, it sends data to the intended destination terminal. The main advantage of DF relaying technique is that by utilizing decoding process, the relay is able to basically exclude the noise accompanied by the re-sent signal. The implemented DF relay in this experiment forwards incoming data utilizing a Selective Decode and Forward (SDF) relaying technique. A data sending decision is taken depending on an appended Cyclic Redundancy Check (CRC). So, it differs from a normal DF relaying technique which sends any data that it receives so it repeals any diversity gain. As a result the fixed DF technique is not analyzed here and all the practical results are assembled for the SDF technique. Experimental implementation for SDF relay terminal is shown in Fig. 6.

C. Destination terminal

The destination terminal is composed of two receiving NI USRPs which are aligned and synchronized with MIMO cable to receive data on two channels (channel one for receiving from source and channel two for relay). A receiver USRP is connected to PC through single Gigabit Ethernet and connected to other USRP through MIMO cable. The USRP device linked to Gigabit Ethernet functions as a switch and transport data from/to both USRP devices. It will handle sampling clock and time synchronization of data. For video communication, at first a Linux terminal is opened to execute a ffplay command line to start a H.264 decoder. This line tells the decoder to keep listening to port 1235 for the incoming video packets to be displayed. First, each receiving USRP carries out carrier down conversion and prepares IQ baseband symbols. Then, they are passed to quadrature demodulator and clock recovery block for symbol synchronization as it performs tracking the symbol clock and re-sampling as needed then it outputs a stream of soft symbols to be combined with any of two different techniques (ERC and improved SNRC). In case of ERC technique is used, the ERC destination shown in Fig.7 simply combines both complex symbols in which the both signals are equally weighted in the combination. In case of improved SNRC technique, the SNRC destination shown in Fig. 8 uses a SNR estimator for each channel then multiplies these SNR estimation weights by each complex symbols and performs combination.

After combination process, the combined symbols are passed to binary slicer which makes hard symbol decision to recover the binary bits. Then, these bits are passed to convolutional decoder and packet decoder. Finally, for voice communication, audio sink block passes the incoming bit stream to output device of PC (speaker) and File Sink block is used to save the incoming stream out to a binary file to be used for further analysis. For video communication, the incoming bit stream is passed to UDP port 1235 so it is sent to ffplay for displaying the video.

IV. Experimental Results

The experiment is conducted on three-terminal network in lab environment. Table I shows the system parameters that are used during the experiments.

TABLE I: Multimedia Cooperative Relaying Implementation Parameters

Parameters	Value
Modulation	GMSK
Operating Center Frequency	500 MHz for Direct Path, 600 MHz for Relay Path.
Data Kind	Voice and Video streaming
Bit Rate	250 Kbps
Distance (S-D)	8 meters
Distance (S-R and R-D paths)	4 meters
Relaying techniques	AF/SDF
Combining techniques	ERC/SNRC

The terminals setup is kept fixed through the overall experiment. The SNR vs. BER experimental curve for voice communication and SNR vs. FER experimental curve for video streaming are investigated. For performance analysis, 1000 packets are transmitted from source terminal for each experiment. For voice communication, after applying AF or SDF relaying techniques, and ERC or improved SNRC techniques at the intended destination terminal, the averaged BER for 1000 packets are obtained.

Fig. 9 shows the plot of experimental BER as a function of the estimated direct path SNR. It shows BER performance comparison for Direct transmission and AF relaying with ERC and improved SNRC combining techniques using GMSK modulations, calculated during the experiments. The AF relaying with any combining technique outperforms Direct

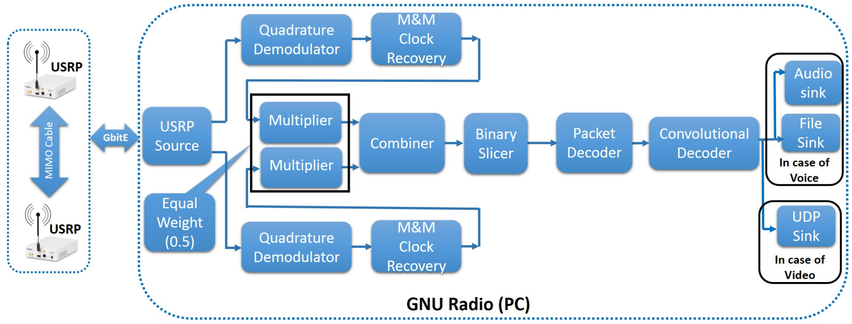

Fig. 7: ERC destination terminal architecture.

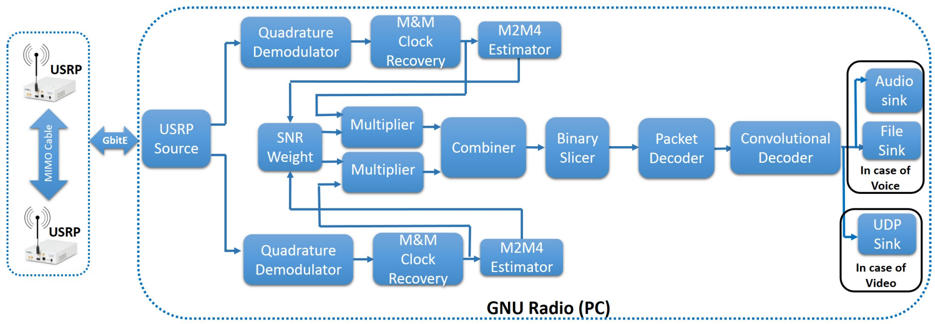

Fig. 8: SNRC destination terminal architecture.

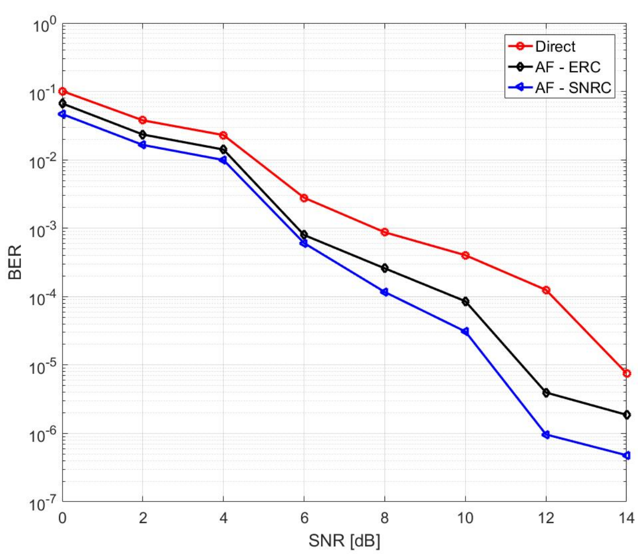

Fig. 9: Experimental BER for Direct transmission and AF relaying with different combining techniques using GMSK modulation.

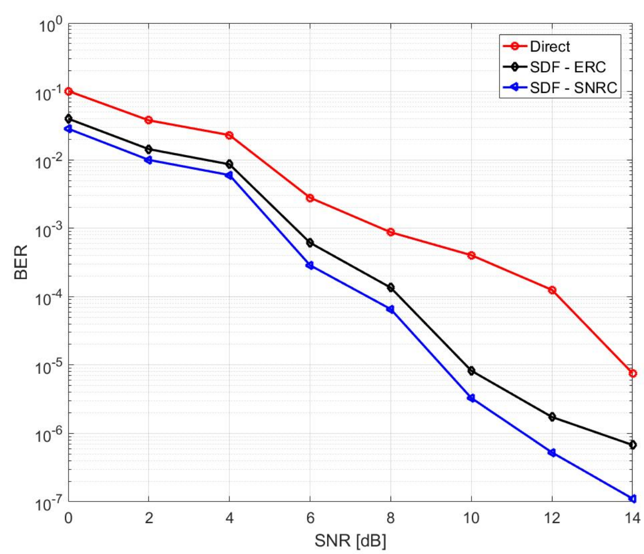

Fig. 10: Experimental BER for Direct transmission and SDF relaying with different combining techniques using GMSK modulation.

transmission in terms of BER. The AF relaying with improved SNRC combining technique outperforms Direct transmission and ERC technique. Fig. 10 illustrates BER performance of SDF relaying with ERC and improved SNRC techniques. It can be seen that SDF relaying perform better than AF relaying.

For video communication, the overall FER over the 1000 frames are obtained. Fig. 11 shows the plot of experimental FER as a function of the estimated direct path SNR. It shows FER performance comparison for Direct transmission and AF relaying with ERC and improved SNRC combining techniques using GMSK modulations, calculated during the experiments. The AF relaying with any combining technique outperforms Direct transmission in terms of FER. The AF relaying with improved SNRC combining technique outperforms Direct transmission and ERC technique. Fig. 12 illustrates FER performance of SDF relaying with ERC and improved SNRC techniques. It can be seen that SDF relaying performs better than AF relaying.

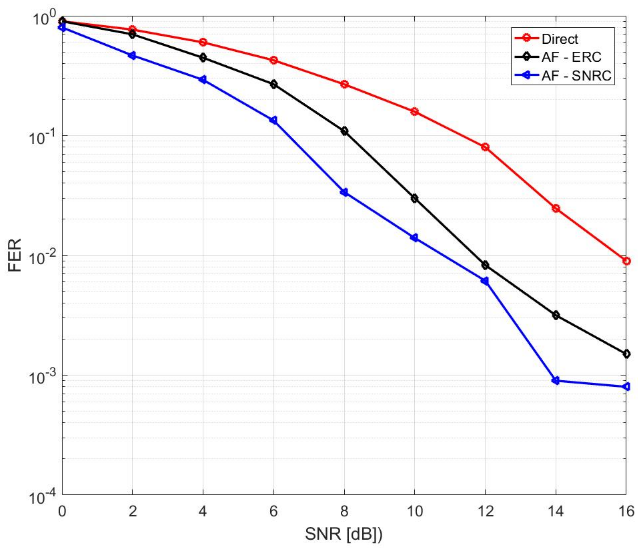

Fig. 11: Experimental FER for Direct transmission and AF relaying with different combining techniques using GMSK modulation.

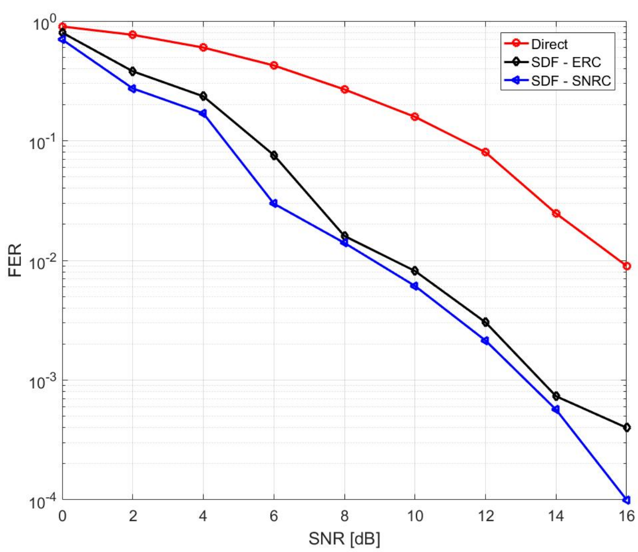

Fig. 12: Experimental FER for Direct transmission and SDF relaying with different combining techniques using GMSK modulation.

V. Conclusion

An efficient multimedia SDR-based standalone cooperative communication system is developed. An improved SNRC technique is proposed. It estimates SNR for each received signal using M2M4 technique which calculates the second-order and fourth-order moments for incoming data complex samples rather than allocating some bits with transmitted signal to estimate SNR values. Experimental performance analysis shows that performance of cooperative communication is better than that of direct communication. The improved SNRC gives better performance than ERC. In future, expanding the implemented cooperative communication framework using multi-relays networks is planned. It can be expanded to future 5G wireless networks like Internet of Things and machine to machine communication.

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