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Performance Comparison of PNC for different Modulation Techniques with Oversampling Digital Filter at the Relay

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***Abstract*–In a wireless transmission network, relay node or intermediate nodes play a very important role. Thus, the use of relay transmission offers significant performance benefits, including being able to achieve spatial diversity through node cooperation and extending coverage without requiring large transmitter powers. In this paper, we consider a Physical-layer Network Coding (PNC) scheme for a two-way wireless system where two source nodes, *A* and *B*, communicate with each other through the aid of relay node using an Amplify and Forward(AF) protocol where the relay oversamples the received signal and subsequently filters before amplification. This study makes an elaborate comparison of performance of PNC for different modulation techniques like Quadrature Phase Shift Keying (QPSK), 8-PSK and 16-quadrature amplitude modulation (16-QAM) and the corresponding improvement in the performance in all the three modulation techniques by oversampled filter at the relay. The simulation results showed that QPSK performs better in terms of sum bit error rate (Sum-BER) and Maximum sum-rate. Also the simulation results indicate that the oversampled digital filter at the relay enhances the Max sum-rate in all the three modulation techniques.**

***Index Terms* – PNC, Two-way relay channels, Amplify-Forward protocol, Sum-BER, Maximum sum-rate.**

I. INTRODUCTION

THIS Physical-Layer Network Coding (PNC) is a promising technique to improve the throughput of a Two-Way Relay Channel (TWRC), in which two end nodes exchange the information through a relay node. The two end nodes send packets concurrently to the relay node in a PNC system [1]. The relay node transforms the superimposed packets to a network-coded packet and broadcast back to the end nodes. Each end node uses their self-information to extract the packet of the other end nodes from the network-coded packet [2]. In a two-way relay transmission scheme, communication can take place over four-time slots, where source A communicates with source B in the first two-time slots with source B remaining idle, and source B communicates to source A in the last two time slots with source A remaining idle. We refer to this scheme as a four-time slot transmission scheme, and its performance has been well studied in different channel environments and Signal-to-Noise Ratio (SNR) variations at the source and relay. One problem with this transmission scheme is the relatively low maximum sum-rate, due to transmission over four-time slots [3]. Recently, the concept of Physical Layer Network Coding (PNC) has attracted a lot of attention. The basic idea behind PNC is that for a two-way relay channel [4], where the multiple access interference is occurring at the relay was exploited so that the communication between the end nodes can be done using a two-phase protocol. Information theoretic studies for the PNC scenario were reported in [5], [6].

Relay-aided communications are widely adopted in cellular networks and ad hoc networks while the end nodes cannot directly communicate with each other [7]. Compared with the store-and-forward relaying method, network coding reduces the necessary number of communication phases and thereby increases network throughput. Physical-layer Network Coding (PNC) employs not only the broadcast nature of wireless channel but also the natural network coding ability derived from the superposition of electromagnetic waves [8], which makes PNC benefit more throughput improvement than Conventional Network Coding (CNC).

Physical-layer network coding is a way to effectively harness interference in wireless networks and to provide significantly higher throughput than conventional strategies for many wireless networking problems [9]. The main idea of PNC is to create an apparatus similar to that of network coding, but at the physical layer that deals with EM (Electro Magnetic) signal reception and modulation. Through a proper modulation-and-demodulation technique at the relay nodes, additions of EM signals can be mapped to Galois field GF (2^n) additions of digital bit streams, so that the interference becomes part of the arithmetic operation in network coding [10]. This paper deliberates a typical two-way relay network, and the PNC process includes various modulation techniques (QPSK, 8-PSK, 16QAM) with the higher sampling frequency and a low-pass filter.

II. Literature Review

The previous works have concentrated on analog network coding such as [2], [11] and some of them have concentrated on physical layer network coding such as [12] [13],[14],[15],[16] using AF and Decode and Forward(DF) protocol. These are discussed as follows.

Louie et al. [12] Investigate the performance of practical physical-layer network coding (PNC) schemes for two-way relay channels. For this, investigate transmission over two, three or four-time slots. Practically they showed two time slot (2TS) PNC scheme offers a higher maximum sum rate, but a lower sum- BER than the 4TS transmission scheme. Also shows that the 3TS PNC scheme offers a good compromise between the 2TS and 4TS transmission schemes, and also achieves the best maximum sum-rate and/or sum-BER in certain practical scenarios. To enable comparison, they derive new closed-form expressions for the outage probability, maximum sum-rate and sum-BER. The results significantly improve a system performance, compared to a single relay network.

Cao et al. [13] The proposed symbol based PNC(SPNC) which is a combination of Antenna Selection based PNC(AS-SPNC) and signal combining based PNC(SC-SPNC) scheme. The analysis of these two schemes confirm their full diversity performance and also viewed as an effective single-input-multiple-output system, in which AS-SPNC and SC-SPNC are equivalent to the general AS scheme and the maximal-ratio combining scheme. Furthermore, an asymptotic analysis of symbol error rate is provided for SC-PNC considering these that the number of relay antennas is sufficiently large. However this method not applied to practical systems like LTE etc. also this SPNC technique is personalized for MPSK modulation, it is feasible to extend the SPNC to MQAM scenario.

Guo et al. [14] propose a new linear vector PNC scheme for spatial multiplexing multiple-input-multiple-output TWRC. The proposed novel typical error event analysis exploits a new characterization of the deep fade events for the TWRC. They derive a new closed-form expression or the average error probability of the proposed scheme over a Rayleigh fading MIMO TWRC. Thus, the analysis shows that the proposed scheme achieves the optimal error rate performance at a high SNR. However, the proposed schemes need to apply networks other than TWRCs, e.g., the multiple-access relay networks or multi-way relay networks.

Toshiaki et al. [17] proposed modulation scheme for the two-way wireless relaying system. The network coding was based on denoise-and-forward (DNF) protocol, consisting of two stages such as multiple access stage and broadcast (BC) stage. The performance evaluations demonstrated that the proposed denoising scheme considerably improves the achievable end-to-end throughput, particularly for Nakagami-Rice fading channels. Furthermore, this study needs to evaluate the design for adaptive modulation and coding based on the channel conditions in DNF two-way relaying systems.

Zhang et al. [2] proposes a non-memory less ANC scheme. In specific, design a soft-input-soft-output decoder for the relay node to process the superimposed packets from the two end nodes to yield an estimated MMSE packet for forwarding back to the end nodes. The analysis shows that the SNR improvement at the relay node is lower bounded by 1/R with the simplest LDPC code. The SNR improvement also proved by numerical simulation with LDPC code. The experimental results indicate that LDPC codes of different degrees are preferred for lower SNRs.

Ding et al. [15] study the application of PNC to the joint design of uplink and downlink transmissions, where the base station and the relay have multiple antennas, and mobile stations have a single antenna. A new network coding transmission protocol is proposed, where 2M uplink and downlink transmissions can be accomplished within two-time slots. An explicit analytic result has developed to demonstrate that the multiplexing gain achieved by the proposed transmission protocol, much better than existing time-sharing schemes. To further increase the achievable diversity gain, two variations of the proposed transmission protocols have also been proposed when there are multiple relays, and the number of the antennas at the base station and relay is increased.

Mukherjee and Swindlehurst [11] examines the susceptibility of analog network coding (ANC) to physical layer attacks from cooperative users while all nodes are equipped with multiple antennas. Specifically, we examine the MIMO TWRC with two users trying to communicate with each other via a relay node in the presence of a passive eavesdropper. They proposed a new performance metric, namely the secrecy sum rate of the MIMO TWRC, to quantify performance. Finally, numerical results are presented to illustrate the improvement in secrecy obtained with the proposed transmission schemes.

Huang et al. [16] consider an irregular repeat-accumulate coded PNC scheme in a Gaussian TWRC. They address the convergence behavior of the iterative receiver of the channel coded PNC at the relay.

Faraji-Dana and Mitran [18] compares the different mappings between FSK and PSK constellation and proves also that many have identical performance in terms of frame error rate (FER). Furthermore, derive a lower bound on the performance of decoding the network-coded combinations. A simulation result shows that the ternary constellation has the best FER performance among all considered cases.

From the above study, few of them concentrated on analog network coding and some of them have concentrated on PNC. Furthermore, in PNC, some of them have focused on AF and DF protocol without considering various modulation techniques.

Compared to an AF protocol the complexity of DF protocol is significantly higher due to its full processing capability. The DF protocol also requires a sophisticated media access control layer which is unnecessary in the AF protocol. The AF protocol is simple to implement except the noise amplification. In our work we are avoiding noise amplification by oversampling the received signal and then filtering the signal at the relay to overcome noise amplification. By oversampling the received signal and taking the average of these samples the decision variable will get closer to the desired signal value and the noise samples average will get closer to the statistical noise mean which is zero.PNC is the promising technique to improve the throughput and flexibility of the system. In this paper, we study and analyze the performance of PNC of the two-way relay system. Furthermore, higher sampling frequency used at the relay makes the digitization more accurate and reduce the noise using a digital filter. Finally, compare the results using with filter and without filter for the three modulation techniques.

III. System Model

The proposed system in this paper is two-way relay channel with three transmission schemes in which source *A* and Source *B* exchange information through the use of relay node R using AF protocol and there is no direct link between them, as shown in figure 1.

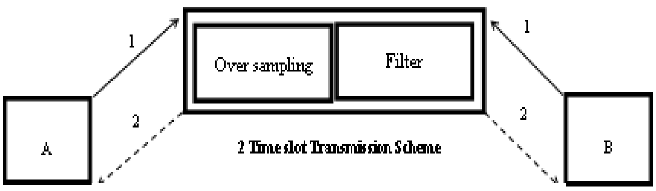

Fig. 1 Block diagram of the proposed system

Let .x_A and x_B be the data symbols transmitted by Source *A* and *B* respectively with power P_A and P_B. The Rayleigh channels considered between source *A* and the relay, and source *B* and the relay are denoted by *h* and *g* respectively. The additive white Gaussian noise at source *A*, and *B* and the relay are denoted by n_A~CN $(0.\sigma_A^2)$, n_B~CN $(0.\sigma_B^2)$, n_r ~CN $(0.\sigma_r^2)$ respectively. The received signal at the relay from source *A* and *B* are multiplied by a gain *G*. The signal is then multiplied by power P_r. Let $\bar{\gamma}_A = \frac{P_A}{\sigma_r^2}$, $\bar{\gamma}_B = \frac{P_B}{\sigma_r^2}$, $\bar{\gamma}_{r,A} = \frac{P_r}{\sigma_A^2}$, $\bar{\gamma}_{r,B} = \frac{P_r}{\sigma_B^2}$

This study deliberates three transmission schemes, which differ in the number of time slots used for the source nodes to communicate with each other through the relay node. In particular, consider total transmission over two-time slot (2TS), three-time-slot (3TS) and four-time slot (4TS). Moreover, analyze the performance of these three schemes in the next two sections, demonstrating that each may outperform the other, depending on different system parameters. Here, consider the channel and noise are constant during these time slots, and that the channels related to each source are identified from that source. The proposed system is illustrated in figure 2.

A. PNC Scheme

In the first time slot, the two source nodes simultaneously transmit to the relay node. In the second time slot the relay node oversamples and filters and subsequently amplifies and forwards the received signals towards two source nodes. The received signal in the first time slot at the relay node can be written as

$$r = \sqrt{P_A}hx_A + \sqrt{P_B}gx_B + nr \qquad (1)$$

The received signal after canceling the self-interference term at source A and B are, given respectively, by

$$y_A^* = G\sqrt{P_r}\sqrt{P_B}hgx_B + G\sqrt{P_r}hn_r + n_A \qquad \text{..... (2)}$$

$$y_A^* = G\sqrt{P_r}\sqrt{P_A}ghx_A + G\sqrt{P_r}gn_r + n_B \qquad \text{….. (3)}$$

The output SNR at source A and B are respectively given as **Error! Reference source not found.**

$$\gamma_{A,2TS} = \frac{\bar{\gamma}_{r,A}\bar{\gamma}_B|g|^2|h|^2}{\bar{\gamma}_{r,A}|h|^2 + \frac{1}{G^2\sigma_r^2}} \qquad \text{..... (4)}$$

$$\gamma_{B,2TS} = \frac{\bar{\gamma}_{r,B}\bar{\gamma}_A|h|^2|g|^2}{\bar{\gamma}_{r,B}|g|^2 + \frac{1}{G^2\sigma_r^2}} \qquad \text{..... (5)}$$

The gain is given as

$$G = \frac{1}{\sqrt{P_A|h|^2 + P_B|g|^2 + \sigma_r^2}} \qquad \text{..... (6)}$$

In order to develop performance measures for the three schemes, it is convenient to express the received SNR in a general form as

$$\gamma = \frac{\beta_{A,\tau TS}\, XY}{\theta_{A,\tau TS}\, Y + \phi_{A,\tau TS}\, X} \quad \text{... (20)}$$

Where *X* and *Y* are exponentially distributed random variables

$\beta_{A,2TS} = \bar{\gamma}_{r,A}, \bar{\gamma}_B,\ \theta_{A,2TS} = \bar{\gamma}_{r,A} + \bar{\gamma}_A,\ \phi_{A,2TS} = \bar{\gamma}_B$ Source A

$\beta_{B,2TS} = \bar{\gamma}_{r,B}, \bar{\gamma}_A,\ \theta_{B,2TS} = \bar{\gamma}_{r,B} + \bar{\gamma}_B,\ \phi_{B,2TS} = \bar{\gamma}_A$ Source B   ... (21)

V. SIMULATION RESULTS

The comparison is made between maximum sum-rate and Sum-BER performance for the three modulation schemes. The result shows the PNC with QPSK modulation scheme has a comparatively higher maximum sum rate as compared to PNC with 8PSK and 16 QAM modulation scheme for the entire signal to noise ratios. Also proved sum-BER of QPSK modulation scheme is lower than PNC with 8PSK and 16QAM modulation scheme. M-ary schemes are more bandwidth efficient but are more susceptible to noise.8PSK and 16 QAM are bandwidth efficient but not power efficient.

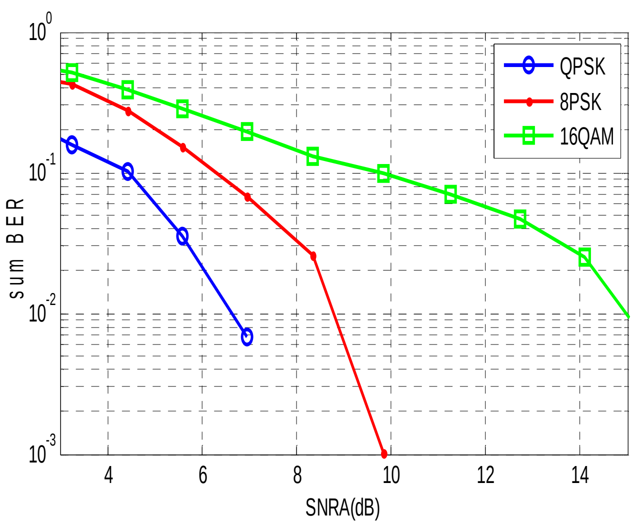

Fig. 3 Sum BER- without filter

Figure 3 represents the SNR Vs Sum BER for the three modulation schemes without using a filter. We see that PNC with QPSK modulation scheme performs better than PNC with 8PSK modulation scheme and PNC with 16QAM modulation scheme.

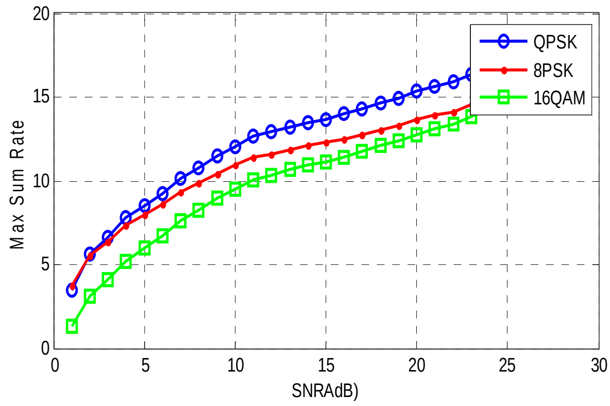

Fig. 4 Maximum sum rate- without filter

Figure 4 represents the SNR Vs maximum sum rate for QPSK ,8PSK and 16QAM without using a filter. We see that the maximum sum-rate of the PNC with QPSK scheme performs better than PNC with 8PSK and 16 QAM transmission scheme for all SNR values.

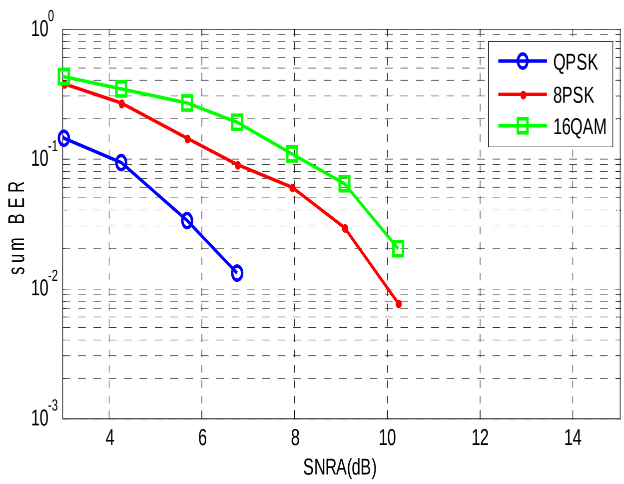

Fig. 5 Sum BER with filter

Figure 5 represents the SNR Vs Sum BER of the three modulation schemes using a filter .We see that from low SNR to high SNR, PNC with QPSK scheme performs better than the PNC with 8PSK modulation scheme and 16 QAM modulation scheme.

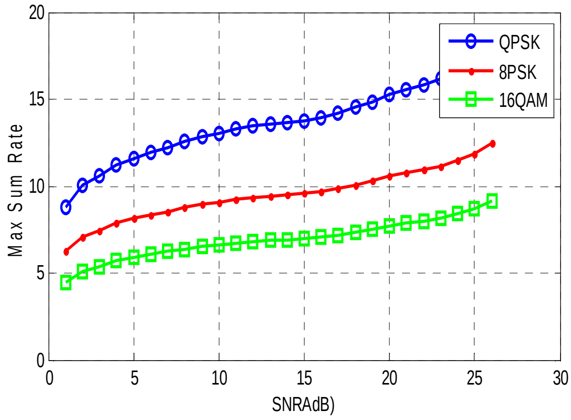

Fig. 6 Max sum rate – with filter

Figure 6 represents the SNR Vs Max sum rate for the three modulation schemes using a filter. We see that the maximum sum-rate PNC with QPSK modulation scheme performs better than the PNC with 8PSK modulation scheme and 16 QAM modulation scheme for all SNR values. We can observe that the performance degradation at low SNR due to noise amplification has been overcome by the proposed method.

VI. Conclusion

In the present study, we have considered a two-way relay network that consists two source nodes A and B, and they connect with one another through the relay node using an AF protocol. We have proposed to use an oversampling digital filter at the relay and the simulation result showed that the performance degradation at low SNR due to noise amplification can be overcome by our method which results in improvement in maximum sum-rate in all the three modulation schemes. Also the simulation results imply that the sum BER is reduced in all the three schemes by the use of filter. Hence the use of a oversampled digital filter at the relay improves the performance of PNC scheme for all system parameters.

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