

An Improved Scheme Based on Physical-layer Network Coding

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Abstract—In the wireless communication system, interference is considered harmful. Wireless networks strive to avoid scheduling multiple transmissions at the same time in order to prevent interference. While Physical layer Network Coding (PNC) was proposed to embrace interference in order to improve throughput performance. During the second stage of PNC, the intermediate node broadcast the mapping signal to all of destinations, and PNC uses the TDM in order to avoid the interference from same frequency. As a result, when the user receives the mapping signal from the relay station, we could not send the second frame. In this paper, an improved scheme based on PNC is proposed in Two-way system. The paper adopts the Paired Communication Multiple Access (PCMA) idea to handle the mixed signal in the same slot, and implements the scheme that the sender could send the frames continuously. Extensive simulation studies show that the new Continuous PNC scheme is feasible and improves the communication throughput effectively by 60%.

Keywords—Network Coding (NC), Physical layer Network Coding (PNC), Two-way relay, Communication throughput, PCMA.

I. INTRODUCTION

As we all known, the throughput of communication is one of key indexes in the communication system, and now lots of investigators are studying the methods of improving the efficiency of communication. Shannon said that the maximum information flow between two points was decided by the min-cut of directed graph in the communication network [1], whereas the traditional communication scheme could not achieve the ideal Shannon limit. In the network layer, the problem of limitation on the network capacity is solved in theory by Ahlswede et al.[2]. He proposed the concept of the Network Coding (NC) in order to improving the efficiency of communication in the paper. In the network communication, the intermediate nodes only play the role of “store-forward” in the conventional system, while in the system using the Network Coding the intermediate node not only store and forward the information but also it encodes the input information. In the network coding scheme, when many packets encounter on the same intermediate node simultaneously, the NC scheme combines the packets into one packet by the desired operations. As a result, the NC technique settles the problem of waiting in the jam network, so it could enhance the capacity of network successfully.

In the wireless communication system, considering the feature of broadcasting, Wu put forward straightforward network coding that it combined the broadcasting and the idea of NC aiming to improve the capacity of wireless

system [3]. In the two-way relay communication model, it need four slots to complete exchanging the information in the traditional half-duplex scheme, while in the scheme of the SNC it could reduce one slot to exchange the information, and boosts the communication efficiency. Although the SNC scheme improves the capacity of network, it stands by the principle that two or more signals in the single channel are forbid to avoid the interference from the same frequency signal. In 2006, the Physical-Layer Network Coding (PNC) was proposed by Zhang S.[4]-[7]. Comparing with the straightforward network coding scheme, the electromagnetic signals are permitted to overlap with each other in the space, and the relay node could process the mixed signal, and then map the mixed signal into a new signal by the means of desired protocol. As a result, the PNC scheme only need two slots to exchange the information, and the communication efficiency is improved by 100% compared with the half-plex scheme.

In this paper, we propose Continuous PNC (CPNC) scheme that the communicating nodes could send the information in the second stage based on the PNC scheme. The CPNC scheme reduces the time-consuming based on the Paired Communication Multiple Access (PCMA) [8],[9]. The key difference between CPNC and PNC is that the CPNC could transmit two signals in the single channel especially in the second slot of PNC. In the second slot, the relay node combines two signals into single signal and broadcasts it to the receivers, because we try to avoid the interference from the same frequency signal in the PNC scheme. The remainder of this paper is organized as follows. Section II gives the model of the PNC scheme. The application of PNC scheme in the model of many-to-many communication is presented in the section three. In the section four, numerical simulation results and discussion are presented. Section five concludes the paper.

II. THE MODEL OF SCHEME

In this section, we will introduce the theory and models of different schemes in the single channel. In order to compare with each other, we assume that symbol-level and carrier-phase synchronization, and the use of power control have been done in all of schemes. In the conventional two-hop system, a possible transmission schedule is given in fig.1. To avoid the self interference in the single channel, the conventional scheme adopts the Time Division Multiple Access (TDMA). So a total of four time slots are needed for the exchange of two frames in opposite directions. In the following, three improved schemes in three node communication system are presented to enhance the throughput performance.

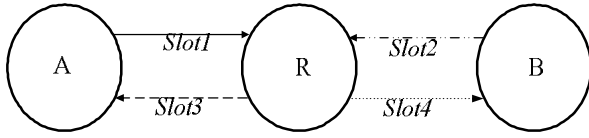


Figure 1. Traditional scheduling scheme

A. Straightforward Network Coding (SNC)

In this part, we will outline the Straightforward Network Coding Scheme and apply the idea of the network coding in the three-node wireless network. Fig.2 illustrates the idea of the SNC scheme. In the scheme, the relay node firstly receives the electromagnetic signals from A and B in separate slots, and then demodulates the signals. After coding and modulating the information demodulated, the relay node broadcasts the mapping signal to two destinations. The above scheme is termed as Straightforward Network Coding Scheme (SNC).

In the fig.2, the destination A sends the S_a to the relay node R, and then B sends the S_b to R. At the relay node, it encodes the two frames as follows:

$$S_{a+b} = S_a \oplus S_b \quad (1)$$

Where $\oplus$ denote bitwise exclusive OR operation being applied over the entire frames of S_a and S_b . And then R broadcasts S_{a+b} to both A and B. When the destination A receives the S_{a+b} , it extracts S_b from S_{a+b} using the local information S_a , as follows:

$$S_{a+b} \oplus S_a = S_{a+b} \oplus (S_a \oplus S_b) = S_b \quad (2)$$

Similarly the B could extracts S_a . This scheme consumes three slots to exchange the information. Compared with the conventional scheme, the throughput is improved by 33%.

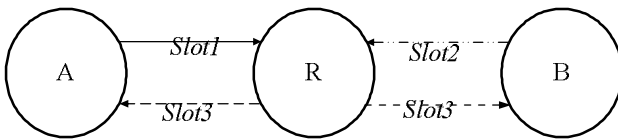


Figure 2. Straightforward network coding scheme

B. Physical-Layer Network Coding (PNC)

Now this section introduces the Physical-Layer Network Coding. It is believed that two or more signals with same frequency could not transmit in single channel. The two schemes above follow that rule. As we all known, when the two signals encounter in the space, ADD is the only operation they could choose. So the PNC scheme was

proposed by Zhang S. et al. in 2006 [10],[11]. The main idea of the PNC is that the ADD operation is permitted for two signals in the space and the scheme views the ADD as a part in the design. The relay node receives the additive signal and maps it into another signal in the finite field. At the receiver, we extract the information after de-mapping.

As illustrated in Fig. 3, A and B transmit $s_1(t)$ and $s_2(t)$ to the relay node in the first slot.

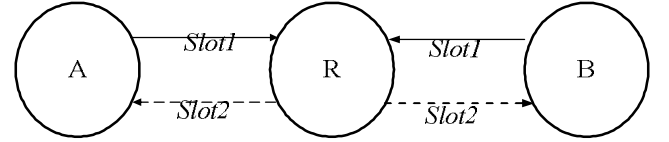


Figure 3. Physical layer network coding

In the second slot, the relay node receives $s_1(t) + s_2(t)$, and then it maps the additive signal into $s_r(t)$ as the protocol designed. R broadcasts the mapping signal to all the receivers and exchanges the information [12].

Taking QPSK for a example, the relay does as follows:

$$\begin{aligned} s(t) &= s_1(t) + s_2(t) \\ &= [a_1 \cos(\omega t) + b_1 \sin(\omega t)] + [a_2 \cos(\omega t) + b_2 \sin(\omega t)] \\ &= (a_1 + a_2) \cos(\omega t) + (b_1 + b_2) \sin(\omega t) \end{aligned} \quad (3)$$

$$\begin{aligned} \text{映射} \\ \Rightarrow s_r(t) &= a_3 \cos(\omega t) + b_3 \sin(\omega t) \end{aligned}$$

Where $s_i(t)$, $i=1$ or 2 , is the band pass signal transmitted by A or B and $s(t)$ is the band pass signal received by R during one symbol period; a_i and b_i are the QPSK modulated information bits of A and B; and ω is the carrier frequency; f is the mapping protocol which is same as ref. [4][10] in the PNC scheme. A total of two time slots are needed, for a throughput improvement of 100% over the traditional transmission scheduling scheme.

C. Continuous Physical-Layer Network Coding (CPNC)

In the second slot of PNC scheme, the relay node broadcasts the mapping signal to all destinations. At the same time, the receivers wait for receiving the mapping signal only to avoid transmit the new next frame. In this section, we try to utilize the slot in order to realize the scheme that the receiver receives the mapping signal and sends next frame. So the period of first exchange is overlapping the next exchange. To decode the information at the receiver correctly, this paper takes the PCMA (Paired Carrier Multiple Access) into consider. As a result, the Continuous Physical-Layer Network Coding is proposed to enable the receiver send and receive the signal simultaneously in this paper. Fig.4 illustrates the main idea of

CPNC scheme.

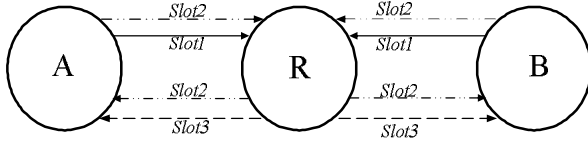


Figure 4. Continuous Physical-Layer Network Coding

Fig.5 is the principle frame of the CPNC scheme, the main difference between PNC and CPNC is the preprocessing block in fig.5. The CPNC scheme will be described in the following.

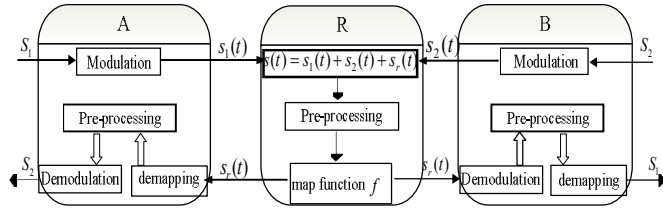


Figure 5. The illustration of CPNC operation

In this paragraph, we will introduce the CPNC scheme based on fig.5. And the time-sequence of CPNC is illustrated in fig.6. In the first slot, A and B transmit A_1 , B_1 to the relay node R simultaneously. In the second slot, the relay node receives the overlapping signal and maps it into $R_1 = f(A_1 \oplus B_1)$, and then broadcasts R_1 to A and B; at the same time, A and B transmit the second frame A_2 , B_2 . At the receiver A, we receive the mixed signal of A_2 and R_1 ; firstly, R_1 is separated from mixed signal based on the local signal A_2 , and then we could get the B_1 as follows:

$$B_1 = A_1 \oplus f^{-1}(R_1) \quad (4)$$

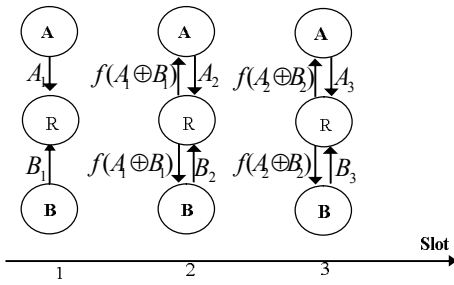


Figure 6. The time-sequence of CPNC

Based on the same operation as A, the B and the relay node could separate the information they need. In the third slot, A and B send the third frames A_3 , B_3 , the operation

is same as the first two slots. A total of two slots are needed on two frames, for a throughput improvement of 25% over the PNC scheme.

III. SIMULATION PERFORMANCE ANALYSIS

In this section, we will adopt QPSK modulation and realize the PNC and CPNC scheme in the single channel of two-hop relay system. The mapping scheme is as same as the ref.[4]. Suppose the received signal energy for one bit is unity, and the noise is Gaussian white with density $N(0, 2)$. We will simulate the capacity in the wireless two-way system [13],[14] in the following.

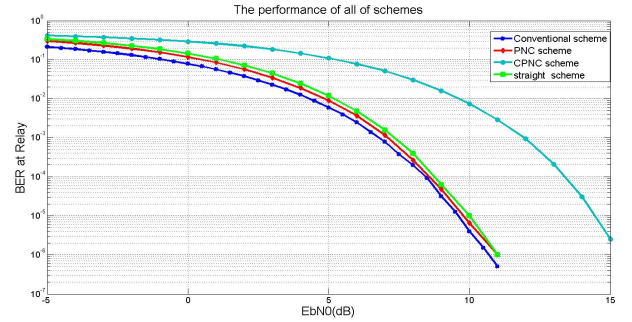


Figure 7. The performance of four schemes in Gaussian channel.

Fig.7 illustrates the performance of four schemes in the Gaussian channel. The simulation results reveal that the BER of PNC is slightly worse than the conventional scheme, but is slightly better than straightforward network coding, and the CPNC is the worst one in four schemes. Furthermore, when the SNR is larger than 10dB, the SNR differences between four schemes except CPNC is less than 0.1 dB, and the performance of CPNC schemes is less than PNC by 5dB. Four schemes perform differences in the communication, because this article adopts different mode in two-hop relay system. To compare the throughput of four schemes, the paper defines the unitary capacity as follows:

$$C_{\text{unitary}} = \frac{C_{\text{snr}}}{C_{\text{max}}} \quad (5)$$

Where the C_{unitary} denotes the unitary capacity, and C_{snr} means the capacity of scheme under the SNR condition in 12 slots, the C_{max} is the maximum capacity in all of C_{snr} in the simulation results.

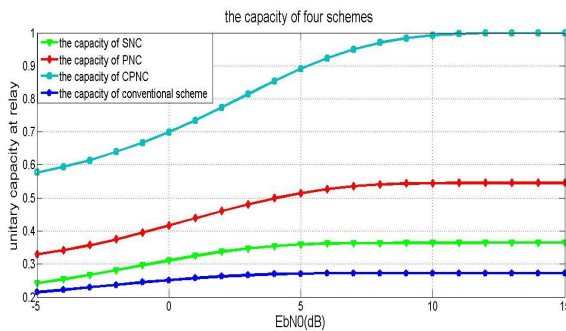


Figure 8. Unitary capacity of four schemes in 12 slots

Fig.8 shows the unitary capacity of four schemes. In the analysis of all of schemes above, the conventional scheme consumes four slots to exchange one frame and it will exchange three frames in twelve slots; the SNC needs three slots in one frame exchange, and it completes four frames in twelve slots; so the PNC could exchange six frames in twelve slots; the CPNC could exchange eleven frames in twelve slots. In the fig.8, it gives us the obvious results, and the simulation results prove that the throughput of CPNC is larger than PNC. So we could gain the conclusion that the CPNC scheme is feasible and effective in two-hop relay system.

IV. CONCLUSIONS

The PNC is introduced to solve the interference of simultaneously arriving electromagnetic waves in wireless relay networks. Based on the idea of the PCMA, an improved scheme called CPNC is proposed in this article. The CPNC scheme achieves the goal that the destination could transmit the information continuously and improve the throughput of wireless system. Simulation results prove that the CPNC is feasible and effective. When the throughput is improved greatly in the scheme, the transmitter must consume more power than the conventional schemes to ensure the good BER performance. So before implementing the scheme in the realistic wireless environment, we will solve the problems include Asynchronous, complexity and memory at all of nodes in the future [15].

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