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## 네트워크 코딩 및 디지털 파운 테인 코드를 사용하여 간단한 양방향 전송 프로토콜

### Simple Bidirectional Transmission Protocols Cooperative Transmission using Network Coding and Digital Fountain Codes

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**요 약** 본 논문에서는 네트워크 코딩 및 파운 테인 코드를 사용한 간단한 양방향 전송 프로토콜을 제안한다. 특히, 제안된 기법의 경우, 두 소스는 중계기의 도움으로 서로에게 메시지를 전송하기 위해 디지털 파운틴 코드를 사용한다. 또한, 중계기는 파운틴 코드와 네트워크 코딩을 사용하여 수신 받은 소스의 메시지를 서로의 소스에게 전송한다. 제안된 프로토콜의 성능을 평가하기 위해 레일리 페일링 채널에서 다양한 몬테-카를로 시뮬레이션을 통하여 전체 평균 처리량을 확인한다. 그 결과 제안된 프로토콜은 높은 SNR 영역에서 네트워크 코딩 기술을 사용하지 않는 두 방향 릴레이 전송 프로토콜보다 우수함을 확인하였다.

**Abstract** In this paper, we propose a simple bidirectional transmission protocol using network coding and digital Fountain codes. In particular, in the proposed scheme, two sources use digital Fountain codes to transmit their message to each other with the help of relays. Then, relays use Fountain codes and network coding to forward the source messages to both sources. To evaluate performance of the proposed protocols, we present the average total throughput over Rayleigh fading channels via Various Monte-Carlo simulations. Results show that the proposed protocol outperforms the two-way relaying transmission protocol without using network coding technique at high SNR region.

**Key Words :** Network coding, Rayleigh fading channel, Fountain codes, cooperative communication.

#### I. Introduction

Recently, rateless codes or Fountain codes (FCs)<sup>[1]</sup> have gained much attention in wireless systems due to its simple implementation. The properties of FCs can be attractive for cooperative communication networks. Cooperative communication [2-3] has gained attention as an efficient method for mitigating the effect of

fading channels. By exploiting the broadcast nature of a wireless channel, cooperative diversity allows single-antenna radios to form a virtual antenna array. Recently, some published works related to the use of FCs in cooperative communication have been proposed<sup>[4-7]</sup>. Results in<sup>[4-7]</sup> presented that these models can enhance the system performances in terms of capacity, throughput and transmission time.

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Furthermore, the network coded transmission can be used to reduce the delay time of relaying the encoded packets. In the protocols proposed in [8–10], the XOR operation of received encoded packets is used at relay nodes. However, the implementation of such protocols is complex, and delay time can be increased due to XOR combination at relays.

In this paper, we propose a simple bidirectional transmission protocols using network coding and digital Fountain codes. In the proposed protocols, the XOR operation is used for the original data. In addition, we also study the bidirectional transmission scheme with multi-relay. Under the assumption that channel state information (CSI) is not available at all transmitters; a simple relay selection strategy using position information is also proposed. Various Monte-Carlo simulations are presented to evaluate performance of the proposed scheme.

The rest of the paper is organized as follows. The system model and the proposed schemes are described in Section II. In Section III, the performance evaluation of the protocols is presented. The simulation results are presented in Section IV. Finally, the paper is concluded in Section V.

## II. System Model

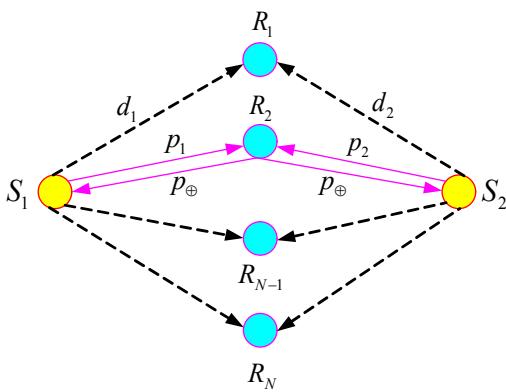


그림 1. 네트워크 코딩을 사용한 양방향 전송 모델.  
Fig. 1. The bidirectional transmission model using network coding.

In Fig. 1, we present a bidirectional transmission model using FC and network coding. In this model, there are two sources  $S_1$  and  $S_2$  attempting to transmit their data to each other. Each source first divides its data into messages. Each message is composed of data packets which contain binary bits and have equal length. The operation of data transmission is divided into stages. At each stage, a source attempts to transmit its message to the remaining source. Assume that there is no direct link between the sources, and the data transmission between them is realized with the help of  $N$  relays, i.e.,  $R_1, R_2, \dots, R_N$ . Let us denote  $d_1$  and  $d_2$  as the distance from  $S_1$  to relays and from  $S_2$  to relays. We assume that all terminals have equal transmit power  $P_t$  and operate in half-duplex mode. It is also assumed that the channels between two nodes are frequency flat Rayleigh fading.

Now, we describe the operation of the first proposed protocol, named PR1. If the source  $S_1$  transmits at the first phase, it encodes its original data  $p_1$  using digital Fountain codes and broadcasts the encoded packets to relays. Relays will collect these packets to recover the data  $p_1$ . As soon as a relay receives enough encoded packets, it sends an ACK message to the source  $S_1$  to inform the status. Then, the source  $S_1$  will stop the data transmission if it can receive  $N_1$  ACK messages from the relays, where the value of  $N_1$  is pre-determined. At the second phase, the source  $S_2$  also uses digital Fountain codes to transmit its original data  $p_2$  to relays. Consider a relay receiving enough encoded packets for recovering the data  $p_2$ ; it checks if it decoded successfully the data  $p_1$  before. If it did, it would send an ACK message to the source  $S_2$ , and this source stops the data transmission. In case that it did not, it would keep silent and the source  $S_2$  would continue transmitting the encoded packets until there would be a relay, decoding successfully both the data

$p_1$  and  $p_2$ . At the third phase, the chosen relay at two previous phases combines two data  $p_1$  and  $p_2$  using XOR operation. The combined data, denoted by  $p_{\oplus}$ , will be encoded by digital Fountain codes right and then be transmitted to the sources  $S_1$  and  $S_2$ . Each source will attempt to collect enough information to recover the data  $p_{\oplus}$ . As soon as a source receives enough information, it sends an ACK message to the chosen relay. The chosen relay will terminate its transmission as soon as it receives two ACK messages from both  $S_1$  and  $S_2$ .

If the source  $S_2$  is the node transmitting its encoded packets at the first phase, the transmission procedure is similar as presented above. In this case, the number of ACK messages that the source  $S_2$  must receive before stopping transmitting the encoded packet in the first phase is denoted by  $N_2$ .

### III. Performance Formulation

The received signal-to-noise ratio (SNR) at a relay  $R_k$ ,  $k = 1, 2, \dots, N$ , due to the transmission of the source  $S_i$  ( $i \in \{1, 2\}$ ) is given as

$$\gamma_{i,k} = \frac{P_t |h_{i,k}|^2}{N_0} = \bar{\gamma} |h_{i,k}|^2 \quad (1)$$

where  $N_0$  is variance of AWGN at relay  $R_k$ ,  $h_{i,k}$  is the channel between nodes  $R_k$  and  $S_i$ , and  $\bar{\gamma}$  is the transmit SNR. Since  $|h_{i,k}|^2$  has an exponential distribution,  $\gamma_{i,k}$  is also an exponential random variable (RV) and its parameter is given as  $\lambda_i = d_i^\beta / \bar{\gamma}$ , where  $\beta$  is the path loss exponent that varies from 2 to 6.

At first, we assume that a receiver can recover successfully the original data if the received information at this node exceeds an amount of information  $T$ . Assume that the source  $S_i$  transmits its encoded

data in the first phase and the source  $S_j$  ( $j \neq i$ ) transmits its data in the second phase. Let  $R_c$  denote the chosen relay, the required delay time for the first phase is calculated by

$$t_1 = \frac{T}{\log_2(1 + \gamma_{i,c})} \quad (2)$$

Also, the delay time for the second phase and third stage is respectively given as

$$t_2 = \frac{T}{\log_2(1 + \gamma_{j,c})} \quad (3)$$

$$t_3 = \frac{T}{\log_2(1 + \min(\gamma_{i,c}, \gamma_{j,c}))} \quad (4)$$

From (2), (3) and (4), we define

$$W_{PR1} = \frac{T}{t_1 + t_2 + t_3} \text{ as the total throughput.}$$

Now, we study the PR0 protocol in which the network coding is not used and hence a best relay using Fountain code is chosen to relay the data  $p_1$  and  $p_2$  to the source  $S_2$  and  $S_1$ , respectively. In the PR0 protocol, the best relay is chosen by the following strategy:

$$R_c = \arg \max \left( \frac{1}{\frac{1}{\log_2(1 + \gamma_{1,k})} + \frac{1}{\log_2(1 + \gamma_{2,k})}} \right) \quad (5)$$

From (5), the total throughput of the PR0 protocol is calculated as

$$W_{PR0} = 2T \max \left( \frac{1}{\frac{1}{\log_2(1 + \gamma_{1,k})} + \frac{1}{\log_2(1 + \gamma_{2,k})}} \right) \quad (6)$$

### IV. Simulation Results

In this section, we provide some Monte-Carlo

simulations to evaluate and compare performance of the considered protocols. In all simulations, we perform 10000 trials and the total throughput is presented by the expected value.

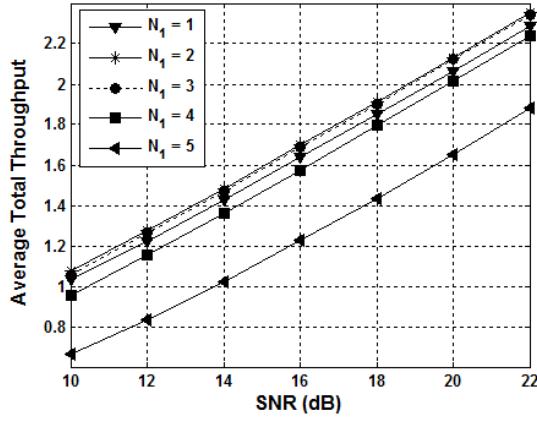


그림 2.  $\beta = 3$ ,  $d_1 = d_2 = 1$ ,  $N=5$  일 때, 전송 SNR의 함수에 따른 PR1 프로토콜의 전체 평균 처리량

Fig. 2. Average total throughput of the PR1 protocol as a function of transmit SNR in dB when  $\beta = 3$ ,  $d_1 = d_2 = 1$  and  $N=5$ .

In Figs. 2–3, we make simulations to compare performance of the PR1 protocol with the various values  $N_1$  and  $N_2$ . In these figures, we present the average total throughput as a function of transmit SNR in dB. In Fig. 2, we assign the values  $\beta$ ,  $d_1$ ,  $d_2$  and  $N$  by 3, 1 and 1, 5, respectively, while varying the value  $N_1$  from 1 to 5. It can be seen from this figure that with  $N_1 = 5$ , the performance is worst and the performance is best when  $N_1 = 2$ . It is also seen that performance in case of  $N_1 = 2$  and  $N_1 = 3$  is quite same. In Fig. 3, we assign the values  $\beta$ ,  $d_1$ ,  $d_2$  and  $N$  by 3, 1.75 and 1, 5, respectively. As we can see, the performance decreases with the increase of  $N_1$ , and increases with the decrease of  $N_2$  and the best performance is obtained at  $N_1 = 1$ .

In Fig. 4, we present the average total throughput as a function of the transmit SNR in dB. In this

simulation, we assign  $\beta$ ,  $d_1$  and  $d_2$  by 3, 1 and 1, respectively while the number of relays  $N$  gets the values 2, 5 and 8. It can be observed from this figure that performance of the PR1 protocol increases when we increase the number of relays  $N$ .

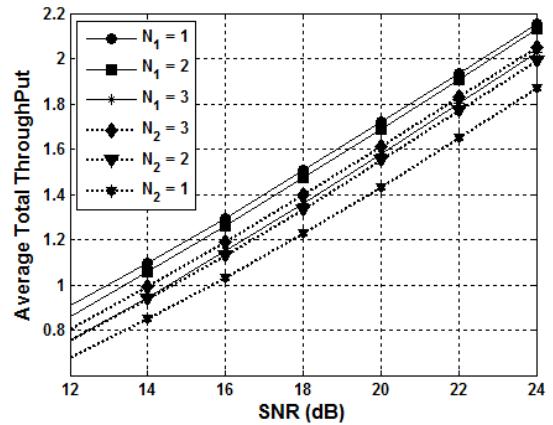


그림 3.  $\beta = 3$ ,  $d_1 = 1.75$ ,  $d_2 = 1$ ,  $N=5$  일 때, 전송 SNR의 함수에 따른 PR1 프로토콜의 전체 평균 처리량

Fig. 3. Average total throughput of the PR1 protocol as a function of transmit SNR in dB when  $\beta = 3$ ,  $d_1 = 1.75$ ,  $d_2 = 1$  and  $N=5$ .

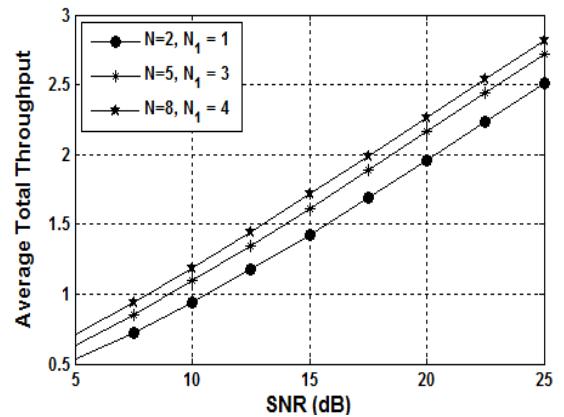


그림 4.  $\beta = 3$  and  $d_1 = d_2 = 1$ , 일 때, 전송 SNR의 함수에 따른 PR1 프로토콜의 전체 평균 처리량

Fig. 4. Average total throughput of the PR1 protocol as a function of transmit SNR in dB when  $\beta = 3$  and  $d_1 = d_2 = 1$ .

In Figs. 5–6, we compare performance of the proposed protocol with that of the PR0 protocol in both symmetric and asymmetric network. In Fig. 5, we fix value  $\beta$ ,  $d_1$ ,  $d_2$ ,  $N_1$  and  $N$  by 3, 1, 1, 4, 7, respectively. As we can see, the proposed protocol outperforms the PR0 protocol. It is due to the fact that the PR0 protocol does not use network coding technique. A similar result is presented in Fig. 6. In this figure, we consider the asymmetric network with  $d_1 = 1.25$  and  $d_2 = 1$ . The parameters  $\beta$ ,  $N_1$  and  $N$  are given by 3, 2, and 5, respectively.

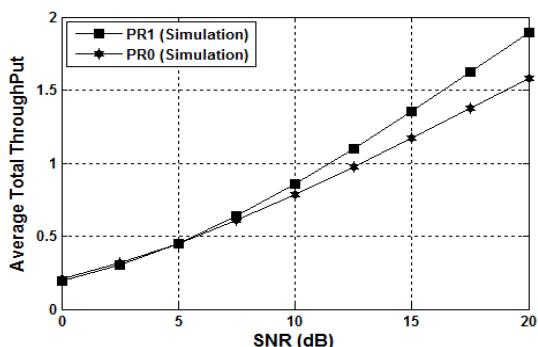


그림 5.  $\beta = 3$ ,  $d_1 = d_2 = 1.25$ ,  $N=7$ , 일 때, 전송 SNR의 함수에 따른 PR1 프로토콜의 전체 평균 처리량.

Fig. 5. Average total throughput of the PR1 protocol as a function of transmit SNR in dB when  $\beta = 3$ ,  $d_1 = d_2 = 1.25$  and  $N=7$ .

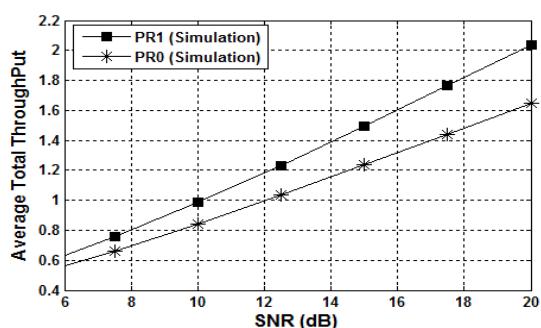


그림 6.  $\beta = 3$ ,  $d_1 = 1.25$ ,  $d_2 = 1$ ,  $N=5$  일 때, 전송 SNR의 함수에 따른 PR1 프로토콜의 전체 평균 처리량.

Fig. 6. Average total throughput of the PR1 protocol as a function of transmit SNR in dB when  $\beta = 3$ ,  $d_1 = 1.25$ ,  $d_2 = 1$  and  $N=5$ .

## V. Conclusion

In this paper, we proposed a bidirectional transmission protocols using network coding and Fountain codes. Performance of the proposed protocols was presented via Monte-Carlo simulations. Results showed that the proposed protocol outperformed the optimal relaying protocol without using network coding technique (the PR0 protocol) over Rayleigh fading channel in terms of average total throughput.

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