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Signal-Aligned Network Coding in Interference Channels with Limited Receiver Cooperation

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Abstract—**In this paper, we propose the ideas of signal-aligned network coding (SNC). We present the ideas in two-user time-varying interference channels with limited receiver cooperation. We assume that the receivers are connected to a central processor via wired cooperation links with individual limited capacities. Our SNC scheme determines the precoding matrices of the transmitters so that the transmitted signals are aligned at the receivers. The aligned signals are then decoded into linear combinations of messages by physical-layer network coding strategy. The key idea of our scheme is to ensure that independent linear combinations of messages, also known as network-coded messages, can be decoded at the receivers. Hence the central processor can recover the original messages of the transmitters by solving the linearly independent equations. We prove that our SNC scheme achieves full degrees of freedom (DoF) by utilizing signal alignment and physical-layer network coding. Simulation results show the DoF achieved by our SNC scheme almost doubles that by the orthogonal transmission scheme in two-user time-varying interference channels with limited receiver cooperation. The performance improvement of our SNC scheme mainly comes from efficient utilization of the signal subspaces for conveying independent linear combinations of messages to the central processor.**

I. INTRODUCTION

Interference is a key challenge in today's wireless networks. Due to the broadcast nature of wireless medium, the signals heard by a receiver are not only the signals from the intended transmitter and the noise, but also the signals from other nearby transmitters. In this paper, we focus on interference channels with limited receiver cooperation. We assume the receivers are connected to a central processor through independent wired cooperation links with individual limited capacities. A special case of our channel model is the scenario in which the receivers are interconnected through cooperation links and one of the receivers acts as the central processor. As forwarding analog signal samples from the receivers to the central processor generates excessive overhead, we focus on the situation that the cooperation links forward digital decoded packets instead of analog signal samples. The traffic of the limited receiver cooperation remains comparable to the wireless throughput. The interference channel with limited receiver cooperation has been widely investigated in many researches such as those about cloud radio access network (C-RAN), distributed multiple-input multiple-output (MIMO) system, wireless local area network (WLAN), etc. This architecture is generally viewed as a promising candidate to improve the network performance by efficient utilization of the wired cooperation links [1].

Physical-layer network coding (PNC) [2] brings the promising idea of network coding to ease the interference problem in wireless channels. There are many promising approaches proposed which make use of the wireless interference for network coding under channel models similar to ours. Compute-and-forward [3]–[7] is one of the examples. However, there are two major problems impairing the performance of compute-and-forward. First, the rank deficiency occurs if the equations forwarded from the receivers are linearly dependent. As a result, the central processor is unable to recover the original messages. Second, there exists a rate penalty which comes from the non-integer parts of the channel coefficients during decoding.

Some researches such as [8]–[11] showed that PNC can be employed together with signal alignment to achieve better performance. Signal alignment was proposed in [8] based on the idea of interference alignment [12]–[14] to investigate the degrees of freedom (DoF) of the MIMO Y channel, in which three users exchanged independent messages with each other via an intermediate relay. Reference [11] studied an uplink distributed MIMO system with a sum backhaul rate constraint. They proposed a scheme utilizing signal alignment and PNC for the block-fading channel, in which the channel coefficients remained constant over a block of symbols. Moreover, the performance of their scheme is limited by the numbers of antenna per node.

Furthermore, [15] and [16] focus on utilizing the advantages of signal alignment to tackle the interference problem in two-hop interference channels. However, SNC is a new transmission strategy in a different situation. Apart from the difference in the channel models, [15] and [16] consider the relays apply linear transformations to the analog signals so that the interfering analog signals are neutralized at the destinations. However, we consider that the receivers and the central processor are communicated through wired cooperation links. Only digital decoded packets can be forwarded via the wired limited cooperation links as forwarding analog signal samples would cause excessive traffic.

In this paper, we propose a signal-aligned network coding (SNC) scheme for two-user time-varying interference channels with limited receiver cooperation. This cooperation is achieved

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through wired cooperation links with individual limited capacities. The SNC scheme for general $K \geq 2$ users and multiple antennas per node is provided in the full paper [17]. As the DoF, also known as the capacity pre-log or the multiplexing gain, provides a first-order approximation to the capacity, it plays an important role in characterizing the capacity behavior in the high SNR regime. We show that our proposed SNC scheme can achieve full DoF. In other words, at high SNR, our SNC scheme is able to achieve approximately the capacity of the channel in which unlimited cooperation among the receivers is allowed.

Our SNC scheme utilizes physical-layer network coding and signal alignment. We consider that the receivers decode linear combinations of messages, also known as network-coded messages, from the transmitters. The decoding of linear equations of messages can be achieved by compute-and-forward or other PNC strategies. Analog signals or raw received signal samples cannot be forwarded from the receivers to the central processor due to the limited capacities of the wired cooperation links. The capacity of each cooperation link is just sufficient to forward the decoded messages or the linear combinations of them in the same finite field. The signal alignment technique used in this paper is based on the precoding over multiple symbol extensions of the time-varying channel. Our SNC scheme designs the precoding matrices so that the signals from the transmitters are aligned at each receiver and independent linear equations of transmitted messages can be decoded.

In this paper, letters of bold upper case, bold lower case, and lower case indicate matrices, vectors, and scalars respectively. $\mathbb{C}^{m \times n}$ denotes the set of all complex-valued $m \times n$ matrices. $\mathbb{F}_q^{m \times n}$ represents the set of all $m \times n$ matrices in a finite field of size q and $\oplus$ means the addition operation over that finite field. $\mathbf{I}_d$ indicates the $d \times d$ identity matrix. Moreover, $(\cdot)^{\mathrm{T}}$, $(\cdot)^{\mathrm{H}}$, $\|\cdot\|_{\mathrm{F}}$, and $\mathbb{E}[\cdot]$ denote transpose, conjugate transpose, Frobenius norm, and statistical expectation respectively.

II. SYSTEM MODEL

We consider a time-varying interference channel with limited receiver cooperation which consists of two transmitters, two receivers, and a central processor as illustrated in Fig. 1. Each receiver is connected to the central processor via an independent noiseless cooperation link. Each transmitter and receiver has one antenna. We assign unique indices $k \in \{1, 2\}$ and $l \in \{1, 2\}$ to each transmitter and receiver respectively. The overall transmission consists of two stages. In the first stage, the transmitters convey messages, which can be coded symbols, to the receivers in the interference channel. We assume that the transmitters send signals synchronously and share the same time, frequency, and code resources. We consider the interference from concurrent transmissions is much stronger than the noise. In the second stage, the receivers process and forward the received messages or the linear equations of them in the same finite field to the central processor via wired cooperation links. Having collected the messages from the receivers, the central processor recovers all original messages of the transmitters. We assume that the capacity of each cooperation link is just sufficient to forward the decoded messages rather than the raw received signals. In other words, the rate-constraint of a cooperation link is just greater than the rates of the links from each transmitter to the receiver connected to that cooperation link. Furthermore, we assume instantaneous channel state information (CSI) is globally available. This CSI assumption is valuable in both theoretical and practical aspects. Our results not only show the significant theoretical DoF gains achieved by our SNC scheme, but also act as a benchmark for future works which make more practical CSI assumptions.

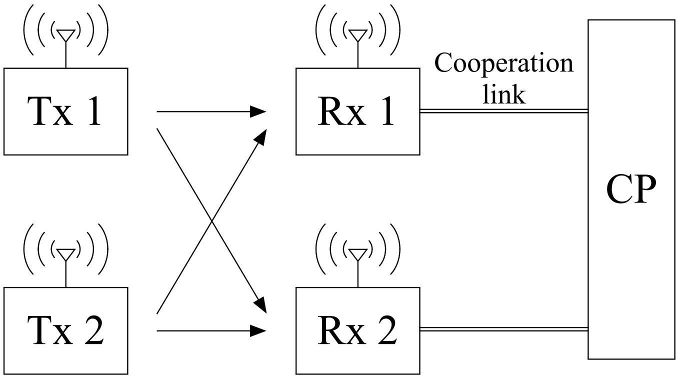

Fig. 1. A two-user time-varying interference channel with limited receiver cooperation, which consists of two transmitters (Tx), two receivers (Rx), and a central processor (CP).

A. Transmitters

The system adopts an N symbol extension of the channel where N is a positive integer. The N symbol extension means that the N symbols transmitted from each transmitter over N slots are collectively denoted as a supersymbol. In the first transmission stage, transmitter k modulates message vector $\mathbf{b}_k(t) \in \mathbb{F}_q^{N \times 1}$ to signal vector $\mathbf{x}_k(t) \in \mathbb{C}^{N \times 1}$ where

$$\mathbf{b}_k(t) = \begin{bmatrix} b_k^{(1)}(t) & b_k^{(2)}(t) & \cdots & b_k^{(N)}(t) \end{bmatrix}^{\mathrm{T}} \tag{1}$$

and

$$\mathbf{x}_k(t) = \begin{bmatrix} x_k^{(1)}(t) & x_k^{(2)}(t) & \cdots & x_k^{(N)}(t) \end{bmatrix}^{\mathrm{T}}. \tag{2}$$

The superscript (i) is used to denote the i-th slot of the N symbol extension. Message vector $\mathbf{b}_k(t)$ is the N symbol extension of independent and identically distributed (i.i.d.) message $b_k(t)$ introduced in (1). Signal vector $\mathbf{x}_k(t)$ is the N symbol extension of signal $x_k(t)$ presented in (2) and $\mathbb{E}[\mathbf{x}_k(t)\mathbf{x}_k^{\mathrm{H}}(t)] = \mathbf{I}_N$. In this paper, the time index t which is a positive integer can be used to describe time slots, frequency slots, or time-frequency slots.

Transmitter k sends signal vector $\mathbf{x}_k(t)$ with linear precoding matrix $\mathbf{V}_k(t) \in \mathbb{C}^{N \times N}$. Let $p_k(t)$ and $p^{\max}(t)$ be the actual transmit power of transmitter k and the maximum transmit power of the system respectively. The transmit power constraint of the system is

$$0 \leq \sum_{k=1}^{2} p_k(t) = \sum_{k=1}^{2} \|\mathbf{V}_k(t)\|_{\mathrm{F}}^2 \leq p^{\max}(t). \tag{3}$$

B. Receivers

The received signal of a receiver is the superposition of the signals from the transmitters weighted by their corresponding channels and the received signal is affected by the noise. With the N symbol extension of the channel, receiver l observes received signal vector $\mathbf{y}_l(t) \in \mathbb{C}^{N\times 1}$ where

$$\mathbf{y}_l(t) = \sum_{k=1}^{2} \mathbf{H}_{l,k}(t)\mathbf{V}_k(t)\mathbf{x}_k(t) + \mathbf{n}_l(t). \tag{4}$$

Diagonal channel matrix $\mathbf{H}_{l,k}(t) \in \mathbb{C}^{N\times N}$ is the N symbol extension of channel coefficient $h_{l,k}(t)$ where

$$\mathbf{H}_{l,k}(t) = \begin{bmatrix} h_{l,k}^{(1)}(t) & 0 & \dots & 0 \\ 0 & h_{l,k}^{(2)}(t) & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & h_{l,k}^{(N)}(t) \end{bmatrix} \tag{5}$$

and $h_{l,k}(t)$ denotes the CSI of the link from transmitter k to receiver l. Moreover, noise vector $\mathbf{n}_l(t) \in \mathbb{C}^{N\times 1}$ is the N symbol extension of noise term $n_l(t)$ with variance $\sigma_l^2(t)$ at receiver l. In this paper, we assume all channel coefficients are i.i.d. zero-mean unit-variance complex Gaussian random variables. Hence, channel matrix $\mathbf{H}_{l,k}(t)$ has rank N almost surely. We also assume all noise terms are i.i.d. complex additive white Gaussian noise (AWGN).

Receiver l applies linear filtering matrix $\mathbf{U}_l(t) \in \mathbb{C}^{N\times N}$ to received signal vector $\mathbf{y}_l(t)$. The filtered signal vector of receiver l is $\mathbf{x}'_l(t) \in \mathbb{C}^{N\times 1}$ where

$$\begin{aligned} \mathbf{x}'_l(t) &= \mathbf{U}_l^{\mathrm{H}}(t)\mathbf{y}_l(t) \\ &= \sum_{k=1}^{2} \mathbf{U}_l^{\mathrm{H}}(t)\mathbf{H}_{l,k}(t)\mathbf{V}_k(t)\mathbf{x}_k(t) + \mathbf{U}_l^{\mathrm{H}}(t)\mathbf{n}_l(t). \end{aligned} \tag{6}$$

Receiver l demodulates filtered signal vector $\mathbf{x}'_l(t)$ to demodulated message vector $\mathbf{b}'_l(t) \in \mathbb{F}_q^{N\times 1}$.

C. Central Processor

In the second transmission stage, receiver l forwards demodulated message vector $\mathbf{b}'_l(t)$ to the central processor through an independent noiseless cooperation link. We consider the capacity of each cooperation link is just greater than the rates of the wireless links from each transmitter to the receiver to which the cooperation link is attached. The central processor collects all forwarded messages from the receivers and then recovers all original messages of the transmitters. The recovered message vector of transmitter k is $\hat{\mathbf{b}}_k(t) \in \mathbb{F}_q^{N\times 1}$. If $\hat{\mathbf{b}}_k(t) \neq \mathbf{b}_k(t)$ for any k, a decoding error occurs. For the sake of simplicity, the time index t is omitted in the rest of this paper.

D. Degrees of Freedom

The capacity of transmitter k at SNR ρ can be expressed as

$$C_k(\rho) = d_k \log_2(\rho) + \mathrm{o}(\log_2(\rho)). \tag{7}$$

$\mathrm{o}(\log_2(\rho))$ is a function that $\frac{\mathrm{o}(\log_2(\rho))}{\log_2(\rho)}$ tends to zero when ρ tends to infinity. The capacity pre-log factor d_k is the DoF of transmitter k, which is also known as the multiplexing gain. The DoF of transmitter k can be found by

$$d_k = \lim_{\rho\to\infty} \frac{C_k(\rho)}{\log_2(\rho)}. \tag{8}$$

III. SNC IN TWO-USER TIME-VARYING INTERFERENCE CHANNELS WITH LIMITED RECEIVER COOPERATION

In this section, we describe the main ideas of our SNC scheme in two-user interference channels with limited receiver cooperation. The system adopts an $N = n+1$ symbol extension where n is a positive integer. We show that DoF tuple $(d_1, d_2) = (\frac{n+1}{n+1}, \frac{n}{n+1})$ is achievable.

Our SNC scheme determines the linear precoding matrices of the transmitters so that the receivers obtain independent linear combinations of messages, which are also known as network-coded messages. The central processor then recovers all original messages of the transmitters by solving the linearly independent equations. The details are as follows:

A. Precoding at Transmitters

First, transmitter 1 modulates $(n+1)\times 1$ message vector $\mathbf{b}_1$ to $(n+1)\times 1$ signal vector $\mathbf{x}_1$ while transmitter 2 modulates $n \times 1$ message vector $\mathbf{b}_2$ to $n\times 1$ signal vector $\mathbf{x}_2$. Afterward transmitter $k \in \{1,2\}$ transmits signal vector $\mathbf{x}_k$ with linear precoding matrix $\mathbf{V}_k$.

We set up the following signal alignment constraints for the transmitters:

$$\mathbf{H}_{1,2}\mathbf{V}_2 \prec \mathbf{H}_{1,1}\mathbf{V}_1, \tag{9}$$

$$\mathbf{H}_{2,2}\mathbf{V}_2 \prec \mathbf{H}_{2,1}\mathbf{V}_1 \tag{10}$$

where $\mathbf{Q} \prec \mathbf{P}$ denotes that the column vectors of matrix $\mathbf{Q}$ is a subset of those of matrix $\mathbf{P}$ in this paper. In general, for each alignment constraint, the signals are just required to be aligned in the same direction. Taking alignment constraint (9) as an example, it could be $\mathbf{H}_{1,2}\mathbf{V}_2 \prec \alpha\mathbf{H}_{1,1}\mathbf{V}_1$ where α is a scalar. As we focus on introducing our SNC scheme in this paper, we do not consider the optimization in this aspect.

In order to fulfill alignment constraints (9) and (10) and the ideas of SNC, we can set the linear precoding matrices of the transmitters as follows:

$$\begin{aligned} &\mathbf{V}_1 \\ &= \begin{bmatrix} \mathbf{G}_{1,2}^{n}\mathbf{w} & \mathbf{G}_{1,2}^{n-1}\mathbf{G}_{2,2}\mathbf{w} & \dots & \mathbf{G}_{1,2}\mathbf{G}_{2,2}^{n-1}\mathbf{w} & \mathbf{G}_{2,2}^{n}\mathbf{w} \end{bmatrix}, \end{aligned} \tag{11}$$

$$\begin{aligned} &\mathbf{V}_2 \\ &= \begin{bmatrix} \mathbf{G}_{1,2}^{n-1}\mathbf{w} & \mathbf{G}_{1,2}^{n-2}\mathbf{G}_{2,2}\mathbf{w} & \dots & \mathbf{G}_{1,2}\mathbf{G}_{2,2}^{n-2}\mathbf{w} & \mathbf{G}_{2,2}^{n-1}\mathbf{w} \end{bmatrix} \end{aligned} \tag{12}$$

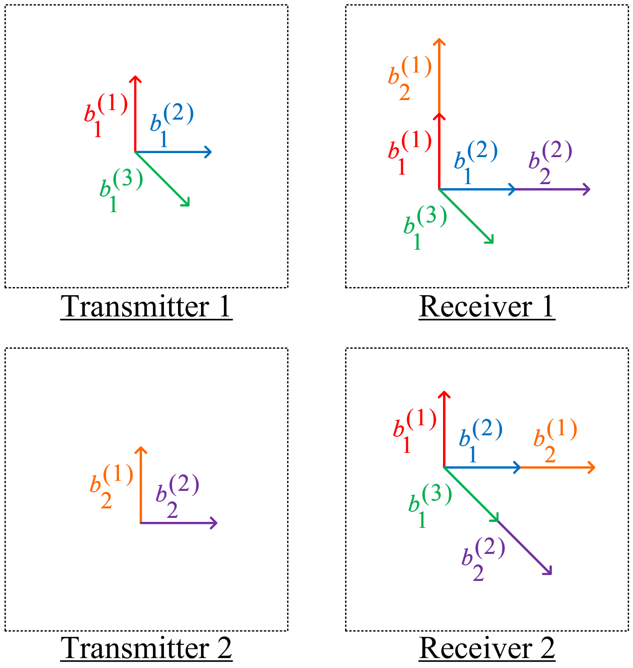

Fig. 2. A 3-dimensional vector diagram illustrating the signal alignment of SNC in the two-user interference channel with limited receiver cooperation.

where $\mathbf{G}_{1,2} = \mathbf{H}_{1,1}^{-1}\mathbf{H}_{1,2}$, $\mathbf{G}_{2,2} = \mathbf{H}_{2,1}^{-1}\mathbf{H}_{2,2}$, and $\mathbf{w}$ is an arbitrary $(n+1)\times 1$ column vector. Here $\mathbf{V}_1$ is an $(n+1)\times(n+1)$ matrix and $\mathbf{V}_2$ is an $(n+1)\times n$ matrix. Without loss of generality, we assume

$$\mathbf{w} = \begin{bmatrix} 1 & 1 & \cdots & 1 \end{bmatrix}^{\mathrm{T}}. \tag{13}$$

As mentioned previously, we focus on introducing our SNC scheme in this paper, we do not consider the optimization of the linear precoding matrices.

B. Decoding and Forwarding at Receivers

The messages decoded at the receivers for the $n = 2$ case are shown in Fig. 2. Now we describe how the linear precoding matrices of the transmitters affect the messages decoded at the receivers in details. As the multiplications of diagonal matrices are commutative, the multiplications of the channel matrices and the linear precoding matrices at receiver 1 are

$$\begin{aligned}&\mathbf{H}_{1,1}\mathbf{V}_1\\&= [\mathbf{H}_{1,2}\mathbf{G}_{1,2}^{n-1}\mathbf{w}, \mathbf{H}_{1,2}\mathbf{G}_{1,2}^{n-2}\mathbf{G}_{2,2}\mathbf{w}, \ldots, \mathbf{H}_{1,1}\mathbf{G}_{2,2}^{n}\mathbf{w}],\end{aligned} \tag{14}$$

$$\begin{aligned}&\mathbf{H}_{1,2}\mathbf{V}_2\\&= [\mathbf{H}_{1,2}\mathbf{G}_{1,2}^{n-1}\mathbf{w}, \mathbf{H}_{1,2}\mathbf{G}_{1,2}^{n-2}\mathbf{G}_{2,2}\mathbf{w}, \ldots, \mathbf{H}_{1,2}\mathbf{G}_{2,2}^{n-1}\mathbf{w}],\end{aligned} \tag{15}$$

where $\mathbf{H}_{1,1}\mathbf{V}_1$ is an $(n+1)\times(n+1)$ matrix and $\mathbf{H}_{1,2}\mathbf{V}_2$ is an $(n+1)\times n$ matrix. The column vectors in (14) and (15) are separated by commas due to space limitation. The first n column vectors of $\mathbf{H}_{1,1}\mathbf{V}_1$ are the same as the column vectors of $\mathbf{H}_{1,2}\mathbf{V}_2$, therefore signal alignment constraint (9) is satisfied.

Receiver 1 applies $(n+1)\times(n+1)$ linear filtering matrix $\mathbf{U}_1^{\mathrm{H}} = (\mathbf{H}_{1,1}\mathbf{V}_1)^{-1}$ to $(n+1)\times 1$ received signal vector $\mathbf{y}_1$. As the first n column vectors of $\mathbf{H}_{1,1}\mathbf{V}_1$ are the same as the column vectors of $\mathbf{H}_{1,2}\mathbf{V}_2$, we can express the $(n+1)\times 1$ filtered signal vector $\mathbf{x}_1'$ as

$$\begin{aligned}&\mathbf{x}_1'\\&= \left[x_1^{(1)} + x_2^{(1)}, x_1^{(2)} + x_2^{(2)}, \cdots, x_1^{(n)} + x_2^{(n)}, x_1^{(n+1)}\right]^{\mathrm{T}}\\&\quad + \mathbf{U}_1^{\mathrm{H}}\mathbf{n}_1.\end{aligned} \tag{16}$$

We treat the aligned signal (e.g. $x_1^{(1)} + x_2^{(1)}$) as an unknown for demodulation rather than demodulate the original signals (e.g. $x_1^{(1)}$ and $x_2^{(1)}$) individually. This idea of PNC demodulation [2] also applies in the rest of this paper. The PNC demodulation can be achieved by compute-and-forward or other PNC strategies. Receiver 1 demodulates filtered signal vector $\mathbf{x}_1'$ to $(n+1)\times 1$ network-coded message vector

$$\begin{aligned}&\mathbf{b}_1'\\&= \left[b_1^{(1)} \oplus b_2^{(1)}, b_1^{(2)} \oplus b_2^{(2)}, \cdots, b_1^{(n)} \oplus b_2^{(n)}, b_1^{(n+1)}\right]^{\mathrm{T}}.\end{aligned} \tag{17}$$

Signal $x_1^{(n+1)}$ is demodulated by conventional demodulation while the other signals are demodulated by PNC demodulation.

The messages decoded at receivers 2 can be understood likewise. Receiver 2 applies $(n+1)\times(n+1)$ linear filtering matrix $\mathbf{U}_2^{\mathrm{H}} = (\mathbf{H}_{2,1}\mathbf{V}_1)^{-1}$ to $(n+1)\times 1$ received signal vector $\mathbf{y}_2$. As the last n column vectors of $\mathbf{H}_{2,1}\mathbf{V}_1$ are the same as the column vectors of $\mathbf{H}_{2,2}\mathbf{V}_2$, receiver 2 can obtain $(n+1)\times 1$ network-coded message vector

$$\begin{aligned}&\mathbf{b}_2'\\&= \left[b_1^{(1)}, b_1^{(2)} \oplus b_2^{(1)}, \cdots, b_1^{(n)} \oplus b_2^{(n-1)}, b_1^{(n+1)} \oplus b_2^{(n)}\right]^{\mathrm{T}}.\end{aligned} \tag{18}$$

C. Decoding at Central Processor

We consider the wired cooperation links only support forwarding the digital decoded packets, rather than analog signal samples, from the receivers to the central processor. The central processor collects network-coded message vectors $\mathbf{b}_1'$ and $\mathbf{b}_2'$ from receivers 1 and 2, respectively, via independent noiseless cooperation links. Obviously, the central processor can recover all original messages of the transmitters by solving any $2n+1$ independent equations with $2n+1$ unknowns. For example, message $b_2^{(1)}$ can be recovered by performing network coding between $b_1^{(1)} \oplus b_2^{(1)}$ from $\mathbf{b}_1'$ and $b_1^{(1)}$ from $\mathbf{b}_2'$ such that

$$(b_1^{(1)} \oplus b_2^{(1)}) \oplus b_1^{(1)} = b_2^{(1)}. \tag{19}$$

Other original messages of the transmitters can be obtained likewise. Hence, the system achieves total $2n+1$ DoF over an $N = n+1$ symbol extension for any positive integer n by our SNC scheme. With a large value of n, the sum DoF achieved by our SNC scheme for the two-user time-varying interference channel with limited receiver cooperation is two. In other words, full DoF can be achieved by our SNC scheme. The DoF result can be extend to K-user MIMO cases in [17].

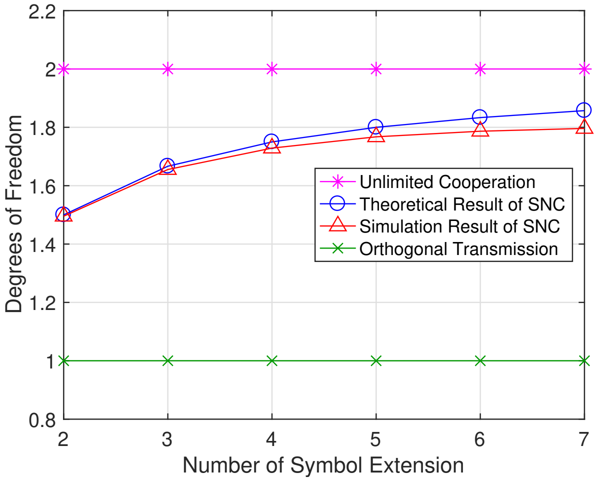

Fig. 3. Average degrees of freedom achieved by the unlimited cooperation scheme, our SNC scheme, and the orthogonal transmission scheme.

IV. SIMULATION RESULTS

We present the simulation results to evaluate the DoF of our SNC scheme in two-user time-varying interference channels with limited receiver cooperation. The performance of our SNC scheme is compared with the unlimited cooperation scheme and the orthogonal transmission scheme. For the unlimited cooperation scheme, we assume the cooperation links from the receivers to the central processor have infinite capacity. This scheme acts as an upper bound for comparison. For the orthogonal transmission scheme, the transmitters take turns conveying their messages to one of the receivers. In other words, the transmitters are dividing the available communication resources.

We assume the total transmit powers for all systems are the same and the noise variances at each node are the same. We compute the DoF by dividing the sum-rate by $\log_2(\text{SNR})$ at a very high SNR. The average DoF are computed using 1000 random channel realizations. Simulation results are illustrated with respect to the number of symbol extension. Fig. 3 shows that the simulation results of our SNC scheme are close to its theoretical results. The gap between them is due to the finite SNR adopted in the simulation. Furthermore, Fig. 3 demonstrates that the DoF achieved by our SNC scheme almost doubles that by the orthogonal transmission scheme in two-user time-varying interference channels with limited receiver cooperation. The performance improvement of our scheme mainly comes from efficient utilization of the signal subspaces for conveying independent linear combinations of messages to the central processor.

V. CONCLUSION

In this paper, we propose the ideas of SNC in two-user time-varying interference channels with limited receiver cooperation. The extension of our SNC scheme to K-user MIMO cases can be found in [17]. This channel model widely characterizes the scenarios in C-RAN, distributed MIMO, WLAN, etc. Our SNC scheme utilizes the precoding matrices of the transmitters to make different combinations of the transmitted messages, which are linearly independent, at each receiver. We prove that our scheme is able to approach arbitrarily close to the upper DoF bound. Simulation results of our scheme coincide with its theoretical results. In terms of DoF, simulation results also show that our SNC scheme outperforms the orthogonal transmission scheme in two-user time-varying interference channels with limited receiver cooperation. The DoF improvement of our scheme mainly comes from efficient utilization of the signal subspaces for conveying linearly independent combinations of messages. Sum-rate maximization by optimizing the precoding matrices in our scheme remains an open problem. This could be considered as a future work.

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