# Self Interference Suppression In Full Duplex MIMO Relay Using Fuzzy Dempster Shafer Theory

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***Abstract :*** The modern day wireless technology requires to have transmission that is reliable, efficient with high capacity and high spectral efficiency. An prospective approach to achieve high capacity transmission is using MIMO relay technique. MIMO relay technique with full duplex mode can transmit and receive the data at same frequency. However, the performance of MIMO relay technique is obstructed by self interference. Self interference occurs due to coupling effect at the relay receiver as the data is being transmitted and received at same frequency. SI suppression method used to minimize the effect of the self interference in order to ensure reliable transmission. Dempster shafer theory is used to build evidence based model for SI suppression. Dempster-shafer is use to model uncertainty and is capable of fusing evidence from multiple sources. However, dempster-shafer theory is use to fail when the sources of evidence are highly conflicting. The work in this paper proposes a novel SI suppression method for MIMO relay FD technique with Fuzzy dempster-shafer theory in order to achieve reliable transmission

***IndexTerms*** - Two-way full-duplex MIMO relay, self-interference, Dempster-Shafer evidence theory

## I. INTRODUCTION

The multiple-input multiple-output (MIMO) relay technique a promising technique for the coverage extension, reliable transmission, capacity and spectral efficiency improvement in wireless communication network. However, two-way half-duplex (HD) MIMO relay with network coding (NC) [1-2] or physical layer network coding (PNC)[3-4] still needs at least two phases to finish an information exchange between two source nodes. Recently, full-duplex (FD) mode that can transmit and receive simultaneously at the same frequency is proposed to improve the system capacity and spectral efficiency. In two-way FD MIMO relay system [5-7], the transmission takes a single phase via combining the multiple access (MA) and broadcast (BC) phase by exploiting FD mode at all nodes. However, due to simultaneous transmission and reception, the selfinterference (SI) caused by coupling effect of the transmitted signal at relay receiver become a serious issue in FD MIMO relay system. Therefore, the SI suppression in FD relay system. is considered as an important technique to ensure the reliable transmission. Most previous research mainly focuses on the SI suppression in one-way FD MIMO relay systems [8-11]. Throughout the previous works, the suppression schemes are mainly classified into three types. Natural isolation [9-10], the basic scheme, is used earliest in SI suppression. Time-domain cancellation [11-12] cancels the SI by subtracting its own transmitted symbol at relay reception. However, since MIMO technique is fully adopted in relay, time-domain cancellation cannot make full use of spatial-domain resources. Therefore, several different spatial-domain suppression schemes that exploit the space degree of freedom to cancel the SI are proposed in [13-19], e.g., null-spacing projection[13-15], Minimum mean square error (MMSE) filter[13-14], antenna selection[16-17], eigenbeamforming[18], beam form selection [14], maximum signal to interference ratio (SIR) [19] and so on. These spatial-domain suppression schemes design transceiver filter matrices from spatial-domain cancellation At present, for two-way FD MIMO relay, most schemes focus on enhancing achievable sum rate, system capacity, outage probability and throughput without considering bit error rate (BER) performance at relay. For example, the power allocation scheme used in [20] aims at maximizing the sum rate of two-way FD relay under residual SI. The author in [6] compares the performance of two-way FD and HD relay and illustrates the benefits of power optimization with residual SI. In [21], the paper mainly aims to maximize end-to-end sum rate by exploiting joint beam forming optimization and power control. Alamouti-based scheme [22] is another scheme that enhances the capacity and outage probability without considering the SI suppression. At present, these schemes mostly research capacity and sum rate problem with residual SI and SI suppression problem is not considered explicitly in two way FD MIMO relay difference signal from the source nodes in the MA phase. Then, the network-coded symbol can be obtained directly by using decision rule without XOR operation. Furthermore, for comparison, another scheme called extended MIMO-LLR-PNC that exploits Log-Likelihood- Ratio (LLR) combining technique in two-way HD MIMO relay [26] is generalized for two-way FD MIMO relay considering SI suppression in soft information computation for network-coded symbol. In the BC phase, the Max-Min antenna selection scheme proposed in [27] that achieves full transmit diversity gain is adopted to transmit the network-coded symbol to each source node. The simulation results show that the proposed DS-SAD-PNC scheme achieve better end-to-end average BER performance than the traditional spatial-domain suppression and extended MIMO-LLR-PNC schemes with a little complexity increased. Dempster-shafer theory is use to model uncertainty and is capable of fusing evidence from multiple sources. However, dempster-shafer theory is use to fails when the sources of evidence are highly conflicting. At that time Fuzzy Dempster theory is used.

The rest of paper is organized as follows. Section II describes the system model. In Section I III, MIMO-LLR-PNC scheme with SI considered is extended in FD mode. D-S evidence theory is briefly reviewed and the novel DS-SAD PNC SI suppression scheme and fuzzy D-S theory is proposed in Section IV. The simulation results are presented and described in Section V. Finally, Section V concludes the paper.

## II. SYSTEM MODEL

A two-way FD MIMO relay system is considered as depicted in Fig. 1, which consists of two source nodes equipped with one transmit and one receive antenna and a relay node equipped with $n_R$ receive antennas and $n_T$ transmit antennas. In this paper, we assume that $nT < nR$ and no direct link can be utilized between two source nodes. Both the relay node and two source nodes work in FD mode and physical isolation between transmit and receive antenna at relay is considered in this model. At the $t$ -th time slot, each source node detects the symbol of ($t$ -1) th time and the symbols are detected with fix delay of a single time slot. The MA, BC and self-interference channels are assumed to be quasi-static flat fading and remain static during one frame transmission phase. Full CSI is accurately known at receiver both in the MA and BC phase

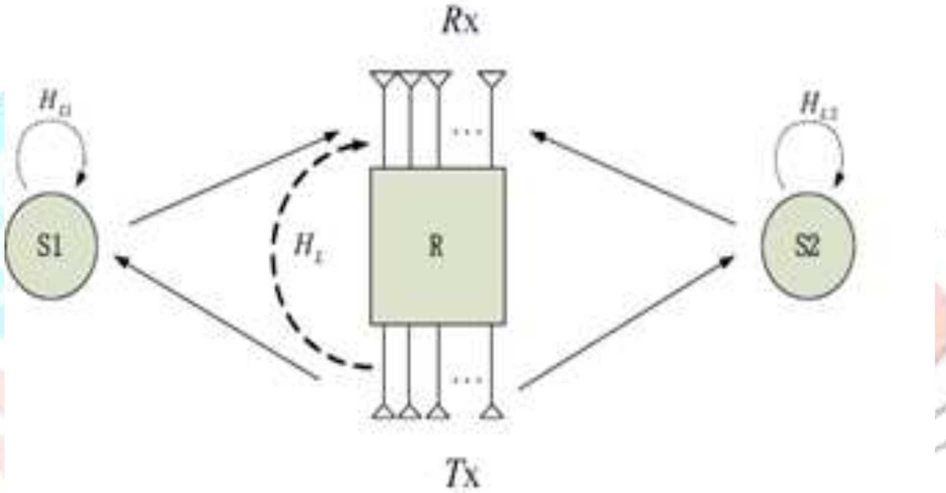


Figure 1. Two-way FD MIMO relay system

In the MA phase, the received signal at $t$ -th time slot atrelay is depicted as follows

$$Y(t) = H_{MA}X(t) + H_L X_L(t) + N_R(t) \qquad (1)$$

where $H_{MA}$ and $H_L$ denote a $n_R \times 2$ MA channel and $n_R \times n_T$ self-feedback channel, respectively. The source nodes transmit a 2×1 signal vector **x**$(t)$, and the relay node transmits a $n_T \times 1$ signal vector $\mathbf{x}_L(t)$ while it simultaneously receives a $n_R \times 1$ signal vector **y**$(t)$; $\mathbf{n}_R(t)$ is a $n_R \times 1$ additive white Gaussian noise vector with zero mean and variance $\sigma^2$.

The Eq. (1) can be rewritten as

$$yi(t) = h_{ij}^{MA} x_j\ (t) + \sum_{L=1,L\neq J}^{L=2} hil_{il}^{MA}\, x_l(t) + \sum_{k=1}^{k=nT} h_{ik}^{L} x_k^{L^2}(t) + n_i^R(t) \qquad (2)$$

$i=1,2,3,\ldots..n_R\ ,\ j=1,2$

where $yi(t)$ denotes the received signal of the $i$-th antenna at the relay in the $t$-th time slot.

In the BC phase, the received signal vector at each source node can be indicated as

$$R_{si}(t) = H_i^{BC} X_L\ (t) + H_{Li} x_i\ (t)\ + N_{si}(t) \qquad (3)$$

where $\mathbf{R}_{si}(t)$ denotes the received signal vector at the $i$-th source node, $\mathbf{Hi}^{BC}$ is the corresponding $2 \times nT$ BC channel sub matrix for each source node, $\mathbf{H}_{Li}$ denotes the self interference channel of i-th source node. $N_{si}(t)$ is additive white Gaussian noise.

For simplicity, we assume that the full CSI are accurately known at each source node. So the SI at each source node can be cancelled completely and this paper mainly focuses on the SI suppression at relay node

## III. GENERALIZED MIMO-LLR-PNC SCHEME IN TWOWAY FD RELAY

In [26], the author presents MIMO-LLR-PNC scheme for two-way HD MIMO relay. Compared with NC, the network coded symbol obtained directly without XOR operation is the most advantage in MIMO PNC. In this paper, this MIMOLLR- PNC scheme is extended in two-way FD mode considering SI suppression in soft information computation for network-coded symbol. In extended MIMO-LLR-PNC, the transmit signals $x1(t)$ and $x2(t)$ are changed to $x1(t) + x2(t)$ and x1(t)-x2(t) $t$ with sum and difference and matrix $\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$

The expression can be written as

$$Y(t) = H_{MA}D^{-1}DX(t) + H_L X_L(t) + N_R(t) \qquad (4)$$

$$= \; H'_{MA}X'(t) + H_L X_L(t) + N_R(t) \qquad (5)$$

$$H'_{MA} = H_{MA}D^{-1}$$

$$X^{'}(t) = DX(t) = \begin{bmatrix} x1(t) & + & x2(t) \\ \\ x1(t) & - & x2(t) \end{bmatrix}$$

According to (4), (2) can be rewritten as

$$yi(t) = h_{ij}^{\prime MA} x_j' \; + \; \sum_{L=1,L\neq J}^{L=2} h'^{MA}_{il} \, x'_l(t) + \sum_{k=1}^{k=nT} h_{ik}^{L} x_k^{L^2} \, (\mathrm{t}) + \mathrm{n}_\mathrm{i}^\mathrm{R}(\mathrm{t}) \; (6)$$

$i$=1,2,3….$n_R$ and $j$=1,2

.

## IV. PROPOSED SI SUPPRESSION BASED ON D-S EVIDENCE THEORY AND FUZZY DS THEORY

In this section, the basic concept of D-S evidence theory is introduced [28] and the proposed SI suppression scheme based on D-S theory is proposed to obtain better BER performance.

### *.A Brief Review of D-S Evidence Theory*

D-S evidence theory based on the constructive interpretation of probability is a generalization of Bayes theory. The constructive interpretation of probability emphasizes not only the importance of objective evidence but also the importance of subjective estimation. So it can fully characterize the uncertainty of propositions. Let$\Theta$ indicate the finite set which contains mutually exclusive and exhaustive hypotheses, called the framework of discernment. All subsets of the framework of discernment constitute a power set $2^{\Theta}$ .

The knowledge about the hypothetical propositions
produces a BPA function, which is defined as a function $m(.)$

$$\mathrm{m}(\Phi) = 0 \qquad (7)$$

$$\forall A \subset \Theta A, m(A) \geq 0 \qquad (8)$$

$$\sum_{\forall A \subset \Theta} m(A) = 1 \qquad (9)$$

where $\Phi$ is a null set, and each subset $A \subset \Theta$ that satisfies $m(A) \geq 0$ is called a focal element set (FES). Actually, the BPA function $m(A)$ can be defined by various methods. In general, PDF is used to denote the BPA of a FES $A$ . Based on the BPA function $m(A)$ , belief function $Bel(A)$ can be

$$Bel(A) = \sum_{B \subseteq A} m(B) \qquad (10)$$

The belief function $Bel(A)$ denotes the total belief assigned to the proposition $A$ . It is important for D-S evidence theory to be able to combine several different evidences from the same framework of discernment through the Dempster’s combining rule, which is defined as the orthogonal sum [28][29]. We assume that $Bel_{1\ldots}$ $Bel_n$ are belief functions of the same framework of discernment, $m_1$,,m….$m_n$ corresponding BPAs. If 1 $n$ $Bel_1 \oplus Bel_n$ exists, the exists, the Dempster’s combining rule can be expressed as follows [30]

$$m_{1-2}\,A = \frac{\sum_{B \cap C = A}\{m1(B)m2(c)\}}{(1-k)} \qquad (11)$$

when A≠ Ø m(Ø)=0 and

$$k = \sum_{B \cap C = \emptyset}\{m1(B)m2(C)\} \ldots \qquad (12)$$

### B. *The Proposed DS Scheme*

Different from the MIMO-LLR-PNC, the proposed DS-SAD- PNC scheme employs D-S evidence theory to estimate the sum and difference signal with SI suppression considered. In DS-SAD-PNC, for BPSK modulation, the set $\Omega = \{0,2,-2\}$ is considered as the framework of discernment. single-point sets, e.g., $A = \{0\}$ *or* $A = \{2\}$ *or* $A = \{-2\}$ , three twice-point sets, e.g., $A = \{0,2\}$ *or* $A = \{0,-2\}$*or* $A = \{-2,2\}$ ,and a three-point set, e.g., $A = \{0,2,-2\}$ . For the computation of BPA, the decision statistics of the sum and difference signal are obtained by ZF linear detection at first as in (6). However, due to SI problem, decreased accuracy of decision statistics leads to the bad BER performance. So, the iteration method is adopted for BPA computation to solve this problem

Firstly, according to (4), the $n_R$ decision statistics of each sum and difference signal $x'_j$ =1,2 is shown as

$$x\hat{}'_{ij}(t) = h'^{MA-1}_{ij} \langle y_i(t) - \sum_{\substack{k=1 \\ k\neq j}}^{k=2} h'^{MA}_{ik}\, x''_k(t)\ )\ \rangle \qquad (13)$$

$$i=1, \ldots..n_R\ ,\ j=1,2$$

In this paper, the BPA $m_{ij}(A)$ of each FES $A$ is defined as the conditional PDF of decision statistics $\hat{x}ij$ *According* to (13), xij^'(t) is a complex Gaussian random variable with Mean $x'_j(t) - h'^{MA-1}_{ij}\ \left(-H^L_i + \sum_{i=1,l\neq j}^{2} h'^{MA}_{ij}\ W'_l H_L\right) X_L(t)$

And variance $\left\|h'^{MA-1}_{ij}\ g'_i\ \right\|^2 \sigma^2$ Then, the conditional PDF$x\hat{}'_{ij}(t)$ of can be written as

$$f(x'_{ij}(t)| \propto (A)\ \forall \subset U \qquad (14)$$

$$= \sum_{X_{L\epsilon\phi}} \frac{1}{\sqrt{2\pi \left\|h'^{MA-1}_{ij} g'_i\right\|^2 \sigma^2}} \left( \frac{\left\|x'_j(t) - \alpha(A) + h'^{MA-1}_{ij}\left(-H^L_i + \sum_{i=1,l\neq j}^{2} h'^{MA}_{ij}\ W'_l H_L\right) X_L(t)\right\|^2}{2\pi \left\|h'^{MA-1}_{ij} g'_i\right\|^2 \sigma^2} \right) \quad (15)$$

where $U$ is all the considered FES and α ($A$) denotes the eigen value of FES $A$ , which is defined as the mean of all elements of FES $A$ [28-29]. The vector $X_L(t)$ comes from the set Φ which is the same as MIMO-LLR-PNC. According toAccording to D-S evidence theory, BPA $m_{ij}(A)$ must be normalized to satisfy (13) $\sum_{\forall A\subset\Theta} m(A) = 1$ and is expressed as

$$m_{ij}(A) = R_{ij} f\left(x^{\wedge}_{ij}(t) \middle| \alpha(A)\right), \forall A \subset U \qquad (16)$$

where $R\ ij$ is the normalization coefficient expressed as

$$R_{ij} = 1 \Big/ \sum_{\forall A\subset U} f\left(x^{\wedge}_{ij}(t) \middle| \alpha(A)\right) \qquad (17)$$

Then, Dempster's combination rule is applied to combine the BPA $m_{ij}$ ( A)from each receive antenna to obtain $m_j(A_1)$ for the sum and difference signal, where $A_1$ denotes all the single point FES. Maximum credibility (MC) rule instead of the least point decision (LPD) rule [29-30] is applied to decide the signal estimation $x''(t)$ corresponding to the maximum $m_j(A_1)$

In order to further enhance the performance of estimation, instead of initial estimation, $x_j''(t)$ obtained by MC rule is substituted into (17), then the BPA $m_j(A_1)$ can be obtained again by using (15) and (16). In this paper, we only use once iteration considering complexity problem. Finally, the decision rule for network-coded symbol can be written as

$$x1 \oplus x2 = \begin{cases} 1\left(m1(A1) \geq m2(A1) \& x1'' = 0\right) or\ (m1(A1) < m2(A1) \& x2'' = 2\ or - 2) \\ -1(m1(A1) \geq m2(A1) \& x1'' = 2\ or - 2) or (m1(A1) < m2(A1) \& x2'' = 0) \end{cases}$$

where $m_1(A_1)$ and $m_2(A_1)$ denote the maximum BPA of all single-point FES for the sum signal $x_1$ and difference signal $x_2$ respectively. The value of $x1 \oplus x2$is decided by the maximum of $m_1(A_1)$ and $m_2(A_1)$

### C. *The Fuzzy DS Scheme*

In real classification problems intrinsically vague information often coexist with conditions of 'lack of specificity originating from evidences not strong enough to induce knowledge, but only degrees of belief or credibility regarding class assignments. The problem has been addressed here by proposing a fuzzy Dempster Shafer Model for multi source classification purposes. The salient aspect of the work is the definition of an empirical learning strategy for the generation of fuzzy Dempster shafer classification rules from a set of exemplified training data. DS measures of uncertainty are semantically related to conditions of ambiguity among the data and then automatically set during the learning process. Partial reduced beliefs in class assignments are then induced and explicitly represented when generating classification rules

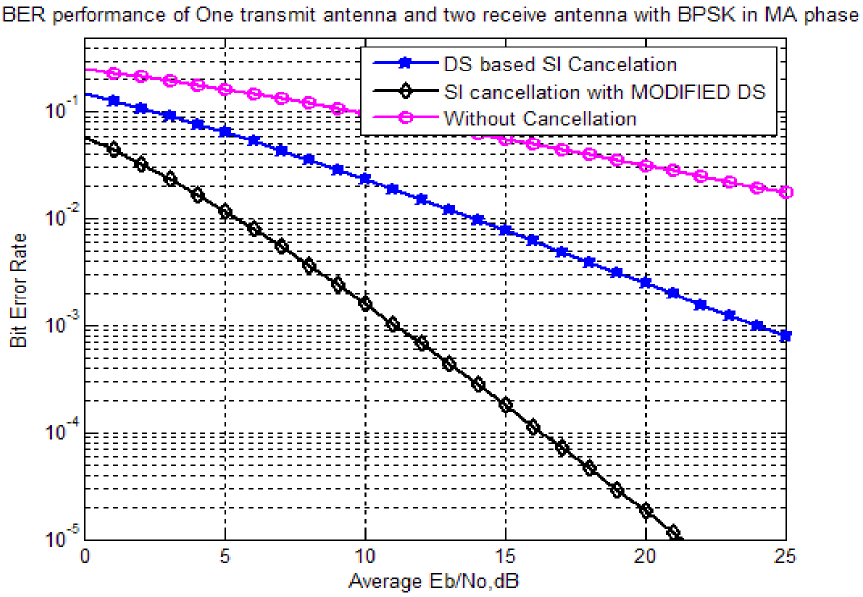
The traditional evidence theory based Dempster shafer theory is based on the normalization of masses which fails when the input sources of evidence are of conflicting nature. The higher the conflict, the more chance is of getting vague answer from dempster shafer theory. The conflct between sources of evidence is indicative of present of unreliable mass value in the DS fusion. This problem can be resolved by fusing only the evidence mass that are reliable. Hence, the mass are to be discounted before being fused by dempster shafer rule. In order to discount the masses there is necessity to find reliability value of source providing the mass value. In our proposed modified DS theory works in following steps:

1) The reliability value of source is obtained from the gaussian distribution
2) The obtained reliability is used to discount the mass value.

3) The discounted mass value is then fused using dempster shafer theory.

$$x1 \oplus x2 = \begin{cases} 1\left(R1m1(A1) \geq R2m2(A1) \& x1' = 0\right) or\ (R1m1(A1) < R2m2(A1) \& x2'' = 2\ or - 2) \\ -1(R1m1(A1) \geq R2m2(A1) \& x1'' = 2\ or - 2) or (R1m1(A1) < R2m2(A1) \& x2'' = 0) \end{cases}$$

## V. SIMULATION RESULTS AND ANALYES



In this section, BER performance of the proposed Fuzzy DS scheme is evaluated in two-way FD MIMO relay system, compared to the DS scheme and Without cncellation scheme. For simplicity, we assume the relay is equipped with two receive antennas and the channels are independently complex Guassian distribution. All the channel state information is available, including the MA, the BC and self-interference channel. The transmit power of each source node and each relay antenna is normalized to 1.In our simulation, whenever in the MA phase or BC phase, SNR is defined as $P/\sigma^2$, denoting the the ratio of the received signal power $P$ to the noise power at each receive antenna. The signal-to-interference ratio (SIR) at relay is set to three decibels(dB). In order to achieve better BER performance for space-domain filter schemes, maximum likelihood(ML) detection is adopted after suppressing the SI in simulation

Firstly, for the relay equipped with one transmit antenna, BER performances of the proposed DS-SAD-PNC and the Fuzzy DS-SAD-PNC are illustrated in Fig. 2 for the MA phase. As shown in figure, the proposed Fuzzy DS-SADPNC scheme is better than the extended DS-SAD-PNC schemes.

In Fig. 3, end-to-end average BER performances of these schemes are compared with each other. As shown in Fig. 3,similar conclusions can be obtained as shown in Fig. 2. However, the end-to-end average BER performance is decided by the worst link in two-way relay. The end-to-end average performances of these schemes have some losses compared with the performances in the MA phase. The Fuzzy DS-SAD-PNC scheme also obtains better performance about 1 *dB* at BER of 10−2 compared with the DS-SAD-PNC

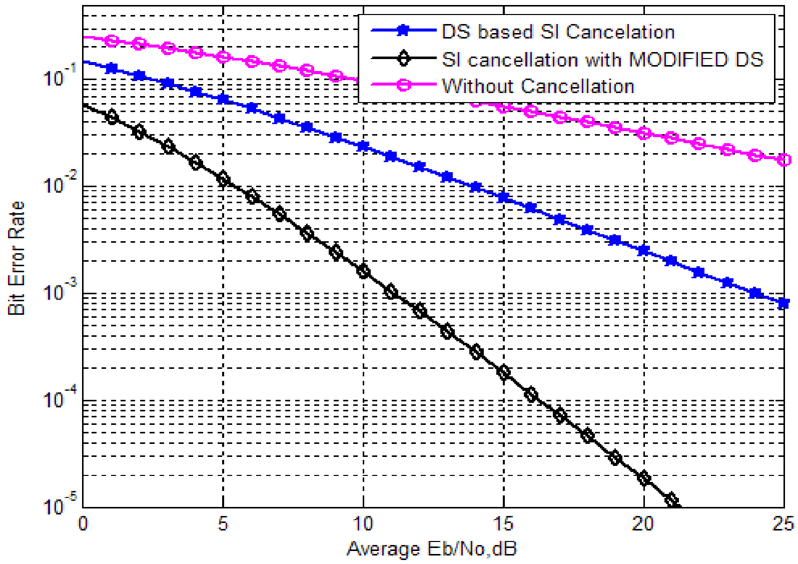


Figure 3. End-to-end average BER performance with relay equipped with one transmit antenna and two receive antennas for BPSK modulation.

## VI. CONCLUSION

In this paper, a novel SI suppression scheme called DSSAD- PNC was proposed in two-way FD MIMO relay system. Different from traditional spatial-domain schemes like ZF and MMSE filter, DS-SAD-PNC adopted D-S theory to detect the sum and difference signal of two source nodes and obtained the network-coded symbol directly with SI cancellation considered in BPA computation. Moreover, MIMO-LLR-PNC was extended in FD mode considering SI suppression in soft information computation for network-coded symbol. Simulation results showed that the proposed DS-SAD-PNC scheme obtained better end-to-end average BER performance compared with the extended MIMO-LLR-PNC and ZF/MMSE filter schemes with a little complexity increased.

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