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A Robust Network Coding Scheme over Two Way Relay Channel

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Abstract: In this paper, a new approach is proposed to improve the performance of the original network coding scheme over two way relay channel (TWRC) in asymmetric network topology conditions. It is shown that although the original network coding technique over TWRC provides good performance in symmetric conditions, where the reliability of the received data at the relay from all source nodes are similar, its performance asymmetric conditions especially when only one of the indirect links is in good condition considerably degrades due to the combining of data with different reliabilities at the relay encoder. The proposed scheme is based on the signalling of a quality measure per source from the relay to each node. The signalled quality measures will be used at each node to clip the bit reliabilities obtained from indirect route prior to their combining with information received via direct route. This new scheme is very flexible and can be employed with any modulation configurations at source and relay nodes. It is shown that the proposed scheme achieves more diversity as well as improves the overall system spectrum efficiency. Simulation results indicate that our new scheme significantly outperforms original ones under static fading channel condition. The performance of this new scheme is also compared with a selective network coding protocol.

Keywords: Network Coding, Relaying, Two Way Relay Channel, Bit Reliabilities.

1. Introduction

The performance of wireless communication will be improved significantly as well as diversity and system robustness by utilizing cooperation between nodes distributed in space especially when direct link between involved nodes fails to provide reliable connection [1]-[3]. Most of the cooperative relaying schemes have been proposed for one way relay channel (OWRC) scenario [1]-[4], where a single source node transmits data to a single destination node with the help of some relay nodes. As an example in Decode and Forward (DF) scheme, the relay node fully decodes the received signal and encodes it appropriately before forwarding to the destination node.

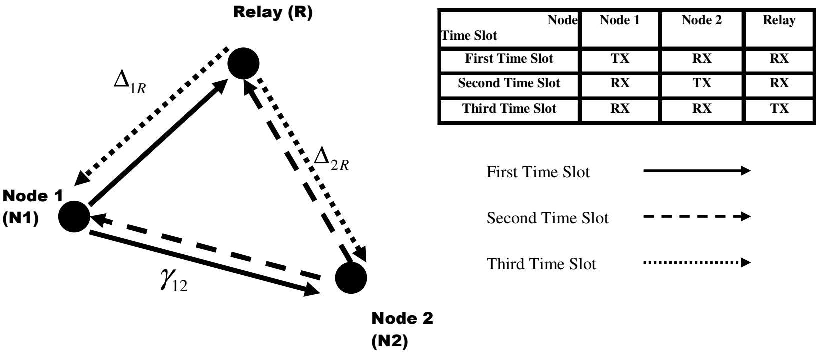
In bidirectional scenarios, when two nodes communicate to each other through the help of a relay as in OWRC, the relay forwarding action toward first and second nodes are carried out in different time slots or frequency bands. A much more efficient approach, which is to allow simultaneous forwarding (same time slot and frequency band) of both messages, has been proposed in [5]-[6]. This approach employs network coding technique to combine different traffics data at the relay node and enables each node to extract its desire message out of the signal broadcasted by the relay. As a result, overall reliability and achievable throughput of all possible communications across the network are improved [7]-[8].

The network coding scheme over TWRC can be applied to many wireless communication scenarios including cellular networks, wireless mesh networks and personal area networks. Several aspects of these networks have considerable effect on the performance of TWRC system including the network topology in terms of the position of the nodes and instantaneous signal to noise ratios (SNR) between involved nodes and the relay. In symmetric cases, the original network coding scheme can improve all communications and their respective throughputs. However, in asymmetric conditions, combing data by using network coding at the relay could not help the iterative joint network and channel decoder, and it may even corrupt final decoding performance because erroneous data could be forwarded by the relay. In this paper we propose an approach to improve the performance of the original network coding scheme in these conditions. The proposed scheme does not require full soft processing at the relay node and rely only on some quality measures to be signalled from relay to other nodes. The adopted measures can be effectively utilised at each node receiver to perform proper combination of the information received through direct and indirect routes. This enhanced network coded scheme is called CNC where the letter ‘C’ stands for clipping, i.e., in our scheme the reliability of the received signal from the relay signal is clipped. Here, the performance of this scheme will be compared with original network coding scheme and also a selective network coding (SNC) protocol.

The remainder of this paper is organised as follows. Section 2 describes the system model for TWRC, exploiting network coding in wireless cooperation and structure of the joint network and channel decoder. Section 3 discusses in detail the proposed CNC scheme over TWRC system. Section 4 describes SNC protocol over TWRC system. Then, the performance of the proposed CNC scheme will be compared with the original non-selective and also with the SNC scheme in Section 5. Finally, concluding remarks are provided in Section 6.

2. System Model

A simple TDD/TDMA TWRC scenario with two source nodes and only one relay has been considered in the following sections (Figure 1). It is assumed that nodes transmission/reception is based on a simple protocol composed of three time slots. The first Node (N1) transmits its message to the second node (N2) and the relay (R) in the channel time slot 1 (solid line), then N2 sends its message to N1 and R during the channel time slot 2 (dashed line). R combines the received information of N1 and N2 through a network encoder and sends back to N1 and N2 in the channel time slot 3 (doted line). As it is seen, instead of allocating two separate time slots for communications from R to N1 and R to N2, only one time slot is used. The channel time slots 1, 2 and 3 are assumed to be orthogonal in time in order to avoid any interference. The transmit (TX) and receive (RX) status of each of the involved nodes have been tabularised in Figure 1.

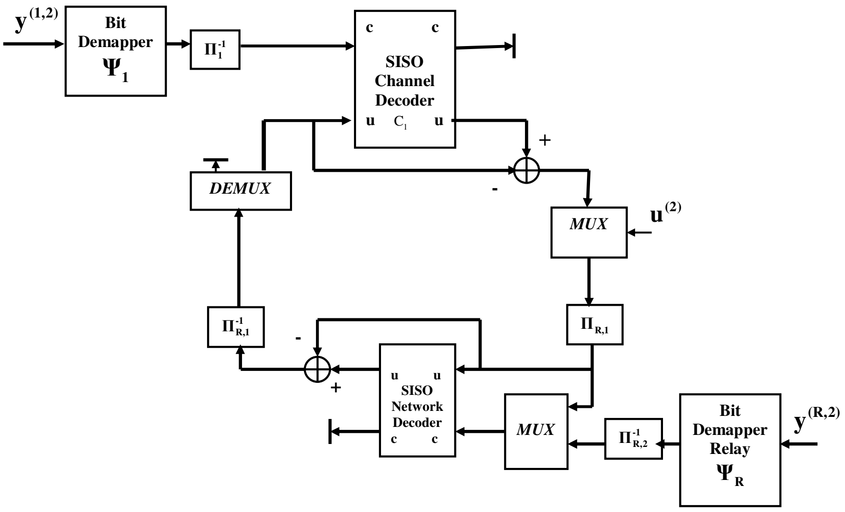


Node Time Slot	Node 1	Node 2	Relay
First Time Slot	TX	RX	RX
Second Time Slot	RX	TX	RX
Third Time Slot	RX	RX	TX

Figure 1: Basic Two Way Relay Channel Model

Let us assume that N1 sends a bit sequence $\mathbf{u}^{(1)}$ to N2 and also that N2 sends a bit sequence $\mathbf{u}^{(2)}$ to N1. The bit sequences $\mathbf{u}^{(1)}$ and $\mathbf{u}^{(2)}$ are encoded separately in their relevant nodes with the channel codes C_1 and C_2 which result in coded sequences $\mathbf{c}^{(1)} = C_1(\mathbf{u}^{(1)})$ and $\mathbf{c}^{(2)} = C_2(\mathbf{u}^{(2)})$ respectively. Then these coded sequences are appropriately interleaved, modulated and transmitted to other nodes during allocated timeslots. Each modulated component belongs to the finite signal alphabet $\Psi_1 \subset \mathbb{C}$ and $\Psi_2 \subset \mathbb{C}$ for N1 and N2 respectively (where $\mathbb{C}$ represents the complex plane). During the first and second time slots R receives signal sequences $\mathbf{y}^{(\mathbf{1,R})}$ and $\mathbf{y}^{(\mathbf{2,R})}$ from N1 and N2 through the equivalent vector channels with probabilities $p(\mathbf{y}^{(\mathbf{1,R})} \mid C_1(\mathbf{u}^{(1)}))$ and $p(\mathbf{y}^{(\mathbf{2,R})} \mid C_2(\mathbf{u}^{(2)}))$ respectively. Then R decodes the received signals $\mathbf{y}^{(\mathbf{1,R})}$ and $\mathbf{y}^{(\mathbf{2,R})}$ separately which result in decoded bit sequences: $\hat{\mathbf{u}}^{(\mathbf{1,R})}$ and $\hat{\mathbf{u}}^{(\mathbf{2,R})}$. It is assumed that $\hat{\mathbf{u}}^{(\mathbf{1,R})}$ and $\hat{\mathbf{u}}^{(\mathbf{2,R})}$ sequences contain only hard bit values: zero or one. Node R employs network coding to generate $\mathbf{c}^{(\mathbf{R})} = NC(\hat{\mathbf{u}}^{(1,R)}, \hat{\mathbf{u}}^{(2,R)})$ from $\hat{\mathbf{u}}^{(\mathbf{1,R})}$ and $\hat{\mathbf{u}}^{(\mathbf{2,R})}$. Then R broadcasts $\mathbf{c}^{(\mathbf{R})}$ towards N1 and N2 after doing appropriate interleaving and modulation with finite signal alphabet $\Psi_R \subset \mathbb{C}$. Recall that Ψ_1, Ψ_2 and Ψ_R are not necessarily identical. These signal alphabets ($\Psi_j, j = 1, 2, R$) have associated one-to-one binary labelling maps $\mu_j : \{0,1\}^{m_j} \to \mathrm{X}_j$ where $m_j = \log_2 |\Psi_j|$. The symbol constellations Ψ_1, Ψ_2 and Ψ_R are subject to power constraints related to N1, N2 and R. Frequency-flat fading single-input single-output channels are assumed between any pair of transmitting-receiving nodes. All receivers at R, N1 and N2 are assumed to have perfect channel knowledge on their corresponding connected channels. No channel knowledge is assumed to be available at corresponding transmitters.

Applying joint design of channel codes C_1, C_2 and network code NC in the form of a distributed turbo channel-network code, the induced redundancy of the coded data will be used to achieve required error correction level as well as to improve the data extraction capability. As N1 and N2 both have knowledge on their own transmitted data $\mathbf{u}^{(1)}$ and $\mathbf{u}^{(2)}$, their receivers will be able to extract the data that they like to receive. This will be realised through an appropriately modified iterative turbo receiver architecture. In this turbo structure, measured bit reliabilities obtained from de-modulation of received signals are fed to the soft input channel and network decoders as it is shown in Figure 2 for the receiver of



(a)

Figure 2: General structure of the iterative joint channel and network decoder of the node 2 (N2)

node N2. In this figure letters u and c at the encoder blocks are related to uncoded bits and coded bits respectively.

N2 receiver performs joint iterative network and channel decoding in order to extract $\tilde{\mathbf{u}}^{(1)}$ from the direct signal $\mathbf{y}^{(1,2)}$ and the relayed signal $\mathbf{y}^{(\mathbf{R},2)}$ received through the equivalent vector channels $p(\mathbf{y}^{(1,2)} \mid C_1(\mathbf{u}^{(1)}))$ and $p(\mathbf{y}^{(\mathbf{R},2)} \mid NC(\hat{\mathbf{u}}^{(1)}, \hat{\mathbf{u}}^{(2)}))$, respectively. Recall that N2 has full knowledge about its own data ($\mathbf{u}^{(2)}$). Similar process is done at N1 receiver. As a result, estimated data at N2 is $\tilde{\mathbf{u}}^{(1)} = f(\mathbf{y}^{(1,2)}, \mathbf{y}^{(\mathbf{R},2)}, \mathbf{u}^{(2)})$ and at N1 is $\tilde{\mathbf{u}}^{(2)} = f(\mathbf{y}^{(2,1)}, \mathbf{y}^{(\mathbf{R},1)}, \mathbf{u}^{(1)})$, Where $f(.)$ represents the iterative channel and network decoding process .

3. Network Coding with Clipping Relay Reliability (CNC)

In order to explain our proposed enhanced scheme, an equivalent binary symmetric channel (BSC) model of the above system (section 2) is adopted as it is shown in Figure 3. Here the link including all the modules from the encoder of N1 to the channel decoder of R has been modelled as a BSC i.e. $BSC(q_1)$ with the bit error probability q_1. Similarly the link between N2 and R has been modelled as $BSC(q_2)$ with bit error probability q_2. A common measure for the bit reliability is log-likelihood ratio (LLR). Therefore the reliability of each BSC channel is $l_{q,j} = \log((1-q_j)/q_j), j = 1,2$.

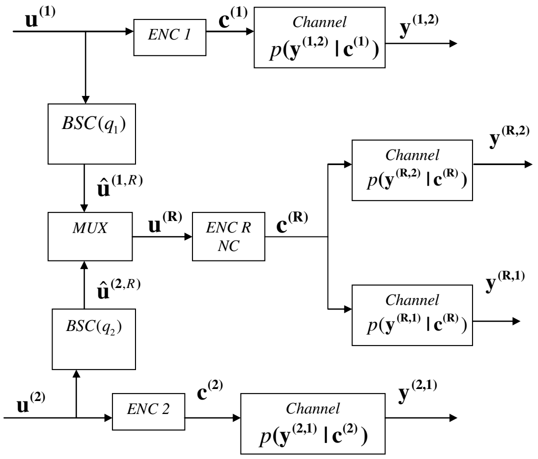


Figure 3 : an equivalent BSC model of the basic TWRC system

As it is seen from the equivalent BSC model, the decoded sequences $\hat{\mathbf{u}}^{(1,\mathbf{R})}$ and $\hat{\mathbf{u}}^{(2,\mathbf{R})}$ are not perfectly reliable. The reliability values $l_{q,1}$ and $l_{q,2}$ are associated to them. Hence, the sequence $\mathbf{c}^{(\mathbf{R})}$ is not perfectly reliable. Since this sequence is forwarded through vector channels $p(\mathbf{y}^{(\mathbf{R},1)} \mid \mathbf{c}^{(\mathbf{R})})$ and $p(\mathbf{y}^{(\mathbf{R},2)} \mid \mathbf{c}^{(\mathbf{R})})$ to N1 and N2, respectively, bit reliabilities of this sequence calculated at N1 or N2 receiver depend on the quality of these channels. Let us assume an asymmetric condition such that the quality of the channel between N2 and R is far better than the quality of the channel between N1 and R. Therefore, the bit reliabilities of the sequence $\hat{\mathbf{u}}^{(1,\mathbf{R})}$ are very low, whereas the bit reliabilities of the sequence $\hat{\mathbf{u}}^{(2,\mathbf{R})}$ are very high. The network-coded sequence $\mathbf{c}^{(\mathbf{R})}$ is transmitted through the good quality vector channel $p(\mathbf{y}^{(\mathbf{R},2)} \mid \mathbf{c}^{(\mathbf{R})})$ to N2. As a result, the bit reliabilities related to $\hat{\mathbf{u}}^{(1,\mathbf{R})}$ part of the network coded signal calculated at N2 receiver will be much higher than bit reliabilities of

$\hat{\mathbf{u}}^{(1,\mathbf{R})}$ calculated at R. Moreover, the performance of the joint iterative channel-network decoder at N2 will be highly degraded since it relies on these unrealistic high reliability values. It can be concluded that the soft values calculated at N2 based on the error free data assumption at R should be clipped with $\pm l_{q,1}$ levels and similarly at N1 receiver with $\pm l_{q,2}$ levels.

Our clipping function over input argument λ (LLR value) with levels $\pm l_{q,j}$ is defined as follows:

$$clip(\lambda, l_{q,j}) \triangleq \begin{cases} l_{q,j} & l_{q,j} \leq \lambda \\ \lambda & -l_{q,j} \leq \lambda \leq l_{q,j} \\ -l_{q,j} & \lambda \leq -l_{q,j} \end{cases} . \tag{2}$$

Figure 4 shows the new structure of the detector for N2 receiver. The extrinsic information (LLRs) after soft-input soft-output (SISO) channel decoder and also after SISO network-decoder are clipped with $\pm l_{q,1}$ levels. Prior to use the proposed CNC scheme, R has to estimate $l_{q,1}$ and $l_{q,2}$ and then signal them back to N1 and N2. The signalling rate depends on the channel variation and at most they need to be signalled every transmitted frame. In order to calculate the reliability levels, we utilise the technique that we have proposed in [9] to estimate the error rate of the bits decoded at R . In [9], BER of decoded bits has been estimated from LLR values by using Gaussian approximation model and by assuming that the relay decoder is able to provide soft-decoded values.

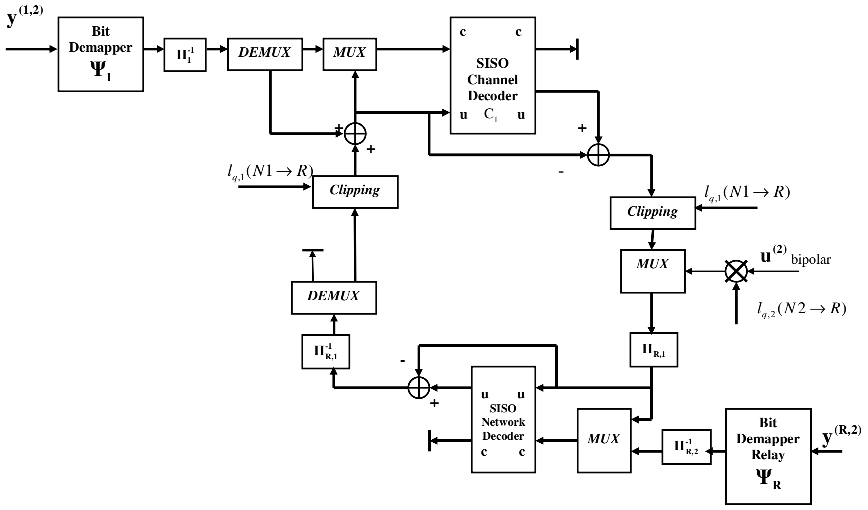


Figure 4 New structure of the iterative joint channel and network decoder of node 2 (N2)

As it has been seen in Section 2 and especially in Figure 2, N2 joint detector has knowledge of its own transmitted data and uses this knowledge with infinite bit reliability to extract the data that it likes to receive from N1. By considering above equivalent BSC channel model, the own data of N2 also need to be clipped before they are utilised in the iterative joint detector of the new structure. As indicated in Figure 4 for N2 receiver, the bipolar version of the sequence $\mathbf{u}^{(2)}$ should be multiplied with $l_{q,2}$ level. A similar clipping method needs to be done at N1 decoder.

4. Selective Network Coding Protocol

In this paper, we also compare the performance of our proposed CNC scheme with a selective network coding (SNC) protocol. In this protocol, R decides whether or not to be involved in cooperation for one or both pairs of nodes based upon its received signal condition from those nodes. It applies network coding when it receives the data from both nodes successfully. As an example, the reliability condition of the data at R can be checked separately by using cyclic redundancy check (CRC) over $\hat{\mathbf{u}}^{(1)}$ and $\hat{\mathbf{u}}^{(2)}$. Following four actions can be taken at R based on this CRC status.

Action 1: If both CRC of the decoded data $\hat{\mathbf{u}}^{(1)}$ and $\hat{\mathbf{u}}^{(2)}$ shows failure then R will transmit nothing. The decoding is done at N1 and N2 based on the directly received sequences.

Action 2: If only CRC of the decoded data from N2 succeeds, then R will encode only $\hat{\mathbf{u}}^{(2)}$ through the relay channel code C_3 and forward it to N1. At the receiver of N1, the distributed turbo decoding is done on the directly received and the relayed sequences. At the receiver of N2 the decoding is done on the directly received sequence.

Action 3: If only CRC of the decoded data from N2 fails, then the R will encode only $\hat{\mathbf{u}}^{(1)}$ through the channel code C_3 and forward it toward N2. The final decoding is similar to action 2.

Action 4: If both CRC checks of the decoded data $\hat{\mathbf{u}}^{(1)}$ and $\hat{\mathbf{u}}^{(2)}$ succeed then R will encode the decoded data from N1 and N2 by using the network code and forward it toward both N1 and N2. The iterative joint network and channel decoding is done at N1 and N2 as described in Section 2.

5. Performance Comparison

In this section BER performance of our CNC scheme is compared with the performance of the original network coding scheme as well as the SNC scheme over TWRC. The performance of the proposed scheme has been studied in many different SNR scenarios. Here, we consider a two way communication scenario including two main nodes (N1 and N2) and one relay node (R), as described in Section 2. At nodes N1 and N2, the information bit sequences are encoded with a 1/2 rate systematic recursive convolutional code with generator polynomial (13, 15) in octal representation. Then the coded bits are interleaved, QPSK modulated and transmitted to other nodes. At R the hard decoding of data from both nodes is done separately. It employs the same convolutional code to generate the network coded data from the hard decoded sequences following an appropriate interleaving. Then, only the parity bits part of the network coded sequence are interleaved and modulated with QPSK constellation and sent back to N1 and N2. When decoding and forward (DF) need to be done, the decoded bits from the desire node are encoded with the same convolutional code and then coded bits are interleaved, QPSK modulated and transmitted to another node. The number of iterations needed for the iterative joint network and channel decoding has been set to ten. Before adding white Gaussian noise (AWGN) to each received signal, one tap complex static single-input single-output Rayleigh fading channel coefficients are multiplied with the transmitted signals. It is assumed that the channel coefficients of the three links are independently generated and are constant during each time slot.

In the following, we compare the performance of communication from N1 to N2 for CNC, SNC and non selective schemes. In Figure 5 and Figure 6, the average SNR for the N1-N2 link (direct link) has been represented by γ_{12}, the SNR offset of the N1-R link compared to the direct link by Δ_{1R} and the SNR offset of the N2-R link compared to the direct link by Δ_{2R}. The SNR offset Δ_{2R} has been set to 5dB in all cases and Δ_{1R} is variable from -5 dB to 5 dB. As a result, the quality of N2-R link is far better than the one of the two other links. The BER performance curves of the CNC and the original network coding schemes have been distinguished by CNC and NC, respectively, in the legend of Figure 5 and Figure 6. When Δ_{1R} is -5 dB, the quality of N1-R link is lower than the direct link. As a result the network coding produces non reliable data by combining the high reliable data received from N2 with the non reliable data from N1. This non reliable network coded data is sent to N2 through a very good quality link (recall that $\Delta_{2R} = 5dB$). As it is seen in Figure 5 the BER performance of the original scheme (NC) is worse than the performance of the direct link. This corruption in the performance of the network coding scheme can be avoided by using our CNC scheme. It is observed that for $\Delta_{1R} = -5dB$, the BER performance of the CNC scheme is both much better than the direct link BER and the original non selective network coding performances.

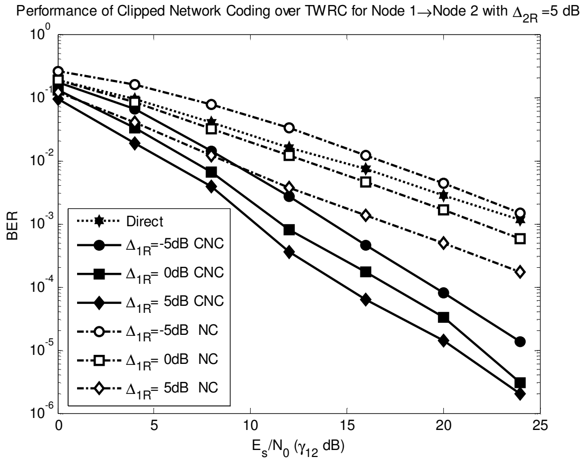


Figure 5 BER performance of CNC over TWRC (N1 to N2 cooperative transmissions) versus direct link SNR (γ_{12})

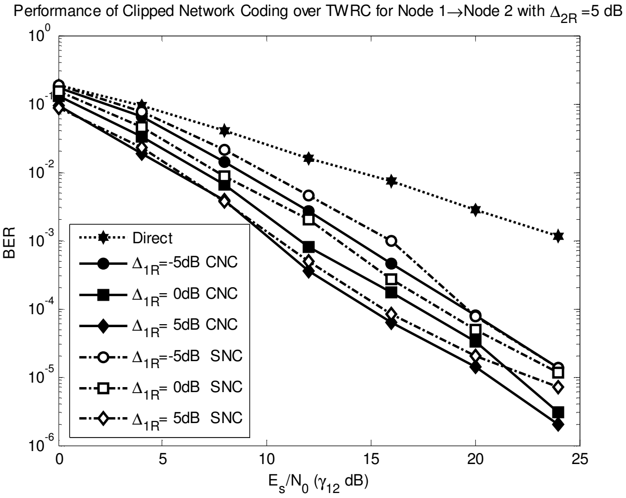


Figure 6 BER performance of CNC and SNC over TWRC system (N1 to N2 cooperative transmissions) versus direct link SNR (γ_{12})

As depicted in both figures, BER performance of the NC scheme gets better than the direct link when Δ_{1R} increases. However, this enhancement is much higher when using our new clipping scheme (CNC). By increasing Δ_{1R}, more improvement is seen on the performance of the CNC scheme. The BER performance of the cooperative transmission from N2 to N1 exhibits a similar trend, but with even a better improvement. Figure 6 compares performance of CNC scheme with SNC scheme. It is observed that the performance of both schemes is much better than original ones. However, in most of the cases, our CNC scheme shows better performance compared with the selective scheme. The performance of CNC schemes in fast fading condition shows a similar trend of improvement compared to the original schemes, but with a smaller achievable gain.

6. Conclusion

We show in this paper that in asymmetric conditions especially when only one of the indirect routes is in a good condition, the original network coding technique over TWRC suffers in performance due to the combining of data with different reliability at the relay. In this paper a new approach, overcoming this problem, i.e. CNC, has been proposed to enhance the original network coding scheme. This approach is based on signalling some quality parameters from the relay back to source nodes. The new structure of joint channel-network decoder for CNC scheme has been provided in section 3. This approach is applicable for any combinations of constellations employed at the source and relay nodes and thus provides a better spectrum efficiency by proper selection of constellations for all three phases (time slots) transmissions. Considerable performance gains are observed in static fading condition.

Acknowledgement

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