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Performance Evaluation of Adaptive LDPC Coded Modulation Cooperative Wireless Communication System with Best-Relay Selection

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ABSTRACT

In this paper the performance of a cooperative wireless communication system based on combined best relay selection (BRS) and adaptive LDPC coded modulation (ACM) scheme is investigated. These investigations are focused on evaluating the performance of the proposed cooperative wireless communication system over independent non-identical Rayleigh fading channels in terms of bit-error rate (BER) using MATLAB® computer simulations and comparing the system performance with ACM direct transmission and ACM cooperative with single relay. The simulations results show that the proposed cooperative scheme achieves lower signal-to-noise ratio (SNR) values for desired bit-error rate (BER) and high spectral efficiency as compared to ACM direct transmission and ACM cooperative with single relay.

KEYWORDS

Cooperative communication, LDPC, ACM, best-relay selection, single relay cooperative, Rayleigh fading

I. INTRODUCTION

Transmission over wireless channels suffers from random fluctuations in signal level known as fading and from co-channel interference [1]. Diversity is a powerful technique to mitigate fading and improve robustness to interference. In classical diversity techniques, the data signal is conveyed to the receiver over multiple (ideally) independently fading signal paths (in time/frequency/space) [2]. Appropriate combining at the receiver realizes diversity gain, thereby improving link reliability. There are several approaches to implement diversity in a wireless transmission. Multiple antennas can be used to achieve diversity. But multiple antennas are not always available or the destination is just too far away to get good signal quality. Recently, cooperative communications for wireless networks have gained much interest due to its ability to mitigate fading in wireless networks through achieving spatial diversity, while resolving the difficulties of installing multiple antennas on small communication terminals. The basic idea in cooperative communication is that in addition to the direct transmission from the transmitter to the receiver, there can be other nodes, which can be used to enhance the diversity by relaying the source signal to its destination, hence forming a virtual multiple-input multiple-output (MIMO) system. In a cooperative communication system, users act as information sources as well as relays. There are two main cooperative methods: amplify-and-forward (AAF) (non-regenerative relays) and decode-and-forward (DAF) (regenerative relays) methods. In the AAF method, the relay receives a noisy version of the signal transmitted by the source and then amplifies its received signal and re-transmits it to the destination [3]. In the DAF method, the relay decodes the noisy version of the signal transmitted by the source and then re-encodes and re-transmits it to the destination.

In cooperative networks with multiple relays, cooperative diversity protocols can be generally categorized into fixed and adaptive relaying protocols. Relay selection is attractive because of its high performance, efficient use of power and bandwidth resources, and simplicity [4]. The best-relay selection scheme for cooperative networks has been introduced in [5] and they called it opportunistic relaying. According to opportunistic relaying, a single relay among a set of *N* relay nodes is selected, depending on which relay provides for the "best" end-to-end path between source and destination. The authors in [5] showed that this scheme has the same diversity order as the cooperative diversity using space-time-coding [6] in terms of the outage probability for both decode-and-forward and amplify-and-forward schemes. However, this important result was given using semi-analytical asymptotic analysis at high SNR only (without deriving a closed-form expression for the outage probability).Many different schemes for single relay selection have been proposed in [5], [7]–[9].

The authors in [10] analyzed the adaptive DAF relaying technique where among N relays that can participate, only k relays ($k < N$), with good channels to the source decode and forward (retransmit) the source information to the destination. The authors in [10] proved that increasing the number of potentially participating relays, N, does not always decrease the outage probability. To improve the outage probability performance, the authors in [11] suggested that only the best relay among the decoding group, *Đ* will send another copy of the source signal to the destination. Hence, the total number of channel (or time slots) needed is reduced from $k+1$ to two only. For this proposed scheme, the authors in [11] derived the high-SNR outage probability approximation and they showed that it outperforms distributed space-time codes for networks with more than three relaying nodes. The authors in [12] presented a performance analysis for the AAF cooperative communications with relay selection and derived a closed-form expressions for the average SER performance for BPSK, M-PSK, and M-QAM signals, also derived a closed-form expression for the outage probability, and an analytical expression for the average end to- end SNR gain obtained from relay selection. The authors in [13] evaluated the performance of coded modulation scheme based on LDPC codes considered direct transmission over additive white Gaussian noise (AWGN) and flat Rayleigh fading channels. The authors in [13] presented a simple adaptive LDPC-coded modulation scheme for direct transmission over flat slowly-varying Rayleigh fading channels. In this scheme, six combinations of encoding and modulation pairs are employed for frame by frame adaptation and the spectral efficiency varies between 0.5 and 5.0 bits/symbol/Hz during data transmission. Their Simulation results show the power and spectral efficiency of coded modulation scheme based on LDPC codes, also their results show that the adaptive LDPC-coded modulation has the benefit of offering better spectral efficiency while maintaining an acceptable error performance.

The authors in [14] proposed an energy efficient cooperative MIMO technique where LDPC code is used as an error correcting code. Their simulations results show that the cooperative scheme outperform SISO scheme in the presence of LDPC code.

In this paper, we propose a cooperative wireless communication system based on combined best relay selection and adaptive LDPC coded modulation (ACM) scheme. Our investigations are focused on studying the performance of the proposed system over independent non-identical Rayleigh fading channels. The main objective of this scheme is to achieve higher spectral efficiency while guaranteeing the same diversity order as that of the conventional cooperative scheme.

To improve spectral efficiency, we introduced adaptive LDPC coded modulation (ACM) at source node which provides multiple coded modulation transmission schemes (CMSs), where each scheme is specified by one of the *M*-ary quadrature amplitude modulation (M-QAM) and LDPC code pair. The source node selects a CMS for transmission and adapt the transmit power on frame-by-frame basis based on the instantaneous signal-to-noise (SNR) between the source and the best selected relay and SNR adaption thresholds, respectively. To contrast the performance of the proposed cooperative communication system we compare its performance with ACM-direct transmission and ACM-cooperative system with single relay. We have employed MATLAB® to write a computer program designed for simulation of the proposed cooperative system to allow various parameters of the system to be varied and tested.

The rest of this paper is organized as follows. In section II, we introduce a system model of the proposed cooperative wireless communication system includes multi-node relay-selection cooperative diversity model with adaptive LDPC coded modulation transceiver structure. In section III, the best relay selection scheme and adaptive LDPC coded modulation (ACM) are introduced. In section IV, error control codes (ECC) and low-density parity-check codes (LDPC) are introduced. The simulation model and MATLAB® simulation results of the proposed cooperative wireless communication system is presented in Section V, followed by conclusions in Section VI.

II. SYSTEM MODEL

We consider a wireless communication system as shown in Figure 1, with one source node (*S*), one destination node (*D*), and *N* half duplex relay nodes R_1, R_2, ……, R_N which are randomly distributed between source and destination. Let $h_{S,D}$, h_{S,R_i} and $h_{R_i,D}$, *i=1,2,…,N* denote The *S-D*, *S*-R_i and R_i-*D* channel coefficients, respectively. We assume that the channel coefficients $h_{S,D}$, h_{S,R_i} and $h_{R_i,D}$ are mutually independent zero-mean, complex Gaussian random variables (flat Rayleigh fading) with variances $\delta^2_{S,D}$, δ^2_{S,R_i} and $\delta^2_{R_i,D}$ respectively. The additive white Gaussian noise (AWGN) terms of all links are modeled as zero-mean complex Gaussian random variables with variance N_0 .We will assume a special case where the source and relay nodes transmit with equal power P.

Assuming that the relay nodes use in-band half duplex relaying, where the relaying is done over two time slots, in the 1st time slot the source node transmits the data to both the destination node and a set of N-relay nodes. The received signals $y_{S,D}$ and y_{S,R_i} at the destination and the relay, respectively, can be written as

$$y_{S,D} = \sqrt{p}\, h_{S,D}\; x + n_{S,D} \tag{1}$$

$$y_{S,R_i} = \sqrt{p}\, h_{S,R_i}\, x + n_{S,R_i} \tag{2}$$

where *p* is the transmitted power at the source, *x* is the transmitted information symbol, $n_{S,D}$, and n_{S,R_i} are additive noise at the receiving nodes.

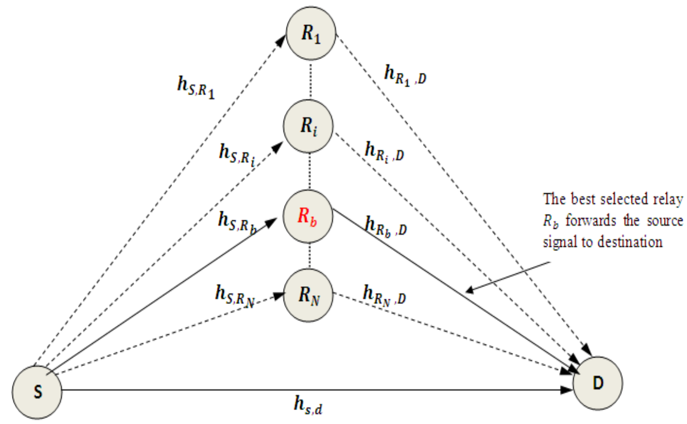

Figure 1. Multi-node cooperative communication system with best relay selection

In a cooperative diversity scheme, if the signal-to-noise ratio of a signal received at any relay of the N-relay nodes exceeds a certain threshold, the relay decodes the received signal and has the ability to forward the decoded information to the destination node. On the other hand, if the channel between the source and the relay suffers a severe fading such that the signal-to-noise ratio falls below the threshold, the relay remains idle. All relay nodes which has the ability to fully decode the source data will belong to a decoding group Đ In the 2nd time slot, the best selected relay from the decoding group *Đ* re-encodes and retransmits the source data to the destination. At the destination node the signals of the direct link and the best cooperative link can be combined using appropriate combing technique i.e., MRC technique [15, 16]. The received signal at the destination from the best selected relay, can be written as

$$y_{R_b,D} = Q\,(y_{S,R_b})\, h_{R_b,D} + n_{R_b,D} \tag{3}$$

where the function Q (·) denotes the ACM cooperative protocol implemented at the selected best relay node[17,18], R_b , $h_{R_b,D}$ is the channel coefficient from the selected best relay to destination and $n_{R_b,D}$ is an additive noise.

Since our proposed cooperative wireless communication system based on combine best relay selection and ACM scheme, Figure 2 shows

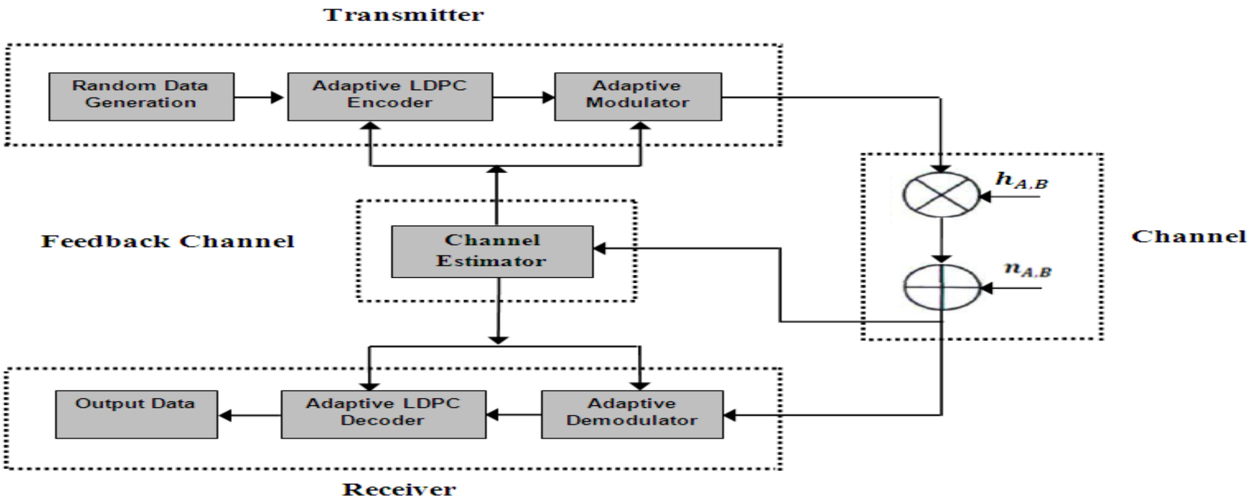

Figure 2. Transceiver structure with adaptive LDPC coded modulation at source node

a simplified block diagram of ACM transceiver structure [13], Where $h_{A,B}$ and $n_{A,B}$ is the channel coefficient and the additive white Gaussian noise (AWGN) of a link from A to B, the terms A and B can be either source (S) and destination (D) or source (S) and Relay (R_i).

III. BEST RELAY SELECTION AND ADAPTIVE LDPC CODED MODULATION (ACM)

In best relay selection (BRS) scheme, a single relay among a set of N available relay nodes is selected depending on which relay provides for the "best" end-to-end path between source and destination. Let $\gamma_{h_{S,D}} \triangleq |h_{S,D}|^2 \frac{E_s}{N_0}$ is the instantaneous SNR between the source and destination, $\gamma_{h_{S,R_i}} \triangleq |h_{S,R_i}|^2 \frac{E_s}{N_0}$ is the instantaneous SNR between the source and relay R_i and $\gamma_{h_{R_i,D}} \triangleq |h_{R_i,D}|^2 \frac{E_s}{N_0}$ is the instantaneous SNR between relay R_i and destination. $\gamma_{h_{S,D}}, \gamma_{h_{S,R_i}}$, and $\gamma_{h_{R_i,D}}$ are exponentially distributed with parameters $1/\bar{\gamma}_{h_{S,D}}$, $1/\bar{\gamma}_{h_{S,R_i}}$, and $1/\bar{\gamma}_{h_{R_i,D}}$, respectively, where $\bar{\gamma}_{h_{S,D}} \triangleq E[\gamma_{h_{S,D}}] \triangleq \delta^2_{S,D} \frac{E_s}{N_0}$, $\bar{\gamma}_{h_{S,R_i}} \triangleq E\left[\gamma_{h_{S,R_i}}\right] \triangleq \delta^2_{S,R_i} \frac{E_s}{N_0}$, and $\bar{\gamma}_{h_{R_i,D}} \triangleq E\left[\gamma_{h_{R_i,D}}\right] \triangleq \delta^2_{R_i,D} \frac{E_s}{N_0}$, and E [•] denotes expectation[19].

We assume that the channel state information (CSI) are available at the source and relay nodes. For a given required spectral efficiency $\bar{\eta}$ the decoding group $Đ$ is given by

$$Đ = \left\{k \in N, \left|h_{S,R_k}\right|^2 \geq \bar{\eta}, k < N\right\} \quad (4)$$

Where $\bar{\eta}$ is given by

$$\bar{\eta} \triangleq \frac{2^{2\eta}-1}{E_s/N_0}.$$

The relay selection algorithm selects the best relay R_b from the decoding group $Đ$ such that [20]

$$b \triangleq argmax_{i=1,2,\ldots,N}\, min\left\{\gamma_{h_{S,R_i}}, \gamma_{h_{R_i,D}}\right\}. \quad (5)$$

The mutual information of the proposed cooperative wireless communication system with combined BRS and AMC is given by [21]

$$I_{BRS} = \begin{cases} \frac{1}{2}\log\left(1+2\frac{E_s}{N_0}\left|h_{S,D}\right|^2\right), & \left|h_{S,D}\right|^2 \geq \eta_D \,\&\, \left|h_{S,R_i}\right|^2 < \bar{\eta} \\ \frac{1}{2}\log\left(1+\frac{E_s}{N_0}\left|h_{R_b,D}\right|^2\right), & \left|h_{S,D}\right|^2 < \eta_D \,\&\, \left|h_{S,R_i}\right|^2 \geq \bar{\eta} \\ \frac{1}{2}\log\left(1+\frac{E_s}{N_0}\left|h_{R_b,D}\right|^2 + \frac{E_s}{N_0}\left|h_{S,D}\right|^2\right), & \left|h_{S,D}\right|^2 \geq \eta_D \,\&\, \left|h_{S,R_i}\right|^2 \geq \bar{\eta} \\ \text{The Source is Idle}, & \left|h_{S,D}\right|^2 < \eta_D \,\&\, \left|h_{S,R_i}\right|^2 < \bar{\eta} \end{cases} \quad (6)$$

where $\eta_D \triangleq \frac{2^{\eta}-1}{E_s/N_0}$

At the source node, the adaptive LDPC coded modulation (ACM) provides multiple coded modulation transmission schemes (CMSs), where each scheme is specified by one of the *M*-ary quadrature amplitude modulation (M-QAM) and LDPC code pair. The source node selects a CMS for transmission and adapt the transmit power on frame-by-frame basis based on the CSI feedback from the receiver. To select the appropriate CMS for ACM wireless communication system, we need to know the SNR thresholds. We assume that *L* CMSs are candidates for the ACM system. The source node decides which CMS should be used at the start of each frame transmission according to a given set of SNR thresholds. For a certain level of BER, we define adaption SNR thresholds set, $\lambda \in \{\lambda_1, \lambda_2, \ldots, \lambda_{L-1}\}$ for the instantaneous SNR for every transmitted frame. Thus, each of the *L* candidate CMS is assigned to operate in a particular SNR region. When the threshold λ falls within a given SNR region, $\lambda_l \le \lambda < \lambda_{l+1}$ where $l \in \{1,2,\ldots,L-1\}$, the associated CSI is sent back to the source node to adapt its corresponding CMS. The corresponding spectral efficiency of each candidate CMS is denoted as η_l and $\eta_1 < \eta_2 < \cdots < \eta_l$.

The instantaneous SNR for each frame of a link from *A* to *B* is given by

$$\left(\gamma_{h_{A,B}}\right)_w = \left(\left|h_{A,B}\right|^2\right)_w (E_s/N_o) \quad (7)$$

where *w* is the index of the transmitted frame.

As mentioned before, when $0 \le \left(\gamma_{h_{A,B}}\right)_w \le \lambda_1$, the first candidate CMS is employed during the w^{th} transmitted frame. The $(l+1)^{th}$ candidate CMS is employed during w^{th} transmitted frame, when $\left(\gamma_{h_{A,B}}\right)_w$ satisfies the following inequality

$$\lambda_l \le \left(\gamma_{h_{A,B}}\right)_w \le \lambda_{l+1} \quad l = (1,2,\ldots,L-1) \quad (8)$$

We can deduce the inequality for instant fading amplitude, $\left|h_{A,B}\right|_w$ when $(l+1)^{\mathrm{th}}$ candidate CMS is employed [22],

$$\sqrt{\frac{\lambda_l}{E_s/N_o}} \le \left|h_{A,B}\right|_w < \sqrt{\frac{\lambda_{l+1}}{E_s/N_o}} \quad l = (1,2,\ldots,L-1) \quad (9)$$

The adaptation thresholds for the fading amplitude are then determined by the relationship

$\sqrt{\frac{\lambda_l}{E_s/N_o}} = v_l$, thus

$$v_l \le \left|h_{A,B}\right|_w < v_{l+1} \quad l = (1,2,\ldots,L-1) \quad (10)$$

Since our proposed cooperative system is based on ACM, the main advantage of ACM is that it makes a good use of time varying nature of wireless channel and hence improves spectral efficiency while keeping the performance at an acceptable level. Thus, due to its adaptive nature, the spectral efficiency of the proposed cooperative system is varied as a function of the instantaneous SNR. The average spectral efficiency (ASE) is defined as the average number of information bits transmitted per symbol duration. For the ACM scheme there are *L* CMSs candidates and the corresponding spectral efficiency of each candidate CMS is denoted as η_l and $\eta_1 < \eta_2 < \cdots < \eta_l$. The ASE is defined as [23]:

$$ASE = \sum_{l=1}^{L} \eta_l \, . \, P_l(\alpha) \quad (11)$$

where $P_l(\alpha)$ is the Rayleigh probability distribution for α being in the interval $[v_l, v_{l+1}]$. The probability density function of the Rayleigh distribution is given by

$$p(\alpha) = 2\alpha . \exp(-\alpha^2) \quad (12)$$

Thus, the ASE is expressed by

$$ASE = \eta_1 . P(0 \le \alpha \le v_1) + \eta_2 . P(v_1 \le \alpha \le v_2) + \cdots + \eta_L . P(v_{L-1} \le \alpha \le \infty) \quad (13)$$

where

$$P(v_l \le \alpha \le v_{l+1}) = \int_{v_l}^{v_{l+1}} p(\alpha)\, d(\alpha) = \int_{v_l}^{v_{l+1}} 2\alpha . \exp(-\alpha^2) d(\alpha) = \exp(-v_l^2) - \exp(-v_{l+1}^2) \quad (14)$$

thus the ASE is given by,

$$ASE = \eta_1.[\exp(-v_0{}^2) - \exp(-v_1{}^2)] + \eta_2.[\exp(-v_1{}^2) - \exp(-v_2{}^2)] + \cdots + \eta_L.[\exp(-v_{L-1}{}^2) - \exp(-v_L{}^2)]$$

$$= \sum_{l=1}^{L} \eta_l.[exp(-v_{l-1}{}^2) - exp(-v_1{}^2)] \quad (15)$$

where $v_0 = 0,\ v_L = \infty$.

IV. ERROR CONTROL CODES (EEC)

In wireless communication systems, errors in data transmission can come from many different sources (i.e., random noise, interference, channel fading and physical defects etc.). These channel errors must be reduced to an acceptable level to ensure reliable data transmission. To combat the errors, we normally use two strategies, either stand-alone or combined. The first one is the automatic repeat request (ARQ). An ARQ system attempts to detect the presence of errors in the received data. If any errors are found, the receiver notifies the transmitter of the existence of errors. The transmitter then resends the data until they are correctly received. In many practical applications retransmission may be difficult or not even feasible at all. For example, it is impossible for any receiver in a real-time broadcasting system to request data to be resent. In this case the second strategy, known as error control codes (ECC) is the only viable solution.

ECC are used for detecting the presence of errors and correcting them. It first adds redundancy (parity bits) to the message to be sent and form a codeword that contains both the message and the redundancy; this process is called encoding and is carried out at the transmitter. It then corrects errors based on the redundancy in a process called decoding that is performed at the receiver [24].

Several different types of ECC exist, but we may loosely categorize them into two families of codes. One is called block codes, which encode and decode data on a block-by-block basis where the data blocks are independent from each other. Block codes include repetition codes, Hamming codes [25], Reed Solomon codes [26], and BCH codes [27]. Consequently block coding is a memoryless operation and can be implemented using combinational logic. In contrast, another family of codes, namely, the convolutional codes [28], works on a continuous data stream, and its encoding and decoding operations depend not only on the current data but also on the previous data. As such, convolutional coding contains memory and has to be implemented using sequential logic.

ECC can also categorized based on decoding algorithms into two families, one is non -iterative decoding algorithms, such as syndrome decoding for block codes or maximum likelihood (ML) nearest codeword decoding for short block codes, algebraic decoding for Reed Solomon and BCH codes, and Viterbi decoding or sequential decoding for convolutional codes. The other family of decoding algorithms is iterative decoding algorithms, such as turbo decoding with component MAP decoders for each component code, and the sum product algorithm (SPA) [29] or its lower complexity approximation, min-sum decoding [30] for low density parity check codes (LDPCs). Since our proposed cooperative wireless communication system based on combined best relay selection and adaptive LDPC coded modulation, LDPC code is considered in this paper as ECC for its superior error correcting capabilities.

A. Low-Density Parity-Check Codes (LDPC)

Low-density parity-check (LDPC) codes, also known as the Gallager codes are a class of linear block error correction codes. LDPC codes were first discovered by Robert Gallager [31, 32] in the early 60s. For some reason, though, they were forgotten and the field lay dormant until the mid-90s when the codes were rediscovered by David MacKay and Radford Neal [33, 34]. Since then, the class of codes has been shown to be remarkably powerful, comparable to the best known codes and performing very close to the theoretical limit of error correcting codes.

More recently, due to their advantages LDPC codes have been proposed for several state-of-the-art wireless standards including IEEE 802.16e wireless MAN [35], IEEE 802.11n wireless LAN [36] and second generation satellites for digital video broadcasting (DVB-S2) [37].

An LDPC code is an (n, k) or (n, w_c, w_r) linear block code whose parity-check matrix H contains only a few 1's in comparison to 0's (i.e., sparse matrix). For an $m \times n$ parity-check matrix (where $m = n - k$), we define two parameters: the column weight w_c which equal to the number of nonzero elements in a column and the row weight w_r which equal to the number of nonzero elements in a row where $w_c << n$ and $w_r << m$.

An LDPC code is regular if w_c is constant for every column and w_r is also constant for every row, and a regular LDPC code will have,

$$m \cdot w_r = n \cdot w_c \qquad (16)$$

the coding rate of the regular LDPC is given by,

$$R = 1 - \frac{w_c}{w_r} \qquad (17)$$

On the other hand, if H is low in density (sparse) but w_c and w_r are not constant, the code is irregular.

Besides the general expression of LDPC codes as an algebraic matrix, LDPC codes can also be represented by a bipartite Tanner graph, which was proposed by Tanner in 1981 [38].A Tanner graph is a bipartite graph introduced to graphically represent LDPC codes. It consists of nodes and edges. The nodes are grouped into two sets. One set consists of n bit nodes (or variable nodes), and the other of m check nodes (or parity nodes). The creation of such a graph is straightforward: Check node i is connected to bit node j if $h_{i,j}$ of the parity matrix H is a 1. From this we can deduce that there are totally $m \cdot w_r$ (or $n \cdot w_c$) edges in a Tanner graph for a regular LDPC code. Apparently the Tanner graph has a one-to-one correspondence with the parity-check matrix.

The Tanner graph of the H (6, 2, 3) rate 1/3 regular LDPC code is shown Figure 3.

The LDPC codes used in this paper is based on the WiMax 802.16e standard. In the WiMax 802.16e standard, the LDPC codes are a set of systematic linear block codes which are built from Richardson-Urbanke encoding algorithm [39] and a special class of Quasi-Cyclic (QC) LDPC codes [40 , 41].

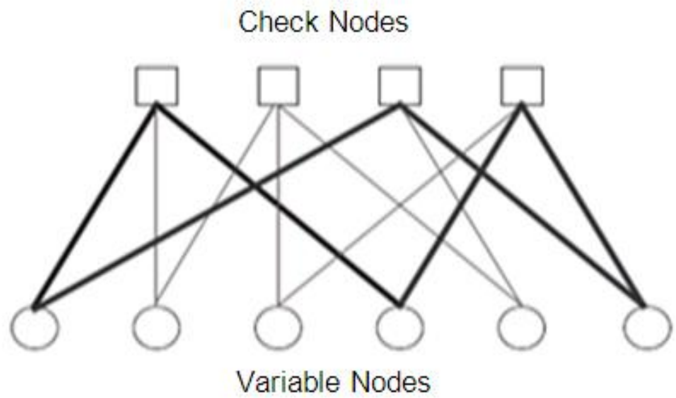

Figure 3. Tanner graph representation of the parity-check matrix in (18), where the bold lines represent 6-cycle

$$H = \begin{bmatrix} 1 & 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 & 1 \end{bmatrix} \qquad (18)$$

The LDPC codes adapted by the IEEE 802.16e WiMAX standard [35] support 19 different codeword lengths with four distinct code rates namely, (1/2, 2/3, 3/4, 5/6) and six different code classes (1/2, 2/3 A, 2/3 B, 3/4 A, 3/4 B, 5/6). The parity check matrix of all six code classes consists of 24 columns and (1-R) $\times$24 rows, with each entry describing a z-by-z sub-matrix which is either a permuted identity matrix or a zero matrix. The first R$\times$24 columns correspond to the systematic information, the second (1-R) $\times$24 columns for the parity information which have a fixed structure required by the encoder design [42].

The sub-matrices z-by-z has a variable size that ranged from 24$\times$24 to 96$\times$96 with incremental granularity of 4, providing 19 codeword lengths ranging from n = 576 to n = 2304 bit with incremental granularity of 96 bit. Figure 4 shows the generic structure of the parity check matrix used in IEEE 802.16e WiMAX standard, with rate 1/2 and codeword length of n = 2304 bit (i.e., z = 96). In WiMAX LDPC codes the BER performance improved with increasing codeword length n [13], thus in all simulations we select LDPC codes with codeword length n=2034 bit.

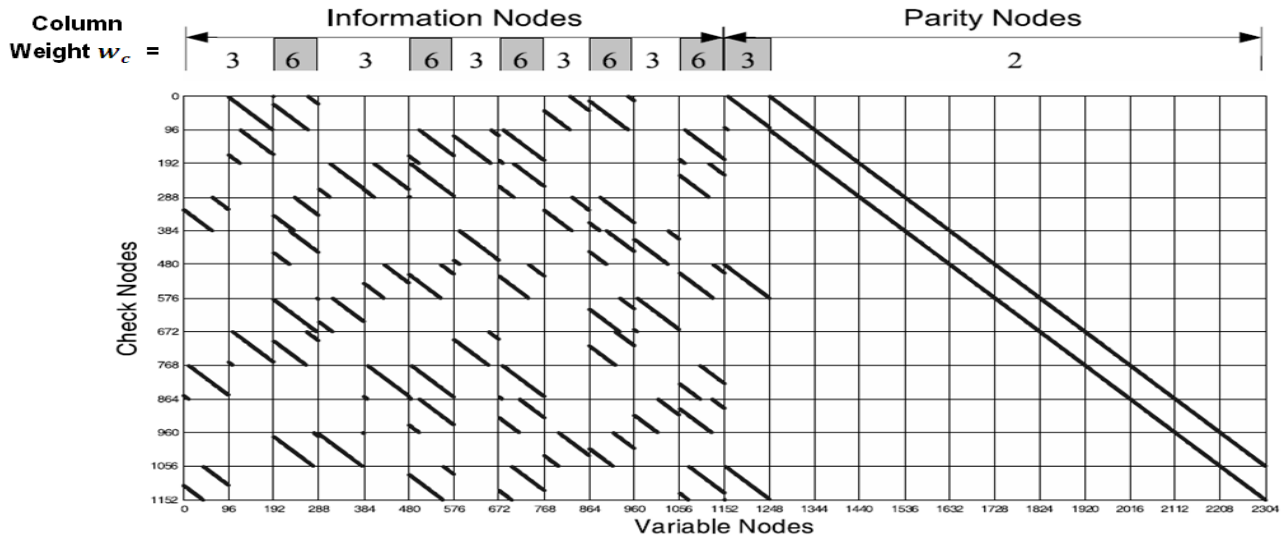

Figure 4. Structure of the parity check matrix *H for* a rate 1/2 WiMAX 802.16e LDPC code with codeword length *n*=2304 bit (*z* = 96), where the bold lines represent elements "1" in *H*

V.SIMULATION MODEL AND RESULTS

In this section we present the simulation model and discuss the simulation results. As we have stated before, our research goal is to evaluate the performance of cooperative wireless communication system with combined best relay selection (BRS) and adaptive LDPC coded modulation (ACM). The system model and block diagram of ACM transceiver structure are shown in Figures 1, 2. We have employed MATLAB® to write a computer program designed for simulation of the proposed system to allow various parameters of the system to be varied and tested. The possible considered parameters and their corresponding values are mentioned in Table 1.

We considered three scenarios for simulations:

1- Direct transmission (without relays), in this case we have only a direct link of distance *d*=1Km from source node (*S*) to destination node (*D*).
2- Cooperative wireless communication system with single relay (*N*=1).
3- Cooperative wireless communication system with best relay selection (BRS), where a single relay among a set of *N* relay nodes is selected, depending on which relay provides for the "best" end-to-end path between source and destination.

Table.1 Simulations parameters and their values

Parameters	Values
Digital Modulation	QPSK, 8QAM, 16QAM, 64QAM, 265QAM
Distance between Source and Destination, *d*	1Km
Number of Relay Nodes, *N*	1, 4, 8
Channels	AWGN, flat Rayleigh fading
LDPC Codes	WiMAX LDPC codes
LDPC Code Rate, r	1/2, 2/3, 3/4, 5/6
Codeword Length, n	2304 bit
Encoding	Richardson-Urbanke algorithm
Decoding	Logarithmic BP algorithm
Maximum number of iterations	30

To evaluate the performance of the proposed ACM scheme, we adopt six different combinations of LDPC coded modulation schemes (CMSs) at which the spectral efficiency can vary from 1 to 6 bits/s/Hz, as shown in Table 2.
Figure 5 shows the BER performance comparison between cooperative wireless communication system with single relay (*N=1*) and cooperative wireless communication system with BRS with

different number of relay nodes N between source and destination, considering transmission over Rayleigh fading channels using rate 1/2 LDPC code and QPSK modulation. It can be observed that, in all cases, increasing the number of available relay nodes between source and destination decreasing the BER level for a given value of SNR.

Figure 6 shows the SNR adaptation thresholds of each candidate pair at $\text{BER} = 10^{-2}$ for different scenarios of simulations. The SNR adaptation thresholds at $\text{BER} = 10^{-2}$ are summarized in Table 3.

Table.2 Spectral efficiency of six candidate pairs for the proposed adaptive LDPC coded modulation scheme

CMS	**Modulation**	**Coding rate**	**Spectral efficiency (bits/s/Hz)**	**SNR adaptation thresholds**
CMS-1	QPSK	1/2	1	$0 \geq SNR \leq \lambda_1$
CMS-2	8-QAM	2/3	2	$\lambda_1 \geq SNR \leq \lambda_2$
CMS-3	16-QAM	3/4	3	$\lambda_2 \geq SNR \leq \lambda_3$
CMS-4	64-QAM	2/3	4	$\lambda_3 \geq SNR \leq \lambda_4$
CMS-5	64-QAM	5/6	5	$\lambda_4 \geq SNR \leq \lambda_5$
CMS-6	256-QAM	3/4	6	$SNR \geq \lambda_5$

Table.3: SNR adaptation thresholds at $\text{BER} = 10^{-2}$ for different scenarios of simulations

SNR Adaptation Threshold(dB)	λ_1	λ_2	λ_3	λ_4	λ_5
Direct Transmission	20	25	28.9	32.5	35
Cooperative Transmission with Single Relay	13.6	19	23.5	28.5	32
Cooperative Transmission with BRS	8.3	14.6	19.5	24.2	28.9

Figure 7 shows the BER performance comparison between direct transmission with different CMSs and with ACM at the source node. Our results show that direct transmission with ACM at the source node achieves lower SNR values for desired BER as compared to direct transmission with different CMSs. We can also observed that the BER curve of direct transmission with ACM is between CMS-3 and CMS-4 and for a $\text{BER} = 10^{-2}$ direct transmission with ACM can have a SNR gain between 3 to 7 dB compared to CMS-5 and CMS-6, respectively and a SNR loss between 3.6 to 6.3 dB compared to CMS-3 and CMS-2, respectively.

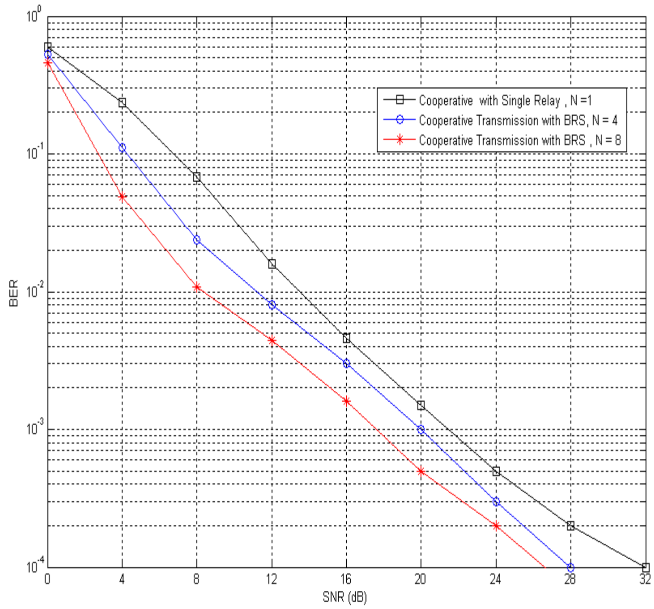

Figure 5. BER versus SNR for different number of relay nodes N, considering transmission over Rayleigh fading channels (r=1/2, n=2304 bit, QPSK, and d=1Km)

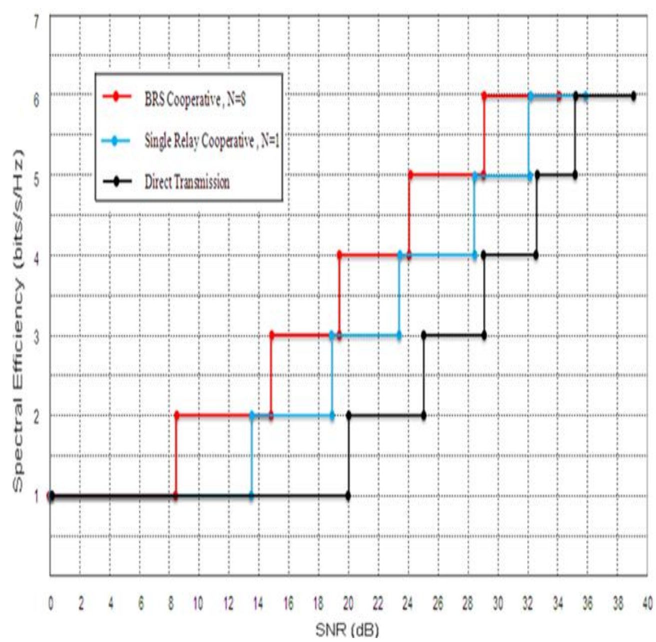

Figure 6. SNR adaptation thresholds of each candidate pair at BER=10^{-2} for different scenarios of simulations

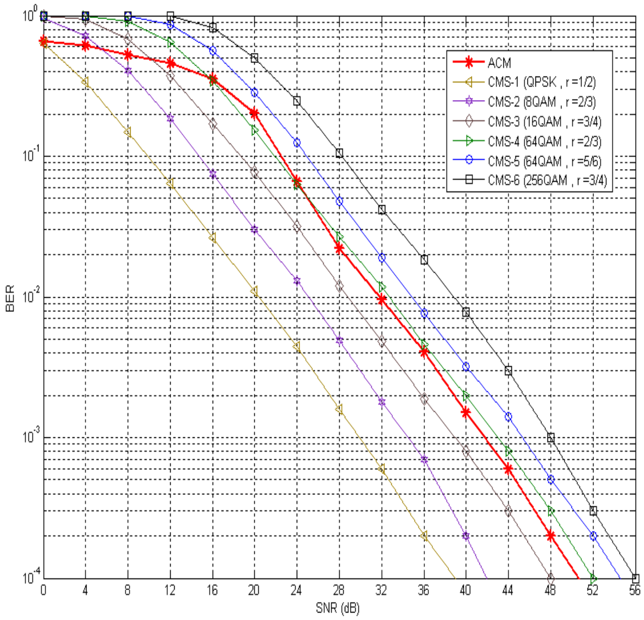

Figure 7. BER performance comparison between direct transmission with different CMSs and with ACM

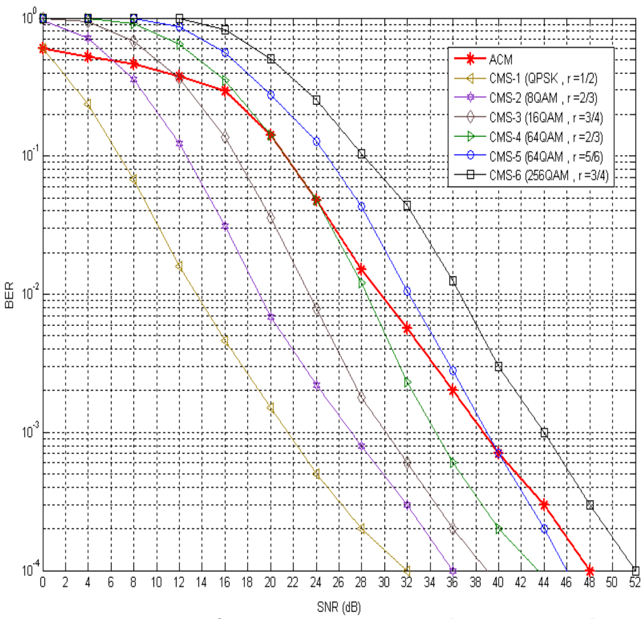

Figure 8. BER performance comparison between single relay cooperative with different CMSs and with ACM, *N*=1

Figure 8 shows the BER performance comparison between single relay cooperative transmission with different CMSs and with ACM at the source node. Our results show that single relay cooperative transmission with ACM at the source node achieves lower SNR values for desired BER as compared to single relay cooperative transmission with different CMSs. We can also observed that the BER curve of single relay cooperative with ACM is between CMS-4 and CMS-5 and for a $\text{BER} = 10^{-2}$ single relay cooperative transmission with ACM can have a SNR gain between 2.2 to 6.4 dB compared to CMS-5 and CMS-6, respectively and a SNR loss between .6 to 6 dB compared to CMS-4 and CMS-3, respectively. Our results also show that single relay cooperative transmission with different CMSs and ACM achieves lower SNR values for desired BER as compared to direct transmission.

Figure 9 shows the BER performance comparison between BRS cooperative transmission with different CMSs and with ACM at the source node. Our results show that BRS cooperative transmission with ACM at the source node achieves lower SNR values for desired BER as compared to BRS cooperative transmission with different CMSs. We can also observed that the BER curve of BRS cooperative with ACM is between CMS-4 and CMS-5 and for a $\text{BER} = 10^{-2}$ BRS cooperative transmission with ACM can have a SNR gain between 2.6 to 8 dB compared to CMS-5 and CMS-6, respectively and a SNR loss between 1.6 to 6 dB compared to CMS-4 and CMS-3, respectively. Our results also show that BRS cooperative transmission with different CMSs and ACM achieves lower SNR values for desired BER as compared to direct transmission and single relay cooperative.

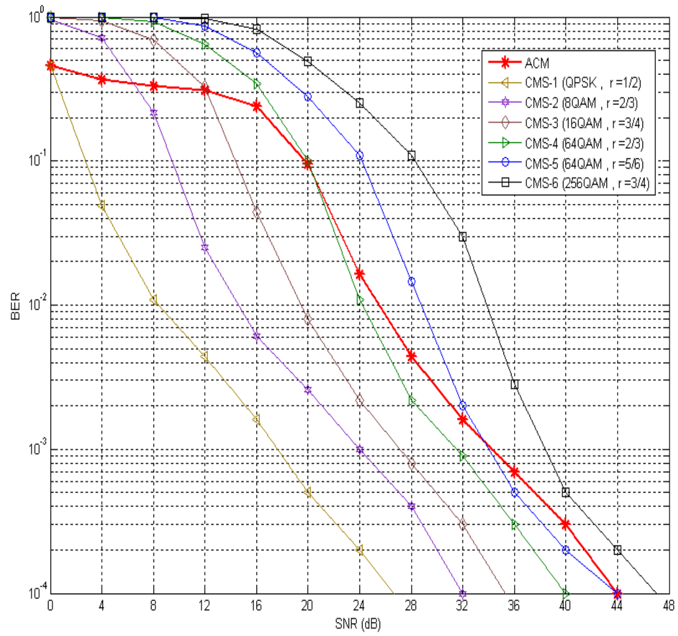

Figure 9. BER performance comparison between BRS cooperative with different CMSs and with ACM, *N*=8

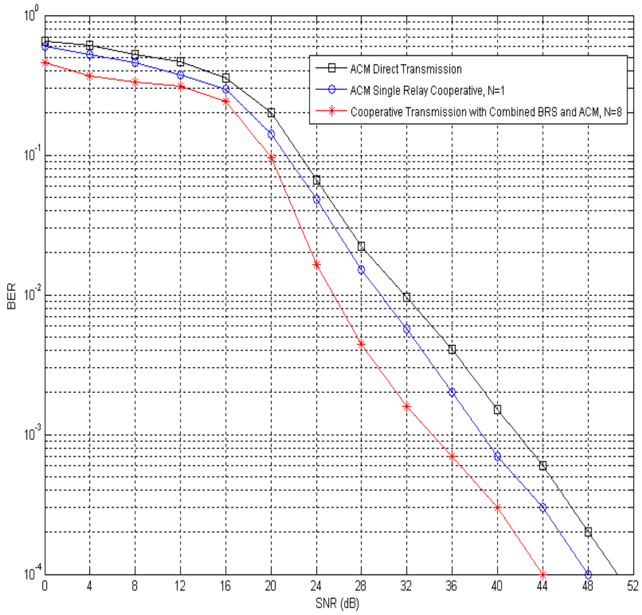

Figure 10. BER performance comparison between ACM direct transmission, ACM cooperative with single relay and Cooperative system with combined BRS and ACM, SNR adaptation threshold at BER = 10^{-2}

Figure 10 shows the BER performance comparison between ACM direct transmission, ACM cooperative system with single relay and the proposed cooperative system with combined BRS and ACM. Our results show that cooperative system with combined BRS and ACM achieves lower SNR values for the desired BER as compared to ACM direct transmission and ACM cooperative system with single relay, for BER = 10^{-2} the proposed cooperative system with combined BRS and ACM can have a SNR gain between 4.4 to 6.5 dB compared to ACM cooperative system single relay and ACM direct transmission, respectively. All result for different scenarios of simulations are concluded in Table 4; from the results it is clear that cooperative transmission with BRS outperform all other scenarios at a given BER level for different CMSs. Figure 11 shows the effect of selecting SNR adaptation thresholds at different BER levels ($BER = 10^{-2}, 10^{-3}$) on the performance of the proposed cooperative system with combined BRS and ACM, from the figure it is clear that the BER performance of the proposed cooperative system improved by selecting SNR adaptation thresholds at lower BER level where lower CMSs are used more frequently.

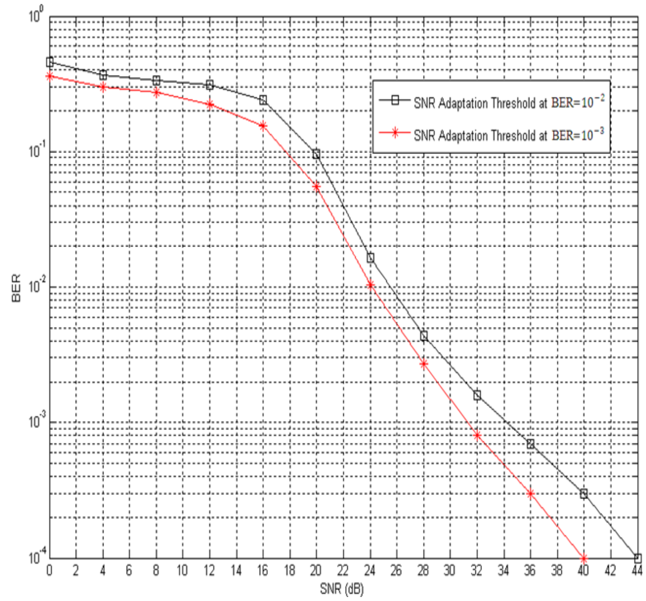

Figure 11. The effect of SNR adaptation threshold on the BER performance of the proposed cooperative system with combined ACM and BRS, *N*=8

Table 4. SNR required at BER level 10^{-2} for different scenarios of simulations

CMSs	Direct Transmission	Cooperative Transmission with Single Relay	Cooperative Transmission with BRS
CMS-1	20	13.6	8.5
CMS-2	25	19	14.6
CMS-3	28.9	23.5	19.5
CMS-4	32.5	28.5	24.2
CMS-5	35	32	28.9
CMS-6	39	36.8	34
ACM	32	29.9	25.5

Figure 12 shows the average spectral efficiency (ASE) of different ACM transmission scenarios, SNR adaptation threshold at BER=10^{-2}. From the figure it is clear that the ASE increases as the SNR increases, also it is clear that the proposed cooperative system with combined BRS and ACM required lower SNR levels to attain the same ASE compared to all other scenarios, and as the number of relay nodes increases the proposed cooperative system achieves lower SNR values for the desired ASE. From the results; we can also observe that, the proposed cooperative system with combined BRS and ACM required SNR value of 25.3 dB to achieve BER level of 10^{-2} as shown in Figure 9, and the ASE at this value of SNR is 6 bits/s/Hz as shown in Figure 12. For the same BER level of 10^{-2}, the SNR values of CMS-1, CMS-2, CMS-3, CMS-4, CMS-5 and CMS-6 are 8.5, 14.6, 19.5, 24.2, 28.9 and 34dB, respectively with spectral efficiency from 1 to 6 bits/s/Hz. Thus, the proposed cooperative system can outperform CMS-5 and CMS-6. Although it required higher SNR value compared to CMS-1, CMS-2, CMS-3 and CMS-4. Figure 13 shows the effect of selecting SNR adaptation thresholds as different BER levels ($BER = 10^{-2}, 10^{-3}$) on the ASE performance of the proposed cooperative system. From the figure it is clear that the ASE of the proposed cooperative system using higher SNR adaptation threshold at BER level of 10^{-2} have a gain of approximately .5 to 1.25 bits/s/Hz for the same SNR value compared to that with lower SNR adaptation threshold at BER level of 10^{-3}.

VI. Conclusions

In this paper, a new cooperative scheme based on combined best relay selection (BRS) and adaptive LDPC coded modulation (ACM) is investigated. To improve the spectral efficiency of the proposed cooperative system, we introduced ACM at source node which provides multiple coded modulation transmission schemes (CMSs), where each scheme is specified by one of the *M*-ary quadrature amplitude modulation (M-QAM) and LDPC code pair (candidate pair).

To contrast the performance of the proposed cooperative system we compare its performance with ACM-direct transmission and ACM-cooperative system with single relay. The simulation results show that the proposed cooperative scheme achived lower SNR values for the desired BER levels and required lower SNR values to attain the same average specral efficiency as comared to ACM direct transmission and ACM cooperative with single relay.

We studied also the effect of selecting SNR adaptation thresholds at different BER levels ($i.e., BER = 10^{-2}, 10^{-3}$) on the performance of the proposed cooperative scheme, the simulation results show that the BER performance of the proposed cooperative scheme improved by selecting SNR adaptation thresholds at lower BER level where lower CMSs are used more frequently. The results also show that the ASE of the proposed cooperative scheme using SNR adaptation threshold at higher BER level of 10^{-2} have a gain of approximately .5 to 1.25 bits/s/Hz for the same SNR value compared to that with lower SNR adaptation threshold at BER level of 10^{-3}.

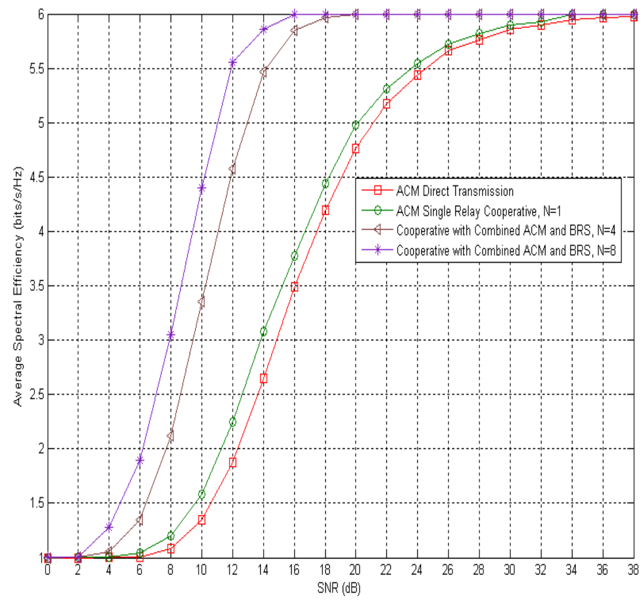

Figure 12. ASE of different transmission scenarios, SNR adaptation threshold at $BER = 10^{-2}$

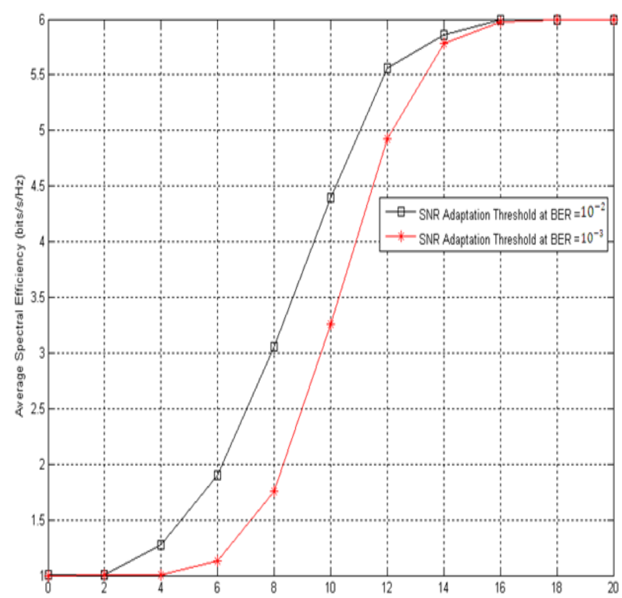

Figure 13. ASE of the proposed cooperative system with combined ACM and BRS, SNR adaptation thresholds at different BER levels ($BER = 10^{-2}, 10^{-3}$), *N*=8

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