HARQ Aided Systematic LT Coding for Amplify-Forward and Decode-Forward Cooperation

Hoang Anh Ngo, Thanh Dang Nguyen and Lajos Hanzo
School of Electronics & Computer Science, University of Southampton
Email: {han08r, tnd03r, lh}@ecs.soton.ac.uk

***Abstract*—Systematic Luby Transform (SLT) codes constitute rateless codes, which are capable of adaptively adjusting their code rate depending on the channel quality without explicit channel state information (CSI) at the transmitters. SLTs are also suitable for space-time collaboration aided relay networks. In this paper, an iterative decoding aided SLT scheme is combined with 16-QAM transmission in a wireless relay aided network. The Bit Error Ratio (BER) results and Extrinsic Information Transfer (EXIT) charts are provided to evaluate the performance of the proposed scheme. The simulation results show that the proposed scheme using amplify-and-forward (AF) relaying achieves a $2.5dB$ gain at a BER of 10^{-5}, while the attainable improvement is nearly $6dB$ for decode-and-forward (DF) relaying, compared to the non-cooperative scheme, where the 16-QAM and the SLT decoder work independently. Moreover, the AF relaying aided SLT coded 16-QAM scheme is more beneficial, when the relay station is close to the source. By contrast, the DF relaying performs best near the mid-point between the source and destination. In addition, a modified Hybrid Automatic-Repeat-reQuest (HARQ) protocol using incremental redundancy is applied along with the SLT coded 16-QAM scheme to enhance the achievable throughput and energy efficiency of cooperative networks. This arrangement reduces the total transmit power by about 8%, compared to the classic HARQ scheme.**

I. INTRODUCTION

Hybrid Automatic Repeat reQuest (HARQ) techniques are capable of supporting reliable data transmission over the wireless channels. This technique was introduced in the 1960s by Wozencraft and Horstein [1], for both error detection and error correction combined with retransmission requests. Their system is now known as the Type-I HARQ. Naturally, the combination of Forward-Error-Correction (FEC) codes and the classic ARQ protocol is capable of improving the achievable throughput and of reducing the number of retransmissions, hence the delay. An improved version of this system, known as the Type-II HARQ, was invented by Lin and Yu [2].

Diverse FEC schemes may be employed in HARQ systems. For example, convolutional coded HARQ was characterized in [3] while the well-known turbo code was combined with the ARQ protocol in [4]. By contrast, in this paper Systematic Luby Transform (SLT) codes [5], which are powerful erasure-filling codes is employed and hence they substantially reduce the number of HARQ retransmissions. The proposed configuration will be referred to as the HARQ SLT scheme.

Multiple-Input-Multiple-Output (MIMO) techniques [6] have been adopted for several wireless standards. In principle, MIMO systems [6] use multiple antennas in different configurations combined with advanced coding schemes for improving the achievable performance, including the throughput and cellular coverage area. However, mobile handsets are constrained both in term of their size and battery power. Hence, their ability to accommodate MIMO elements is limited. This problem may be circumvented by the sophisticated concerted activation of the single antennas of multiple mobile stations as in amplify-and-forward (AF), decode-and-forward (DF) as well as compress-and-forward (CF) cooperation.

In this paper, we proposed a HARQ aided SLT coded 16-QAM scheme for employment in relay-aided networks. The novelty and rationale of our proposed scheme is summarized as follows:

1) *First, we contrived a novel system based on the concatenation of SLT codes and 16-QAM, where the decoder and the demodulator iteratively exchange extrinsic information. We will demonstrate that the arrangement is capable of providing a significant coding gain for transmission over wireless Rayleigh fading channels, compared to the system where the SLT coding scheme and the demodulator operate independently.*
2) *Furthermore, a sophisticated HARQ aided SLT coded 16-QAM scheme using iterative detection was introduced in a relay-aided wireless network. The proposed scheme provides an increased spatial diversity for the signals received at the destination. As a result, the achievable BER performance is enhanced. Moreover, we investigate the best transmit power sharing between the source and the relay stations and determine the best location for both AF and DF relaying schemes.*
3) *Finally, we improve the HARQ aided SLT coded 16-QAM scheme in order to reduce the number of incremental redundancy transmissions required. Hence, we reduce the system's total transmit power and increase the attainable throughput. Where possible, analytical expressions are provided for characterizing the system.*

The outline of this paper is as follows. Section II summarizes the characteristics of SLT codes using iterative detection (ID) and its concatenation with the 16-QAM demodulator in order to iteratively exchange extrinsic information. The resultant coding scheme is referred to as the ID-SLT 16-QAM arrangement. In Section III, the proposed coding scheme is applied to wireless relay networks in order to improve their performance. The system's architecture and mathematical characterization is provided in Sections IV and V. Finally, Section VI details our simulation results recorded for the HARQ aided SLT coded 16-QAM system, followed by our conclusions.

II. ITERATIVE DECODING AIDED SYSTEMATIC LUBY TRANSFORM CODES

Luby tranform (LT) codes [7] were originally designed for the Binary Erasure Channel (BEC). When employed for transmission over wireless channels, which impose both fading and inter-symbol interference (ISI), the LT code might become contaminated, which results in catastrophic inter-packet error propagation during LT decoding [8]. In order to mitigate the deleterious effects of error propagation, LT codes have been frequently combined with physical-layer FEC codes [8]. The idea of combining classic FEC codes with LT codes by directly amalgamating them was proposed in [5], where systematically concatenated parity bits were incorporated in order to

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create the family of SLT codes. It was also shown in [5] that the soft decoding process of SLT codes may be carried out based on the classic concept of LDPC decoding.

The original LT code of [7] utilized the Robust Soliton Degree (RSD) distribution for bit encoding. However, the RSD distribution consists of many single parity check bits, also known as degree-one nodes, which typically have a significantly lower reliability than information nodes. Hence, employing the RSD is not suitable for LT codes involving iterative soft decoding, especially when relying on simple parity check codes. To improve the achievable performance of both LT codes and SLT codes, the authors of [8], [9] have proposed several improved distributions, namely the Improved RSD distribution and the Truncated Degree (TD) distribution. The TD has a low number of degree-one nodes and hence will be employed for designing the proposed systems.

When utilizing Soft Input and Soft Output (SISO) information for iterative decoding, the SLT decoder exchanges extrinsic information with the 16-QAM demodulator, which also uses SISO information in its bit-to-symbol demapping process, through a pair of interleaver and de-interleaver components. This model is shown in Figure 1, where the soft output of the demodulator is fed forward to the SLT decoder. After carrying out SLT decoding, the resultant extrinsic information is fed back to the demodulator as the *a-priori* information. The demodulator then exploits both the *a-priori* information and the channel's output information, which is demapped to bits and passed to the SLT decoder again. This process continues until the syndrome checking condition of the SLT decoder is satisfied or the affordable number of iterations is exhausted. The exchange of extrinsic information with the demodulator will enhance the attainable decoding performance of the SLT decoder. Consequently, a significant coding gain is achieved by the system. The performance of the iterative decoding process might be beneficially visualized by EXIT charts [10].

Typically, the classic Gray bit-to-symbol mapping scheme is the best in non-iterative arrangements, but does not benefit from iterative decoding [6]. Hence, a set-partitioning (SP) based mapping scheme was chosen for the demodulator.

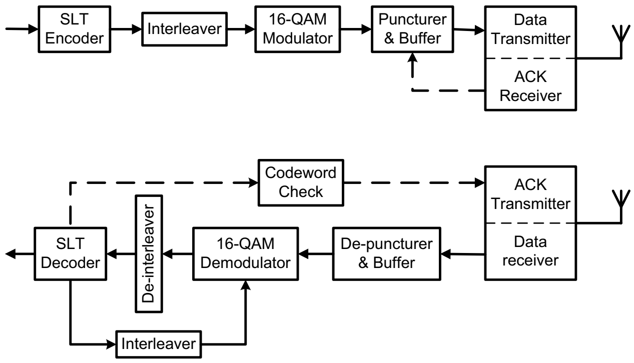

Fig. 1. Block diagram of the HARQ ID-SLT coded 16-QAM scheme

III. ID-SLT Coding in Wireless Cooperative Communications Network

A single-relay-node aided cooperative communications network includes the Source Station (SS), the Relay Station (RS) and the Destination Station (DS). The transmissions are divided into two time slots. During the first time slot, the SS broadcasts its data both to the RS and to the DS. In the second slot, the RS forwards data to the DS. Based on the two versions of the received signal, the DS recovers the original data.

A. Amplify-and-Forward Scheme

During the first time slot, the source broadcasts its signal $x_{s,k}$. The signals received at the RS and the DS, namely $y_{sr,k}$ and $y_{sd,k}$ are expressed as

$$y_{sr,k} = \sqrt{G_{sr}}\sqrt{P_s}h_{sr,k}x_{s,k} + n_{sr,k}, \quad (1)$$

$$y_{sd,k} = \sqrt{P_s}h_{sd,k}x_{s,k} + n_{sd,k}, \quad (2)$$

where $k \in \{1, 2, ..., N_s\}$ is symbol index, N_s is the number of transmitted symbols, G_{sr} is the SS-RS path-loss-related power gain [11], $h_{sr,k}$ and $h_{sd,k}$ are the complex non-dispersive Rayleigh fading factors, while $n_{sr,k}$ and $n_{sd,k}$ represent the AWGN with zero mean and a variance of N_0.

The signal received from the source by the RS is amplified and forwarded to the DS. The relayed signal arriving at the DS is expressed as

$$y_{rd,k} = \sqrt{G_{rd}}\sqrt{P_{relay}}h_{rd,k}\beta y_{sr,k} + n_{rd,k}, \quad (3)$$

where G_{rd} is the RS-DS path-loss-related power gain [11], $\beta \leq \sqrt{\frac{1}{G_{sr}P_s|h_{sr}|^2+N_0}}$ is the gain at the RS [11]. Naturally, the unwanted noise and interference are also amplified by the RS and forwarded to the DS.

At the DS, the receiver combines the two received signal versions y_{sd} and y_{rd} into

$$y_{d,k} = y_{sd,k} + y_{rd,k}, \quad (4)$$

and then passes them to the demodulator. Finally, SLT decoding is carried out, as detailed in the previous section. Having briefly considered AF relaying, let us now discuss DF relaying.

B. Decode-and-Forward Scheme

The signal processing operations carried out during the first time slot are identical to those of the AF scheme. The RS's receiver, however, decodes the received signal and re-encodes them, before forwarding them to the destination. Hence, Eq. (3) has to be replaced by

$$y_{rd,k} = \sqrt{G_{rd}}\sqrt{P_{relay}}h_{rd,k}x_{relay,k} + n_{rd,k}, \quad (5)$$

where $x_{relay,k}$ is the re-encoded signal at the RS.

The decoding process at the destination ensues similarly to that of the AF scheme.

IV. HARQ with Incremental Redundancy for ID-SLT Coding

A. System Architecture

Again, there are two basic types of HARQ, namely the Type-I HARQ and the Type-II HARQ. The transmitter of the classic Type-I HARQ scheme typically retransmits all the information and parity bits of corrupted packets, when a negative acknowledgement (ACK) is received, while the receiver simply drops erroneous packets [12]. In the H-ARQ type II scheme, the information part and the parity part are sent together during the first transmission attempt. However, during the second transmission attempt additional parity information is transmitted. There are also two ways of information combining in H-ARQ protocol, namely Chase Combining and Incremental Redundancy (IR-HARQ). When the different received replicas are combined in the soft-value domain, the resultant technique is referred to as the HARQ using Chase Combining. In fact, the method simply boosts the received SNR after chase combining. In other words, it does not provide an additional coding gain and does not increase the achievable effective throughput. By contrast, the Type-II HARQ uses Incremental Redundancy (IR-HARQ) where the transmitter sends additional redundancy during the retransmission stages. The receiver combines the additional redundant bits with those received before, in order to recover the original information bits. Naturally, this method is expected to provide an increased coding gain at the receiver. Due to these advantages, in this section the SLT coded HARQ using IR is chosen for investigation here.

The IR-HARQ aided SLT coding scheme is shown in Fig. 1. As shown in this figure, the information bits are encoded and modulated, before they are passed to the puncturing and buffering components. A fraction of the parity bits is punctured, in order to achieve the highest possible code rate during the first transmission, while storing the remaining punctured bits for IR transmissions, as and when needed. In the receiver, the SLT decoder and the syndrome checking block will generate a status signal in order to inform the transmitter about the outcome of the CRC check operation. If a positive ACK is received corresponding to a legitimate decoded code word, the buffered parity bits that were previously punctured will be deleted. Otherwise, incremental redundancy is transmitted, until we reach the maximum affordable number of IR transmissions. In this paper, the original cooperative IR-HARQ scheme is referred to as the *"passive cooperative IR-HARQ"*.

In this contribution, an *"active cooperative IR-HARQ"* scheme is proposed for cooperative wireless networks. There, both the relay's and the destination's receivers feed their decoding status back to the source. If negative ACKs are received from both the RS and the DS, the IR transmission is carried out as usual. If a negative ACK is received from the DS and a positive ACK is received from the RS, the IR transmissions are implemented at the relay only, while the source remains idle. Clearly, the arrangement requires the collaboration among all stations, especially the assistance of the RS. Note that this IR-HARQ procedure is only suitable for the DF cooperative scheme and the IR transmissions require extra timeslots. During IR transmission, only a single version of the signal may arrive from the RS to the DS. Thus, there may not be any spatial diversity gain. To compensate for the resultant diversity loss, the relay may choose to increase its transmit power.

B. Capacity and Power

Based on expressions in this section, we showed that the active cooperative scheme could not only improve the capacity but also reduce the total transmit power, compared to the passive one. For a convenient analysis, in the active scheme, the IR transmissions are divided into two time slots as well. During the first time slot, the RS's transmit power is set to P'_{relay}, while in the second slot, it is set to P_{relay}.

1) Capacity: Let us assume that during the first transmission of the passive cooperative scheme, the source sends m_c bits and in each IR transmission, it sends l_c bits, while the number of IR transmissions is $n \in \{1, 2, ...n_{max}\}$, where n_{max} is the maximum number of IR transmissions. For the active scheme, the first transmission is the same as that of the passive one. The number of IR transmissions at both the source and the RS is denoted as n_s, while the number of IR transmissions at the RS only is n_r. Also note that we have to obey $n_s + n_r = n$ to make the comparison between the two systems a fair one.

As demonstrated in [11], the average normalized capacity of a passive cooperative single-relay-aided IR-HARQ system in the AWGN channel may be expressed as Eq. (6), while the average capacity of the active cooperative single-relay-aided IR-HARQ system in an AWGN channel equals to Eq. (7), in which d_{sd}, d_{sr} and d_{rd} are the SS-DS, SS-SR and RS-DS distance, respectively, while α is the path-loss exponential [13]. The difference is that P_s in the third term of Eq. (6) was replaced by P'_{relay} in Eq. (7).

Introduce $P'_{relay} = Ps$ and $d_{rd} \leq d_{sd}$, we have

$$log_2 \left(1 + \frac{P_s}{d_{sd}^{\alpha} N_0} + \frac{P_{relay}}{d_{rd}^{\alpha} N_0}\right) \leq log_2 \left(1 + \frac{P'_{relay}}{d_{rd}^{\alpha} N_0} + \frac{P_{relay}}{d_{rd}^{\alpha} N_0}\right). \tag{10}$$

Hence, it follows that we have

$$\bar{C}_{passive} \leq \bar{C}_{active}. \tag{11}$$

The equality condition of Eq. (11) is met, when we have

$$P'_{relay} = \left(\frac{P_s}{d_{sd}^{\alpha}}\right) d_{rd}^{\alpha} = P_s \left(\frac{d_{rd}}{d_{sd}}\right)^{\alpha}. \tag{12}$$

This condition implies that the capacity of the active cooperative IR-HARQ scheme is higher than that of the passive one, if the RS's transmit power is set higher than $P_s \left(\frac{d_{rd}}{d_{sd}}\right)^{\alpha}$.

2) Transmit Power: The average total transmit energy of each symbol of the passive cooperative single-relay-aided IR-HARQ system is expressed as Eq. (8), while that of the active cooperative single-relay-aided IR-HAQR system is calculated as Eq. (9). Again, P_s in the second term of Eq. (8) was replaced by P'_{relay} in Eq. (9)

If P'_{relay} is restricted to P_s, it may be inferred from Eq. (8) and Eq. (9) that we have

$$\bar{P}_{passive} \geq \bar{P}_{active}. \tag{13}$$

Based on the analysis provided above, it is concluded that the *"active cooperative IR-HARQ"* scheme has a higher capacity and a lower total energy consumption, compared to the *"passive cooperative IR-HARQ"*, if the three stations collaborate.

V. SYSTEM PERFORMANCE

The BER performance of the ID-SLT coded 16QAM scheme of Fig. 1 is shown in Fig. 2. The detailed parameters of each scheme can be seen in Table I. It is observed in Fig. 2 that there is an approximately $2.5dB$ gain, when the 16-QAM mapper and the SLT decoder iteratively exchange their extrinsic information in the context Scheme-1. Introducing AF relaying in Scheme-2 provides only a slightly improvement of about $0.2dB$. As mentioned before, AF relaying simply amplifies the received signal at the relay and then forwards it. Thus it does not benefit from the coding gain of SLT coding. A clearer view is provided by the EXIT chart [6] of Fig. 3.

$$\bar{C}_{passive} = \frac{m_c + n_s l_c}{m_c + n l_c} log_2 \left(1 + \frac{P_s}{d_{sd}^{\alpha} N_0} + \frac{P_{relay}}{d_{rd}^{\alpha} N_0}\right) + \frac{n_r l_c}{m_c + n l_c} log_2 \left(1 + \frac{P_s}{d_{sd}^{\alpha} N_0} + \frac{P_{relay}}{d_{rd}^{\alpha} N_0}\right), \tag{6}$$

$$\bar{C}_{active} = \frac{m_c + n_s l_c}{m_c + n l_c} log_2 \left(1 + \frac{P_s}{d_{sd}^{\alpha} N_0} + \frac{P_{relay}}{d_{rd}^{\alpha} N_0}\right) + \frac{n_r l_c}{m_c + n l_c} log_2 \left(1 + \frac{P'_{relay}}{d_{rd}^{\alpha} N_0} + \frac{P_{relay}}{d_{rd}^{\alpha} N_0}\right), \tag{7}$$

$$\bar{P}_{passive} = P_s + P_{relay} = \frac{(m_c + n l_c)(P_s + P_{relay})}{m_c + n l_c} = \frac{(m_c + n_s l_c)(P_s + P_{relay})}{m_c + n l_c} + \frac{n_r l_c (P_s + P_{relay})}{m_c + n l_c}, \tag{8}$$

$$\bar{P}_{active} = \frac{(m_c + n_s l_c)(P_s + P_{relay})}{m_c + n l_c} + \frac{n_r l_c (P'_{relay} + P_{relay})}{m_c + n l_c}, \tag{9}$$

There is only a tiny gap between the EXIT functions of Scheme-1 and Scheme-2 of Table I, which explains why AF relaying provides only insignificant benefits for the ID-SLT coded 16-QAM system. By contrast, Scheme-3 of Table I first recovers and then re-encodes the source's bits at the relay. Thus, this process benefits from the coding gain of the SLT code. Therefore, its performance becomes substantially better than that of the two previous schemes. More particular by a $3dB$ gain was achieved for the same system even without inner iterations between the SLT decoder and the 16-QAM symbol-to-bit demapper. There is a further gain of approximately $2.5dB$, when four inner iterations are applied at the relay. The EXIT chart of Fig. 3 also reveals that at $E_b/N_0 = 4dB$ there is a widely open EXIT-tunnel for Scheme-3, which is not the case for Scheme-1 and Scheme-2. This implies that the DF relaying scheme, namely Scheme-3 of Table I, is expected to outperform the two remaining schemes. When increasing the number of inner iterations from one to two without increasing the number of inner iterations at the destination's receiver, the required SNR is reduced by about $1dB$. However, no additional obvious improvements are attained, when the number of iterations is further increased, as evidenced by the two overlapped curves of Scheme 3 in Fig. 2.

Fig. 4 illustrates our BER results for Scheme-2 and Scheme-3 of Table I at different source powers P_s. We assumed the total transmit power was fixed to unity, and the position of the RS is fixed at the mid-point between the SS and the DS. In Scheme-2, the BER degrades, when the sources power is increased. An E_b/N_0 difference of 2dB emerges, when increasing the sources' power from 0.33 to 0.80. However, the system performs best at $P_s = 0.5$ in Scheme-3. Both increasing and decreasing the sources power degrade the BER.

In Fig. 5 we assumed that the transmit powers at both the source and relay were 0.5, and the normalized distance between the source and the destination is unity. It can be observed in Fig. 5 that Scheme-2 performs slightly better, when the relay gets closer to the source, i.e. for $d_{sr} = 0.33$. Explicitly, an E_b/N_0 improvement of $0.5dB$ is seen, when changing the source-to-relay distance from 0.67 to 0.33. This observation suggests that Scheme-2 performs better for a relatively high received signal quality than for a lower quality, because in the latter case, it may suffer from excessive noise amplification. By contrast, the best location for Scheme-3 appears at $d_{sr} = 0.5$, where relaying achieves a good balance between correcting errors and avoiding error propagation.

Fig. 6 shows simulation results for IR-HARQ aided SLT coding in our wireless relay network. In these simulations, the SLT code $\{1000, 3000\}$, encoding 1000 uncoded bits into 3000 coded bits, was chosen, while the other parameters were the same as those of Scheme-3 in Table I. The first transmission employs the SLT code $\{1000, 2000\}$, and each IR transmission includes 200 extra bits. The maximum number of IR transmissions is five. The source's and relay's transmit powers are 0.67 and 0.33, respectively. If an IR transmission is required and the codeword recovered at the relay is legitimate, the relay will forward the data at a power of $P'_{relay} = P_s$. The "no-HARQ" scheme, where no retransmission was employed and the source simply transmitted all 3000 bits both to the RS and to the DS, is provided as a benchmarker for a convenient comparison.

When the passive cooperative IR-HARQ is applied, the number of IR transmissions required, marked by circles in Fig. 6.a, remains constant in the low E_b/N_0 region, namely below $2dB$. Then it successively decreases, until no more IR transmissions are required in the high E_b/N_0 region, namely above $8dB$. The trend is similar to that characterizing the active cooperative IR-HARQ strategy. However, the number of IR transmissions required by the active strategy is always lower. Particularly, the number of IR transmissions required, which is shown in the curve marked by triangles, is reduced by approximately 20% in the E_b/N_0 region between $4dB$ and $6dB$, while the source of the active cooperative scheme activates IR transmissions a third less frequently than the passive one.

Parameters	**Scheme-1**	**Scheme-2**	**Scheme-3**
Relaying type	none	AF	DF
N^o of data bits	1200	1200	1200
SLT code rate	1/2	1/2	1/2
Degree distribution type	TDD	TDD	TDD
Modulation type	16-QAM	16-QAM	16-QAM
N^o of outer iter.	8	8	8
N^o of inner iter. at RS	unavailable	unavailable	0, 2 & 4
N^o of inner iter. at DS	0 & 4	0 & 4	0 & 4

TABLE I
ID-SLT CODED 16-QAM SCHEMES' PARAMETERS

- outer inter.: iterations inside SLT decoders
- inner inter.: iterations between SLT decoders & 16-QAM demodulator

Fig. 6.b characterises the average transmit energy of the entire system with the aid of the continuous curves, while that of the relay is marked by the dash curves. Due to the reduction of the number of IR transmissions as mentioned in the context of Fig. 6.a, the total transmit energy also decreases in Figure 6.b. In the region between $4dB$ and $6dB$, the achievable power reduction is approximately 8%.

VI. CONCLUSION

In this paper, we have proposed a HARQ aided SLT coded 16-QAM system for wireless relay-aided networks in order to improve the attainable system performance. The simulation results show that when AF and DF relaying are employed along with the proposed SLT coded 16-QAM scheme, the system achieved a gain of about $2.5dB$ and $6dB$, respectively, at the BER of 10^{-5}, compared to the non-cooperative scheme where the 16-QAM and the SLT decoder operate independently. Moreover, we found that the AF relaying aided SLT coded 16-QAM scheme benefits more when the RS is roaming close to the source. By contrast, the DF relaying aided scheme achieves its best performance near the mid-point. The system's performance was improved by the cooperative ARQ protocol combined with SLT coding. More particularly, it reduces the number of IR transmissions by approximately 20%, while the total transmit power was reduced by about 8% in the E_b/N_0 region between $4dB$ and $6dB$.

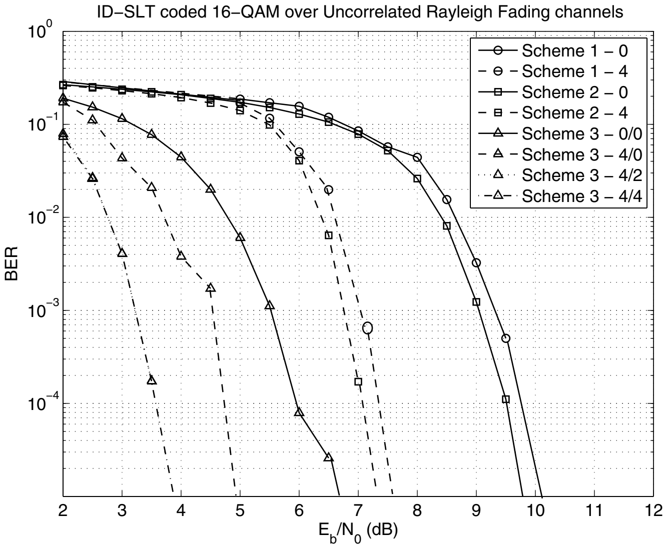

Fig. 2. BER of the ID-SLT coded 16-QAM schemes as shown in Table 1.
- Scheme A-x: Scheme A uses x inner iter. at DS.
- Scheme B-y/z: Scheme B uses y inner iter. at DS; and z inner iter. at RS.

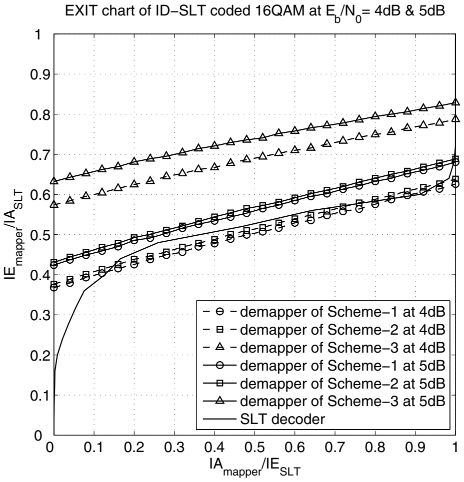

Fig. 3. EXIT chart for the ID-SLT coded 16-QAM schemes over uncorrelated Rayleigh fading channels at $E_b/N_0 = 4dB \ \& \ 5dB$

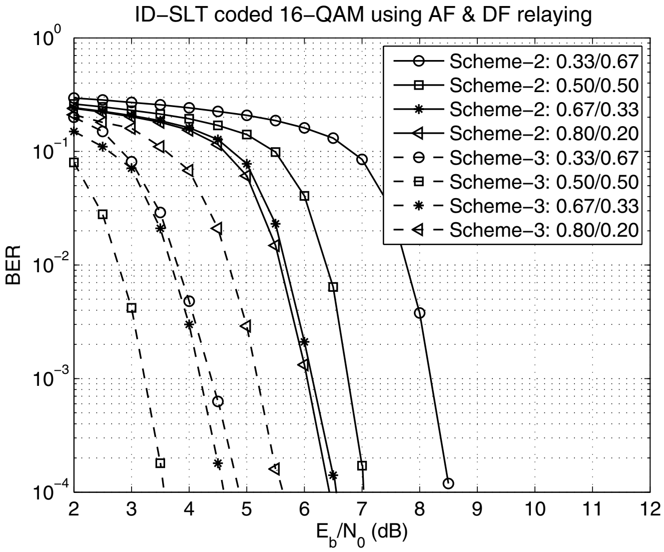

Fig. 4. BER of the ID-SLT coded 16-QAM scheme over uncorrelated Rayleigh fading channels in conjunction with AF and DF cooperation using different normalized source powers: $P_s = \{0.33, 0.50, 0.67, 0.80\}$ and $P_{relay} = 1 - P_s$; normalized distance of $d_{sr} = 0.5$ and $d_{rd} = 1 - d_{sr}$

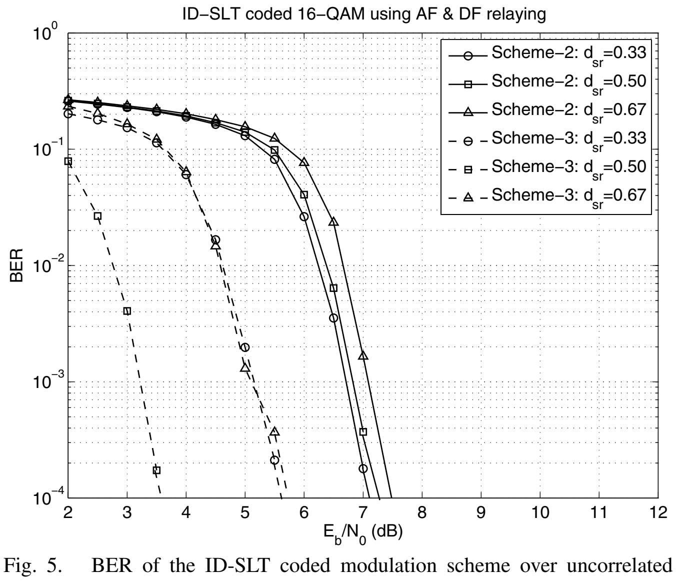

Fig. 5. BER of the ID-SLT coded modulation scheme over uncorrelated Rayleigh fading channels in conjunction with AF and DF cooperation using normalized source powers: $P_s = 0.50$ and $P_{relay} = 1 - P_s$; different normalized distance: $d_{sr} = \{0.33, 0.50, 0.67\}$ and $d_{rd} = 1 - d_{sr}$

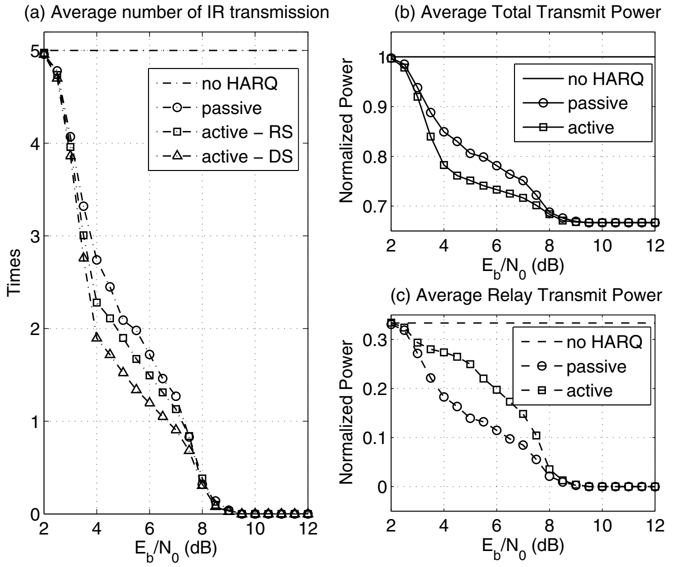

Fig. 6. Average number of IR transmissions & Average Transmit Energy over uncorrelated Rayleigh fading channels for different HARQ schemes

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