

Rate Adaptation for Decoding-and-Forward Relay Channel by Random Projections Codes

Min Wang, Qin Zou, Caihui Liu

College of Mathematics and Computer Science, Gannan Normal University, Ganzhou, China Email: mwangcs@gmail.com, qzoumath@gmail.com, liu_caihui@163.com

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Abstract

This paper investigates rate adaptation schemes for decoding-and-forward (DF) relay system based on random projections codes (RPC). We consider a classic three node relay system model, where relay node performs on half-duplex mode. Then, we give out receiving diversity relay scheme and coding diversity relay scheme, and present their jointly decoding methods. Furthermore, we discuss the performance of the two schemes with different power allocation coefficients. Simulations show that our relay schemes can achieve different gain with the help of relay node. And, we should allocate power to source node to just guarantee relay node can decode successfully, and allocate remain power to relay node as far as possible. In this way, this DF relay system not only achieves diversity gain, but also achieves higher and smooth spectrum efficiency.

Keywords

Rate Adaptation, Decoding-and-Forward Relay, Random Projections Codes, Rateless Code

1. Introduction

Rate adaptation is an important issue in wireless communication system. Traditional rate adaptation techniques implemented at transmitter, such as hybrid automatic repeat request (HARQ) and adaptive modulation and coding (AMC), have two defects. The first one is that it is always difficult to estimate channel state information (CSI) accurately, because the channel may vary drastically during several data packets transmission. The other one is that the transmission rate can be adjusted among limited modulation coding schemes (MCS), the coarse granularity of MCS results in a staircase of spectrum efficiency. To solve the two problems mentioned above, three new schemes [1]-[3] have proposed for smooth rate adaption, and all of them implement rate adaptation at receiver and attain continuous spectrum efficiency. Random projection codes (RPC) [3] [4] is a promising technique to implement rate adaption at receiver in modern wireless communication system.

How to cite this paper: Wang, M., Zou, Q. and Liu, C.H. (2016) Rate Adaptation for Decoding-and-Forward Relay Channel by Random Projections Codes. *Journal of Computer and Communications*, **4**, 169-179. http://dx.doi.org/10.4236/jcc.2016.44015 Relay is a new distributed space and time diversity technology. To improve system performance, relay system makes use of the broadcast feature of wireless communications. And it enhances energy efficient and enlarge transmitting range by multi-user's collaboration. Furthermore, under the condition of no CSI, relay system can adaptively modulate and transmit data by using rateless code. Tian *et al.* [5] have proposed a novel encode method of rateless code to resolve the error floor problem of LT code [6] for wireless relay networks. based on decode-and-forward (DF) and compress-and-forward protocols, Chen *et al.* [7] have proposed a full-duplex adaptive relaying scheme by using Raptor codes [8]. Reference [9]-[11] have investigated distributed LT codes, and analyze the asymptotic performance of their proposed distributed coding schemes. Yue *et al.* [12] [13] have proposed raptor-based distributed network codes scheme, and have given the derivation of upper and lower bit error rate (BER) for their proposed scheme.

However, these schemes and their analysis are all based on LT codes or raptor codes. This paper investigates the rate adaptation schemes based on random projections codes for decoding-and-forward (DF) relay system. We consider classic three node relay system model [14]. In this system model, relay node performs on halfduplex mode. The communication channel is divided broadcast channel and forward channel. Source node uses random projections matrix (RPM) G_1 to encode, and broadcasts progressively modulation symbols to relay node and destination node. In forward mode, relay node uses RPM G_r to encode, and forwards progressively modulation symbols to destination node. Destination node will joint decoding after receiving signals from source node or relay node. If decoding successfully, destination node will feedback ACK to source node and relay node, and prepare for transmission of next data frame. Otherwise, it will receive successive signals.

How to design relay schemes is a critical problem. This paper proposes receiving diversity scheme and coding diversity scheme, and presents the joint decoding methods. Furthermore, we discuss the system performance of two relay schemes with different power allocation coefficients. Simulations show that the most power allocation coefficients achieve different gain with the help of relay node. We should allocate power to source node to just guarantee relay node decoding successfully, and allocate remain power to relay node as far as possible. In this way, this DF relay system not only achieves diversity gain, but also achieves higher and smooth spectrum efficiency.

The rest of this paper is organized as follows. Section 2 briefly reviews RPC and its standard decoding algorithm. Section 3 presents the classic relay system model of three nodes, and collaboration scheme based on RPC. Section 4 proposes the decoding and forward relay schemes. The simulation evaluations are included in Section 5. Finally, Section 6 concludes this paper with some discussions on future work.

2. Introduce to Random Projections Codes

In this section, we review the RPC [4] and present the decoding algorithm.

2.1. RPC Encoding

A bipartite graph representation of RPC encoding is provided in Figure 1. Red square and blue circle denote symbol nodes and variable nodes, respectively. Each edge is assigned with a weight $w \in W$, where



 $W = \{w_1, w_2, \dots, w_L\}$ is a vector of real number with length *L*. The bipartite graph can be represented by G = (U, V, E), where $U = b_j$, $j = 1, \dots, N$ is the set of bits, $V = s_i$, $i = 1, \dots, M$ is the set of measurements representing modulated symbols, and *E* defines the connection between the two sets. In RPC encode, the signal entries are binary. Each coded symbol is calculated by

$$s_i = \sum_{l \in N(i)} w_{i_l} \cdot b_{i_l} \tag{1}$$

where w_{i_i} is the weight corresponding to i_i -th bit b_{i_i} , N(i) denotes the set of neighbors of *i*-th variable or symbol node. The RPC encoding process can be described by

$$\boldsymbol{s} = \boldsymbol{G} \cdot \boldsymbol{b} \tag{2}$$

where G is a RPM with $M \times N$, b is a bits block with length N, s is the RPC encoded symbols vector with length M.

In order to make use of two dimensional modulation, two consecutive symbols are combined together to form In-phase and Quadrature-phase (IQ) modulation symbol, *i.e.*, $x_i = s_{2i-1} + \sqrt{-1} \cdot s_{2i}$, $i = 1, \dots, N/2$.

2.2. RPC Decoding

RPC decoding algorithm uses belief propagation algorithm which is different from LDPC [15] [16]. Since RPC is employing weighted sum check, probability convolution operation is used in horizontal iteration instead of log(tanh) operation in LDPC. The decoding algorithm of RPC scheme is depicted as factor graph shown in **Figure 1**. The edges with a weight w_{ij} denotes the connections between variable nodes and corresponding symbol nodes, arrow line denotes the probability message flow. r_{ij}^t defines the probability message from the *i*-th symbol node to the *j*-th variable node in the *t*-th iteration. $q_{ji}^{(t+1)}$ defines the probability message from the *j*-th variable node in the (t + 1)-th iteration. The probability message $q_{ji}^{(t+1)}$ is computed by the multiplication of probability values r_{ij}^t , $i' \in N(j) \setminus i$, from all its neighbors excluding the *i*-th symbol node. Similarly, the probability message r_{ij}^t is given by the convolution of the channel priori probability and all probability values $q_{ji}^{(t-1)}$, $j' \in N(i) \setminus j$, from its neighbors except *j*-th variable node. The RPC decoding algorithm include initialization, horizontal processing, vertical processing and decision steps. Audience interested in the RPC decoding algorithm are referred to reference [4].

In summary, RPC is a linear code with rateless characteristics like LT codes. It is obvious that RPC can generate infinity symbols when the row number of G is infinity. RPC adopts weighted sum to check received symbol rather than odd even parity used in LT codes and LDPC. RPC decoding reuses the framework of sum product algorithm for LDPC, but probability convolution operation is used in horizontal iteration instead of log(tanh) operation. The obvious difference is that RPC combines channel coding and modulation together, and aims to implement rate adaption. In contrast, LDPC is only channel coding scheme.

3. System Model

3.1. Channel Model

We consider the Gaussian relay system model shown in **Figure 2**. This system model includes three nodes, *i.e.*, source node denoted as *S*, relay node denoted as *R*, and destination node denoted as *D*. There are three channel links, *i.e.*, *SD* link, *SR* link and *RD* link. The distance between the source node and the destination node is normalized to 1, *d* denotes the distance between the source node and the relay node, and (1-*d*) denotes the distance between the relay node, and the destination node. Here, we set d = 0.5 and channel fading factor $\alpha = 2$. Then, The corresponding channel gains of *SD*, *SR* and *RD* link are $c_{rd} = 4$, $c_{sr} = 4$ and $c_{rd} = 4$, respectively.

Assuming that the relay node *R* performs in half duplex mode, the relay channel is divided into broadcast mode (BC) and forward mode (FM). If $t(0 \le t \le 1)$ denotes the time slot of BC mode, then (1-t) is the time slot of FM mode. In BC mode, source node *S* transmits signals x_1 in *t* time slot. The received signals at relay node *R* and destination node *D* are



$$y_r = \sqrt{c_{sr}} x_1 + n_r \tag{3}$$

and

$$y_{d_1} = \sqrt{c_{sd}} x_1 + n_{d_1}$$
 (4)

respectively. Here, n_r and n_{d_1} are the AWGN noise in R and D, respectively.

After BC transmitting, relay node R starts decoding based on y_r . If successfully decoding, R re-encodes and modulates signals for D in FM mode. Otherwise, R keeps silence. Such that D may receives signals from R.

$$y_{d_2} = \sqrt{c_{rd}} x_r + n_{d_2}$$
(5)

where x_r is the modulation signals in relay node *R*, and n_{d_2} is the AWGN noise at destination node *D* in FM mode.

We define the random variables of n_r , n_{d_1} and n_{d_2} are Z_r , Z_{d_1} and Z_{d_2} , respectively. And, we let the powers of Z_r , Z_{d_1} and Z_{d_2} are unit energy. We define the random variable of x_r is X_r , and the random variable of x_1 is X_1 . So, system resource can be characterized by total power *P*. P_r denotes average symbols energy of X_r , P_{s_1} denotes average symbols energy of X_1 . The constraint of transmitting power at *S* and *R* are

$$E\left[\left|X_{1}\right|^{2}\right] \leq P_{s_{1}} \tag{6}$$

and

$$E\left[\left|X_{r}\right|^{2}\right] \leq P_{r} \tag{7}$$

respectively. Furthermore, system resource allocation is under constraint of inequality (8).

$$tP_{s_1}\left(1-t\right)P_r \le P \tag{8}$$

3.2. Collaboration Scheme Based on RPC

We assume that source node *S* uses RPM G_1 to encode in BC mode, and relay node *R* uses RPM G_r to encode in FM mode. Let $\boldsymbol{b} = [b_1, b_2, \dots, b_N]$ denotes the bits block at resource node *S*. We use the method proposed in [17] to construct RPM. To ensure power of transmitting symbols match the transmission power, we introduce two scaling parameters α_{s_1} and α_r corresponding to x_1 and x_r , respectively. Equation (3) can be rewritten by

$$y_r = \sqrt{c_{sr}} \alpha_{s_l} G_l b + n_r \,. \tag{9}$$

If relay node R participates in collaboration communications, Equations (4) and (5) can be changed as

$$\begin{cases} y_{d_1} = \sqrt{c_{sd}} \,\alpha_{s_1} G_1 b + n_{d_1} \\ y_{d_2} = \sqrt{c_{rd}} \,\alpha_r G_r b + n_{d_2} \end{cases}$$
(10)

Otherwise, destination node D starts decode by using received signals y_{d_1} in BC mode.

To implement rate adaptation in DF relay system, we propose following communication protocol. Assuming that source node S can completely synchronize with relay node R. Given a SNR, source node S first broadcasts k_0 modulation symbols. Then, S broadcasts progressively k_{Δ} modulations symbols in the subsequent time slots. After the first successfully decoding, relay node R transmits $(k_0 + lk_{\Delta})$ modulation symbols in the first FD mode. Here, l is the number of transmitting progressively. Then, relay node R forwards progressively k_{Δ} modulation symbols to destination node D at subsequent FD mode. Destination node D starts decoding after receiving all the symbols from relay node and source node. If successfully decoding, destination node will feedback ACK to source node S and relay node R. And, source node S and relay node R will transmit next bits block. Otherwise, source node S and relay node R continue progressively transmit modulation symbols.

4. Decoding-and-Forward Scheme

It is important that how to design relay schemes according to two random projections matrix G_1 and G_r . In this section, we discuss two schemes as following.

4.1. Receiving Diversity Scheme

In this scheme, we let $G_1 = G_r$. The modulation symbols of source node *S* in BC mode are the same as modulation symbols of relay node *R* in FM mode, *i.e.*, $x_1 = x_r$. There are two cases should be discussed according to whether relay node *R* forward information to destination node *D*.

The first case is that relay node R has participated in collaboration communication. Destination node D receives two signal vectors with the same symbols and different noise. After simple deformation, Equation (10) can be written as

$$\begin{cases} \tilde{y}_{d_1} = G_1 b + \tilde{n}_{d_1} \\ \tilde{y}_{d_2} = G_1 b + \tilde{n}_{d_2} \end{cases}$$
(11)

where $\tilde{n}_{d_1} = \frac{1}{\sqrt{c_{sd}}\alpha_{s_1}}n_{d_1}$, $\tilde{n}_{d_2} = \frac{1}{\sqrt{c_{rd}}\alpha_r}n_{d_2}$. The standard variance of \tilde{n}_{d_1} and \tilde{n}_{d_2} are $\tilde{\sigma}_{d_1} = \frac{1}{\sqrt{c_{sd}}\alpha_{s_1}}$ and

 $\tilde{\sigma}_{d_2} = \frac{1}{\sqrt{c_{rd}}\alpha_r}$, respectively. Furthermore, we can use maximum ratio combining (MRC) to reduce channel

noise, and get

$$y_d = \frac{\tilde{y}_{d_1}\tilde{\sigma}_{d_2} + \tilde{y}_{d_2}\tilde{\sigma}_{d_1}}{\tilde{\sigma}_{d_1} + \tilde{\sigma}_{d_2}}$$
(12)

and

$$\sigma_d = \sqrt{\frac{\tilde{\sigma}_{d_1}\tilde{\sigma}_{d_2}^2 + \tilde{\sigma}_{d_2}\tilde{\sigma}_{d_1}^2}{\tilde{\sigma}_{d_1}^2 + \tilde{\sigma}_{d_2}^2}} .$$
(13)

The second case is that destination node *D* only receives signals \tilde{y}_{d_1} from source node *S*.

Finally, Destination node D can get the estimation of bits block b by calling the standard decoding algorithm of RPC and RPM G_1 .

4.2. Coding Diversity Scheme

In this scheme, we set $G_1 \neq G_r$. The modulation symbols transmitted by source node *S* in BC mode are different with the modulation symbols sent by relay node *R* in FM mode, *i.e.*, $x_1 \neq x_r$. Like receiving diversity scheme, we also discuss two case as following.

If relay node R has participated in collaboration communication, the received signals in destination node D are

$$\begin{cases} \tilde{y}_{d_1} = G_1 b + \tilde{n}_{d_1} \\ \tilde{y}_{d_2} = G_r b + \tilde{n}_{d_2} \end{cases}$$
(14)

where $\tilde{n}_{d_1} = \frac{1}{\sqrt{c_{sd}}\alpha_{s_1}}n_{d_1}$, $\tilde{n}_{d_2} = \frac{1}{\sqrt{c_{rd}}\alpha_r}n_{d_2}$. Since $G_1 \neq G_r$, destination node *D* needs find linear equation (14).

Here, the *SNR* of \tilde{y}_{d_1} is $\sqrt{c_{sd}} P_{s_1}$, and the *SNR* of \tilde{y}_{d_2} is $\sqrt{c_{rd}} P_r$. In this case, we can't use directly RPC decoding algorithm to estimate bits block \boldsymbol{b} . We need modify two place in decoding algorithm. The first one is that we let $\boldsymbol{G} = [\boldsymbol{G}_1; \boldsymbol{G}_r]$, and make use of \boldsymbol{G} to estimate bits block \boldsymbol{b} . The another one is that we use \tilde{n}_{d_1} to perform noise probability convolution when horizontal iteration in \boldsymbol{G}_1 , and use \tilde{n}_{d_2} to perform noise probability convolution iteration in \boldsymbol{G}_r .

If relay node *R* isn't participate in communication, destination node *D* only receives signals \tilde{y}_{d_1} . In this case, we can call directly RPC decoding algorithm to estimate bits block **b**.

5. Simulations

In this section, we evaluate our proposed schemes by BER and capacity metrics in simulations. β_1 denotes the proportion that P_{s_1} accounted for the total power P, β_r denotes the proportion that P_r accounted for the total power P. And it must satisfy the condition $\beta_1 + \beta_r = 1$. Because it is hard to find the closed-form of BER, we analyze the influence that power allocation to relay schemes by running simulations. Table 1 gives out seven pairs of power allocation coefficients. In simulations, we choose $W = \{\pm 4, \pm 4, \pm 2, \pm 1\}$ as weight set, and use the method proposed in [17] to construct RPM.

5.1. Comparison of BER Performance

In BER simulations, we set the length of bits block N = 400, rate is 1bps, and *SNR* range is from 5 dB to 15 dB. Figure 3 and Figure 4 describe the *BER* performance comparison among different power allocation coefficients in receiving diversity scheme and coding diversity scheme, respectively. From this two figures, we can observe



Figure 3. BER performance comparison among different power allocation coefficients in receiving diversity scheme.



Figure 4. BER performance comparison among different power allocation coefficients in coding diversity scheme.

Table 1. Power allocation coefficients.							
	1	2	3	4	5	6	7
$\beta_{_1}$	0.5	0.7	0.3	0.4	0.6	0.2	0.8
eta_r	0.5	0.3	0.7	0.6	0.4	0.8	0.2

two interesting points. The first one is that most power allocation coefficients achieve different gain compare to the *BER* performance of original *SD* direct link. And, the gain is larger with β_1 increasing in low *SNR* range. The reason is that the probability of decoding successfully at relay node is low, and the power allocated to source node decides the performance of relay system. Contrarily, the gain is larger with β_r increasing in high *SNR* range. With the increasing of *SNR*, the probability of decoding successfully at relay node is enhanced, and the more power allocated to relay node can help destination node decoding. But, when β_1 equals to 0.2 or 0.3, the BER performance of relay schemes are lower than original *SD* direct link in all *SNR* range. The reason is that relay node can't decoding successfully and the power allocated to relay node is too high. This results in the waste of power.

Figure 5 describes the *BER* performance comparison between receiving diversity and coding diversity with the same of power allocation coefficients. From these figures, we can't observe which relay scheme achieves better performance than other. The reason is that the rate is 1bps, it is not enough to distinguish whose *BER* performance is better.

5.2. Comparison of Capacity Performance

In capacity simulations, we set the length of bits block N = 400. To implement rata adaptation, we stack a RPM with 400×400 four times to form a bigger RPM with 1600×400 . The number of transmitting progressively equals to 10. The *SNR* range is from 5 dB to 30 dB, and we run 1000 data frames in each *SNR*. We first compare the capacity performance between RPC and AMC schemes of IEEE 802.11a, as shown in **Figure 6**. RPC attains continuous and smooth spectrum efficiency, and its capacity performance is better than that of AMC. Then, we present the capacity performance comparison of our proposed schemes. **Figure 7** and **Figure 8** show the capacity performance comparison among different power allocation coefficient in receiving diversity scheme and coding diversity scheme, respectively.



Figure 5. BER performance comparison between receiving diversity scheme and coding diversity scheme with different power allocation coefficients. (a) $\beta_1 = 0.2$, $\beta_r = 0.8$; (b) $\beta_1 = 0.3$, $\beta_r = 0.7$; (c) $\beta_1 = 0.4$, $\beta_r = 0.6$; (d) $\beta_1 = 0.8$, $\beta_r = 0.2$; (e) $\beta_1 = 0.7$, $\beta_r = 0.3$; (f) $\beta_1 = 0.6$, $\beta_r = 0.4$.



Figure 6. Capacity performance comparison between RPC and AMC schemes of IEEE 802.11a.



Figure 7. Capacity performance comparison in receiving diversity scheme.



Figure 8. Capacity performance comparison in coding diversity scheme.

From Figure 7, we can observe three interesting points. The first one is that most power allocation coefficients can achieve different gain with the help of relay node, except $(\beta_1 = 0.2, \beta_r = 0.8)$. The highest capacity of relay system of $(\beta_1 = 0.6, \beta_r = 0.4)$ reaches 7.18 *bits/symbols/Hz*, while SD direct link only reaches 6.63 bits/symbols/Hz. The maximum gain of relay system is 1.07 bits/symbols/Hz at *SNR* = 22 dB, the minimum gain of relay system is 0.38 bits/symbols/Hz at *SNR* = 6 dB. The second one is that capacity performance gains are larger with β_1 increasing in low *SNR* range. The third one is that the capacity performance relates to the proportion of β_1 and β_r . The capacity performance curve of $(\beta_1 = 0.7, \beta_r = 0.3)$ can verify this point. It first crosses with the performance curve of $(\beta_1 = 0.3, \beta_r = 0.7)$ at *SNR* = 26 dB. And it is under the performance curve of $(\beta_1 = 0.3, \beta_r = 0.7)$ when *SNR*> 26 dB. This phenomenon illustrates that $(\beta_1 = 0.3, \beta_r = 0.7)$ just satisfies the condition of decoding successfully of relay node at *SNR* = 26 dB, and the rest of power is allocated to relay node. While $(\beta_1 = 0.7, \beta_r = 0.3)$ wastes energy because of source node with too much energy.

From **Figure 8**, we also observe similar features as receiving diversity. Firstly, compare to the *SD* direct link, the power allocation coefficients, except $(\beta_1 = 0.2, \beta_r = 0.8)$ and $(\beta_1 = 0.8, \beta_r = 0.2)$, achieve different capacity gain with the help of relay node. The highest capacity of $(\beta_1 = 0.5, \beta_r = 0.5)$ reaches 7.21 bits/symbols/ Hz. Secondly, in low *SNR* range, the capacity gains are larger with the β_1 increasing. Thirdly, with the *SNR* increasing, capacity is not only relate to the proportions of β_1 and β_r , but also relate to the relay schemes. We find that $(\beta_1 = 0.8, \beta_r = 0.2)$, $(\beta_1 = 0.7, \beta_r = 0.3)$ and $(\beta_1 = 0.6, \beta_r = 0.4)$ have outstanding performance in low *SNR* range, and their capacity performance less than others in high *SNR* range.

Figure 9 shows the capacity comparison between receiving diversity scheme and coding diversity scheme with the same power allocation coefficient. We find two interesting phenomenon from these figures. For top figures, in low *SNR* range, the capacity performance of two schemes is very close, and from a loss to more gain gradually with β_1 increasing. While in high *SNR* range, coding diversity scheme achieve more gain than receiving diversity. And, the cross points are higher with β_1 increasing. The cross values are 18 dB, 21 dB and 22 dB, respectively. For bottom figures, in low *SNR* range, the capacity performance of two schemes are very close. While, the capacity performance of receiving diversity is better than coding diversity in high *SNR* range, and worse than coding diversity in middle *SNR* range.

6. Conclusions

This paper presents a rate adaptation scheme for DF relay channel by RPC. We consider a classic relay system model of three nodes, where relay node performs on half-duplex mode. And, we propose receiving diversity and coding diversity relay schemes, and their joint decoding methods. We also discuss the performance of receiving



Figure 9. Capacity performance comparison between receiving diversity scheme and coding diversity scheme with different power allocation coefficients. (a) $\beta_1 = 0.2$, $\beta_r = 0.8$; (b) $\beta_1 = 0.3$, $\beta_r = 0.7$; (c) $\beta_1 = 0.4$, $\beta_r = 0.6$; (d) $\beta_1 = 0.8$, $\beta_r = 0.2$; (e) $\beta_1 = 0.7$, $\beta_r = 0.3$; (f) $\beta_1 = 0.6$, $\beta_r = 0.4$.

diversity and coding diversity schemes with different power allocation coefficients. Simulations show that our DF relay schemes can achieve capacity gain with the help of relay node. Given a *SNR*, power should be allocated to relay node as far as possible under a condition which ensure relay node can decode successfully.

In the future, we will work on the optimization design of distributed random projections codes by degree distribution and EXIT analysis method. Especially, we focus on how to select weight set and construct random projections matrix.

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References

- Gudipati, A. and Katti, S. (2011) Strider: Automatic Rate Adaptation and Collision Handling. ACM SIGCOMM Computer Communication Review, Toronto, 15-19 August 2011, 158-169. <u>http://dx.doi.org/10.1145/2043164.2018455</u>
- [2] Perry, J., Iannucci, P.A., Fleming, K.E., Balakrishnan, H. and Shah, D. (2012) Spinal Codes. Proceedings of the ACM SIGCOMM 2012 Conference on Applications, Technologies, Architectures, and Protocols for Computer Communication, 49-60. <u>http://dx.doi.org/10.1145/2342356.2342363</u>
- [3] Cui, H., Luo, C., Wu, J., Chen, C.W. and Wu, F. (2013) Compressive Coded Modulation for Seamless Rate Adaptation. *IEEE Transactions on Wireless Communications*, 12, 4892-4904. <u>http://dx.doi.org/10.1109/TWC.2013.090413.121308</u>
- [4] Cui, H., Luo, C., Tan, K., Wu, F. and Chen, C.W. (2011) Seamless Rate Adaptation for Wireless Networking. Proceedings of the 14th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems, Miami, 31 October-4 November 2011, 437-446. <u>http://dx.doi.org/10.1145/2068897.2068971</u>
- [5] Tian, S., Li, Y. and Vucetic, B. (2013) A Rateless Code for Dynamic Decode-and-Forward Relaying in Wireless Relay Networks. *IEEE Wireless Communications and Networking Conference (WCNC)*, Shanghai, 7-10 April 2013, 3551-

3556.

- [6] Luby, M. (2002) LT Codes. Proceedings of the 43rd Annual IEEE Symposium on Foundations of Computer Science, 271-280. <u>http://dx.doi.org/10.1109/sfcs.2002.1181950</u>
- [7] Chen, Y.-M., Lo, H.-L., Ueng, Y.-L. and Lee, H.-C. (2013) A Cooperative System Using an Adaptive Relaying Protocol and Rateless Codes. *IEEE 78th Vehicular Technology Conference (VTC Fall)*, 2-5 September 2013, 1-5.
- Shokrollahi, A. (2006) Raptor Codes. *IEEE Transactions on Information Theory*, 52, 2551-2567. http://dx.doi.org/10.1109/TIT.2006.874390
- [9] Yang, H., Jiang, M., Shen, H. and Zhao, C. (2015) A Distributed LT Code Design for Multiple-Access Relay Networks Subject to Erasures. *IEEE Communications Letters*, 19, 509-512. <u>http://dx.doi.org/10.1109/LCOMM.2015.2398412</u>
- [10] Hussain, I., Xiao, M. and Kildehoj Rasmussen, L. (2015) Erasure Floor Analysis of Distributed LT Codes. *IEEE Transactions on Communications*, 63, 2788-2796. <u>http://dx.doi.org/10.1109/TCOMM.2015.2451640</u>
- [11] Shao, H., Xu, D. and Zhang, X. (2015) Distributed Luby Transform Coding for Three-Source Single-Relay Networks Based on the Deconvolution of Robust Soliton Distribution. *IET Communications*, 9, 167-176. <u>http://dx.doi.org/10.1049/iet-com.2014.0586</u>
- [12] Yue, J., Lin, Z., Vucetic, B., Mao, G. and Aulin, T. (2013) Performance Analysis of Distributed Raptor Codes in Wireless Sensor Networks. *IEEE Transactions on Communications*, 61, 4357-4368. <u>http://dx.doi.org/10.1109/TCOMM.2013.090513.120913</u>
- [13] Yue, J., Lin, Z., Vucetic, B., Mao, G. and Aulin, T. (2014) Performance Analysis of Distributed Raptor Codes in Wireless Relay Networks. 11th Annual IEEE International Conference on Sensing, Communication, and Networking (SECON), Singapore, 30 June-3 July 2014, 221-229.
- [14] Van Der Meulen, E.C. (1971) Three-Terminal Communication Channels. Advanced Applied Probability, 3, 120-154.
- [15] Gallager, R. (1962) Low-Density Parity-Check Codes. Ph.D. Dissertation, MIT, Cambridge.
- [16] MacKay, D. and Neal, R. (1997) Near Shannon Limit Performance of Low Density Parity Check Codes. *Electronics Letters*, 33, 457-458. <u>http://dx.doi.org/10.1049/el:19970362</u>
- [17] Wang, M., Wu, J., Shi, S.F., Luo, C. and Wu, F. (2012) Fast Decoding and Hardware Design for Binary-Input Compressive Sensing. *IEEE Journal on Emerging and Selected Topics in Circuits and Systems*, 2, 591-603.