(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
1 April 2010 (01.04.2010)

PCT

(10) International Publication Number
WO 2010/036809 A2

(51) International Patent Classification:
H04L 1/00 (2006.01)

(21) International Application Number:
PCT/US2009/058240

(22) International Filing Date:
24 September 2009 (24.09.2009)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/194,209 25 September 2008 (25.09.2008) US

(71) Applicant *(for all designated States except US)*: **ALCATEL-LUCENT USA INC.** [US/US]; 600-700 Mountain Avenue, Murray Hill, NJ 07974-0636 (US).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: **JACOBSEN, Noah, B.** [US/US]; 357 W. 39th Street Apartment 1, New York City, NY 10018 (US).

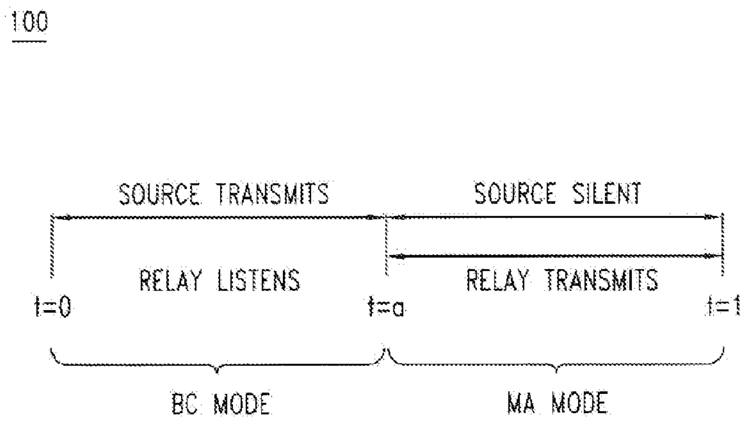
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

(54) **Title**: METHOD AND APPARATUS FOR RELAYING INFORMATION

FIG. 1



(57) **Abstract**: To address the need for new relay communications techniques that are able to increase communication rates, lower power consumption, and/or reduce interference, various embodiments are described. In some embodiments, a code rate is selected (901) to maximize a source-to-relay link capacity based on at least one resource constraint and a link quality between a source node and a relay node. Information encoded at the selected coding rate is then broadcast (902) to both a relay node and the destination node during a first coding interval. In some embodiments, the at least one resource constraint includes the amount of transmit power allocated to broadcasting the information.

WO 2010/036809 A2

METHOD AND APPARATUS FOR RELAYING INFORMATION

Reference(s) to Related Application(s)

The present application claims priority from a provisional application, Serial No. 61/194209, entitled "TDMA CODE DESIGN FOR HALF-DUPLEX RELAY SYSTEM," filed September 25, 2008, which is commonly owned and incorporated herein by reference in its entirety.

Field of the Invention

The present invention relates generally to communications and, in particular, to relaying information in wireless communication systems.

Background of the Invention

The relay channel has been studied actively by the information theory community since pioneer work by Cover and El Gamal in the 1970s [1]. The capacity of the relay channel, though characterized for certain specific cases, is in general an open problem. Practically speaking, relays have been used for wireless communication for a while, either as amplify-and-forward radios which simply re-transmit a scaled version of the received signal or as a multi-hop device which is capable of decoding and retransmitting the source message. New solutions in this space that are able to increase communication rates, lower power consumption, and/or reduce interference are clearly desirable.

Brief Description of the Drawings

FIG. 1 is a diagram depicting a time-axis representation of a half-duplex relay channel.

FIG. 2 is a diagram depicting a linear relay geometry.

FIG. 3 is a graph depicting a numerical evaluation of bounds for the linear geometry with distance d = 1/2 and path loss p = 3.

FIG. 4 is a graph depicting capacity of a TDMA relay system with various input constellations.

FIG. 5 is a graph depicting TDMA LDPC relay code performance with BPSK inputs.

FIG. 6 is a graph depicting capacity results for both TDMA and Multi-Hop (MH) relay codes.

FIG. 7 is a logic flow diagram of relay functionality in accordance with various embodiments of the present invention.

FIG. 8 is a logic flow diagram of relaying information in accordance with various embodiments of the present invention.

FIG. 9 is a logic flow diagram of relaying information in accordance with various embodiments of the present invention.

Specific embodiments of the present invention are disclosed below with reference to FIGs. 1-9. Both the description and the illustrations have been drafted with the intent to enhance understanding. For example, the dimensions of some of the figure elements may be exaggerated relative to other elements, and well-known elements that are beneficial or even necessary to a commercially successful implementation may not be depicted so that a less obstructed and a more clear presentation of embodiments may be achieved. In addition, although the logic flow diagrams above are described and shown with reference to specific steps performed in a specific order, some of these steps may be omitted or some of these steps may be combined, sub-divided, or reordered without departing from the scope of the claims. Thus, unless specifically indicated, the order and grouping of steps is not a limitation of other embodiments that may lie within the scope of the claims.

Simplicity and clarity in both illustration and description are sought to effectively enable a person of skill in the art to make, use, and best practice the present invention in view of what is already known in the art. One of skill in the art will appreciate that various modifications and changes may be made to the specific embodiments described below without departing from the spirit and scope of the present invention. Thus, the specification and drawings are to be regarded as illustrative and exemplary rather than restrictive or all-encompassing, and all such modifications to the specific embodiments described below are intended to be included within the scope of the present invention.

Summary of the Invention

To address the need for new relay communications techniques that are able to increase communication rates, lower power consumption, and/or reduce interference, various embodiments are described. In some embodiments, signaling is received during a first coding interval, the signaling being encoded at a first coding rate to convey information from a source node. During a second coding interval, subsequent to the first coding interval, signaling is received from a relay node. The signaling from the relay node is based on signaling received at the relay node from the source node. The information from the source node is then recovered using the signaling received from the source node and the signaling received from the relay node.

Additionally, in some embodiments, signaling is received from a source node during a first coding interval and then decoded. During a second coding interval, subsequent to the first coding interval, relay signaling based on the decoded signaling is transmitted. Information from the source node is then recovered using the signaling received from the source node and signaling received from a relay node. In these embodiments, transmitting the relay signaling may involve encoding based on a source-to-destination link quality and a relay-to-destination link quality.

Additionally, in some embodiments, a code rate is selected to maximize a source-to-relay link capacity based on at least one resource constraint and a link quality between a source node and a relay node. Information encoded at the selected coding rate is then broadcast to both a relay node and the destination node during a first coding interval. In these embodiments, the at least one resource constraint may include transmit power allocated to broadcasting the information.

Detailed Description of Embodiments

To provide a greater degree of detail in making and using various aspects of the present invention, a description of our approach to wireless relay communications and a description of certain, quite specific, embodiments follows for the sake of example. FIGs. 1-6 are referenced in an attempt to illustrate some examples of specific embodiments of the present invention and/or how some specific embodiments may operate.

A list of references is provided below and is referred throughout the description that follows:

[1] T. M. Cover and A. El Gamal, "Capacity theorems for the relay channel," IEEE Trans. Inform. Theory, vol. 25, no. 5, pp. 572–584, Sept. 1979.

[2] G. Kramer, M. Gastpar, and P. Gupta, "Cooperative strategies and capacity theorems for relay networks," IEEE Trans. Inform. Theory, vol. 51, no. 9, pp. 3037–3063, Sept. 2005.

[3] D. Blackwell, L. Breiman, and A. J. Thomasian, "The capacity of a class of channels," Annals of Mathematical Statistics, vol. 30, no. 4, pp. 1229–1241, Sept. 1959.

[4] W. L. Root and P. P. Varaiya, "Capacity of classes of Gaussian channels," SIAM Journal on Applied Mathematics, vol. 16, no. 6, pp. 1350–1393, Nov. 1968.

[5] S. Vishwanath, S. Jafar, and S. Sandhu, "Half-duplex relays: cooperative communication strategies and outer bounds," in International Conference on Wireless Networks, Communications and Mobile Computing, Maui, HI, USA, June 2005.

[6] S. ten Brink, G. Kramer, and A. Ashikhmin, "Design of low-density parity-check codes for modulation and detection," IEEE Trans. Commun., vol. 52, no. 4, pp. 670–678, Apr. 2004.

[7] N. Jacobsen and R. Soni, "Design of rate-compatible irregular LDPC codes based on edge growth and parity splitting," in Proc. IEEE Vehicular Tech. Conf. (VTC), Baltimore, MD, Sept. 2007.

[8] M. Tüchler and J. Hagenauer, "EXIT charts of irregular codes," in Proc. Conf. on Inform. Sciences and Systems (CISS), Princeton, NJ, USA, Mar. 2002.

[9] T. Richardson, A. Shokrollahi, and R. Urbanke, "Design of capacity-approaching irregular low-density parity-check codes," IEEE Trans. Inform. Theory, vol. 47, no. 2, pp. 619–637, Feb. 2001.

[10] "LdpcOpt," http://lthcwww.epfl.ch/research/ldpcopt/.

Herein, we consider the so called decode-and-forward protocol, in which the relay decodes all or part of the source transmission and cooperatively communicates the source bits to the destination. By leveraging the cooperative capability of the relay, a decode-and-forward system is able to yield capacity approaching performance for many important channel geometries. Further, we show that a practical code design is able to perform well with respect to information theoretic benchmarks. Other strategies, including the amplify-and-forward and compress-and-forward protocols, are known to be preferable in certain other cases [2].

The half-duplex relay channel is considered. In the half-duplex model, during one coding interval, the relay listens to the source transmission for a fraction α of the total time and transmits cooperatively with the source for the remaining $1-\alpha$ fraction of time. The slotted format arises due to the inability of the relay to simultaneously transmit and receive radio signals. This constraint portrays current radio hardware limitations. Diagram 100 depicts a time-axis representation of a half-duplex relay channel. The first time slot, during which the relay and destination listen to the source signal, is termed the Broadcast (BC) mode, and the second slot, during which the relay and source are transmitting, is termed the Multiple-Access (MAC) mode. The time-sharing parameter α is chosen to maximize the capacity.

In designing the source and relay encoders, the flexibility to simultaneously address a variety of channel geometries is emphasized, thereby maximizing the utility. The goal is to approach the capacity uniformly over the set of possible channel realizations. For this, a simple linear geometry is assumed, and the relay channel is viewed as a class of channels parameterized by the Signal-to-Noise Ratio (SNR) of its constituent links. The capacity of a class of channels is known [3], [4], and the existence of so-called "universal codes," which uniformly approach the capacity, is proved.

Herein, we show that universal code performance for half-duplex relay channels can be approximated using a simple adaptation of rate-compatible Low Density Parity Check (LDPC) codes, named Time Division Multiple Access (TDMA) relay codes.

Channel Model And Capacity Results

First, the channel model is described and capacity results are summarized. For simplicity, the geometry (see diagram 200) is modeled as linear, with the relay 202 at a distance d from the source 201 on a unit line between the source 201 and destination 203. All links are assumed to represent real Additive White Gaussian Noise (AWGN) channels. A total power constraint, P, is imposed, such that $P = P_{BC} + P_{MAC}$, where P_{BC} and P_{MAC} represent the total system power consumed during BC and MAC modes respectively. In order to evaluate any benefit for using the relay, we compare to a point-to-point (non-cooperative) link with source power P.

The relay and destination received signals are given by:

$$Y_R = a_{SR} X_1 + N_R, \tag{1}$$

$$Y = a_{SD} X + a_{RD} [0\ X_R] + N, \tag{2}$$

where the source signal $X = [X_1\ X_2]$ is defined in terms of its BC component X_1 and MAC component X_2, and the MAC mode relay signal is given by X_R. Thus, $P_{BC} = E(X_1^2)$ and $P_{MAC} = E(X_2^2) + E(X_R^2)$. In the following, a power sharing parameter, β, is defined such that $P_{BC} = \beta P$ and $P_{MAC} = (1 - \beta) P$.

Link attenuations are modeled with scalar amplitude gain factors, a_{SR}, a_{RD}, and a_{SD}, that vary as $d^{-p/2}$, where p denotes the wireless propagation path loss exponent. The relay and destination receiver noise, N_R and N, are modeled as i.i.d. Gaussian with unit variance.

General case capacity bounds

In the general half-duplex model, the relay can cooperatively transmit in band with the source, regarding all or part of the source message, during MAC mode. The relay encoder function is constrained to depend only on the symbols received during previous BC mode. One BC/MAC cycle is comparable to one channel use in a non-cooperative system. In the following capacity evaluations, Shannon's Gaussian capacity formula is defined in terms of the SNR, x, as $C(x) = \frac{1}{2}\log(1+x)$.

Although the capacity is still an open problem, certain bounds are known. The best known achievable rate, found in [5], uses Gaussian inputs, with dirty paper pre-coding during BC mode and distributed beamforming during MAC mode:

$$C_{LB} = \max_{\alpha,\beta,\gamma,\Sigma} \min\left\{ \alpha C\left(\frac{\beta\gamma P}{\alpha d^p}\right), (1-\alpha)C\left(\frac{h^T\Sigma h}{1-\alpha}\right)\right\} + \alpha C\left(\frac{\beta(1-\gamma)P}{\alpha}\right), \quad (3)$$

where γ is a dirty-paper power splitting parameter, $h = [1\ (1-d)^{-p/2}]^T$ denotes the MAC channel, Σ denotes the covariance of $X_{MAC} = [X_2\ X_R]^T$, i.e.

$$\Sigma = (1-\beta)P \begin{bmatrix} \delta & \rho\sqrt{\delta(1-\delta)} \\ \rho\sqrt{\delta(1-\delta)} & 1-\delta \end{bmatrix}, \quad (4)$$

$\delta = E(X_2^2)/P_{MAC}$ is the MAC power share, and

$$\rho = E(X_2 X_R)/\sqrt{E(X_2^2)E(X_R^2)}$$

denotes the MAC correlation coefficient.

An outer bound on the capacity is given by the cut-set bound with a half-duplex relay throughput constraint as in [5]:

$$C_{UB} = \max_{\alpha,\beta,\Sigma} \alpha C\left(\frac{\beta P}{\alpha}\right) + (1-\alpha)C\left(\frac{h^T\Sigma h}{1-\alpha}\right), \quad (5)$$

such that

$$\alpha C\left(\frac{\beta P}{\alpha d^p}\right) \geq (1-\alpha) C\left(\frac{(1-\delta)(1-\beta)P}{(1-\alpha)(1-d)^p}\right). \qquad (6)$$

Capacity of the TDMA relay code

We further define a constrained version of the half-duplex relay model, named the Time Division Multiple Access (TDMA) relay model, in which the source node is constrained to be silent during the MAC coding interval. Thus, $X = [X_1\ 0]$, the relay and source transmissions are orthogonal. In this case the capacity is easily computed.

In the TDMA relay model, the joint channel is interpreted as a mixture of AWGN channels in which the time-sharing parameter, α, and power-sharing parameter, β, are optimized. Further, in the decode-and-forward protocol, the rate from source to relay has to be less than source-relay link capacity. The overall capacity can be written using the Gaussian formula follows:

$$C_{TDMA} = \max_{0<\alpha,\beta<1} \min\left\{\alpha C\left(\frac{\beta P}{\alpha}\right) + (1-\alpha) C\left(\frac{(1-\beta)P}{(1-\alpha)(1-d)^p}\right), \alpha C\left(\frac{\beta P}{\alpha d^p}\right)\right\}. \qquad (7)$$

Multi-hop

In the multi-hop relay protocol, relay decodes the source message and transmits a re-encoded version. Thus two links must be traversed and the capacity can be expressed as the minimum of the two:

$$C_{MH} = \max_{\alpha,\beta} \min\left\{\alpha C\left(\frac{\beta P}{\alpha d^p}\right), (1-\alpha) C\left(\frac{(1-\beta)P}{(1-\alpha)(1-d)^p}\right)\right\}. \qquad (8)$$

Graph 300 depicts a numerical evaluation of the above bounds for the linear geometry with distance $d = 1/2$ and path loss $p = 3$. In all cases, Gaussian inputs are evaluated. Note that the TDMA relay code is able to closely approximate the general case capacity, while significantly improving upon the multi-hop rate.

The rates attained using specific input constellations, with the TDMA relay protocol, are compared to TDMA relay capacity in graph 400. Although we provide performance data for an LDPC code with binary modulation, it is straight forward to generalize the degree distribution optimization for an arbitrary modulation alphabet. For details, see [6].

LDPC Code Optimization

The Edge Growth and Parity Splitting (EG/PS) technique, introduced in [7], is used to develop rate compatible LDPC codes, representing the same information bits, for use in the TDMA relay framework. The BC code word is chosen to approach the source-relay capacity. The relay, having decoded the source bits, transmits a compatible code word during MAC mode.

Since the destination radio receives both BC and MAC mode transmissions, the relay parity matrix is constructed for the joint AWGN channel parameterized by the source-destination and relay-destination SNR. In the above optimization, the base parity matrix employed by the source encoder, imposes a constraint on the relay parity check matrix. The relay encoder degree distribution optimization is detailed next.

TDMA LDPC code optimization

The LDPC parity matrices are optimized using an adaptation of Extrinsic Information Transfer (EXIT) chart techniques [8], which approximate the density evolution algorithm for analyzing irregular LDPC degree distributions [9]. A summary of the technique is provided here.

In order to optimize for the joint AWGN channel, the variable node transfer functions are parameterized by the link SNR, in addition to the variable degree as in standard EXIT charts. To this end, let $A(d_v, s)$ denote the extrinsic information transfer function for a degree d_v variable node with SNR s. Analogously, the degree distribution for variable nodes with channel s is given by $p_v(d_v, s)$, where $\sum_{d_v} p_v(d_v, s) = 1$. The channel mixture distribution, representing the fraction of code bits observing channel s, is written as $p(s)$, where $\sum_s p(s) = 1$. The check node extrinsic information transfer functions follow the standard definition: $B(d_c)$ denotes the transfer function for a check node of degree d_c.

Using the above notation the adapted EXIT optimization is performed as follows. The base code parity matrix is constructed to approach the source-relay link capacity. Then, the check node degree distribution, $p_c(d_c)$, of the extension parity matrix, used by the relay, is obtained by concentrating the average check node degree as close as possible to the its optimal value as prescribed by the density evolution algorithm (this can be found online for arbitrary code rates [10]) while adhering to the constraints of the EG/PS algorithm [7]. This yields the following overall check node transfer function: $B_{opt} = \sum_{d_c} p_c(d_c)B(d_c)$. Finally, the extension code variable distribution is obtained via least squares curve fitting, as in standard EXIT chart optimizations:

$$p_v(d_v, s) = \arg\min \left\| \sum_s p(s) \sum_{d_v} p_v(d_v, s) A(d_v, s) - B_{opt}^{-1} \right\|^2, \quad (9)$$

such that

$B_{opt}^{-1} < \sum_s p(s) \sum_{d_v} p_v(d_v, s) A(d_v, s)$.

Results

We provide performance results using the EG/PS parity matrix construction algorithm with parameters determined by the above optimization. The time sharing and power sharing parameters correspond to the optimal values given by (7). The Bit Error Rate (BER) results using BPSK modulation are depicted in graph 500. In a decode-and-forward protocol, two link capacities must be satisfied, namely the source-relay capacity and the overall relay channel capacity. Graph 500 shows that these two capacities are approached simultaneously by the TDMA LDPC code. Further, by comparing to the non-cooperative capacity (which uses the same total power and thus has the same average SNR), the benefit for utilizing the relay can be measured with respect to the overall rate achieved. We find that this benefit can be greater than 5 dB.

TDMA Relay Code for Half-Duplex L2-Based Relay in an LTE Advanced Embodiment

The following introduces a new error coding relay protocol, termed the Time Division Multiple Access (TDMA) relay protocol for L2 capable based relay terminals (RT). The TDMA Relay protocol is able to exploit the cooperative communication capability of a relay radio transceiver in a manner that is both practical and superior to existing Multi-Hop (MH) (L3-only capable RTs) techniques for either L2 or L3 capable RTs. We show that by using a simple adaptation of rate-compatible error correcting codes, we can achieve gains of up to 5 dB over multi-hop relay techniques (L3-only capable RTs) that do not use cooperative coding. We provide capacity results as well as performance examples with an already designed rate-compatible LDPC code optimized for the TDMA relay framework. This L2 based protocol can be practically implemented without significant amounts of coordination between the RT and the LTE-advanced capable eNB. Note that existing turbo code structures for release 8 capable UEs can still be supported albeit without the same performance benefit.

The TDMA Relay coding framework is defined for a half-duplex relay system in which the RT is constrained to either receive or transmit but not both simultaneously. Further, in the TDMA Relay framework, the source (either eNB for downlink case or UE for uplink case) is constrained to be silent while RT transmits. This yields a time-slotted structure in which, during one coding interval, source transmits the information message during the first time slot, termed Broadcast (BC) mode, and during the second time slot, termed Multiple Access (MAC) mode, RT transmits additional coded bits. Since the system is decode-and-forward, RT is required to reliably decode the transmitted message. The destination radio is assumed to receive both source and RT transmissions. Thus the optimal coding strategy for RT is to send rate-compatible code bits based on the received source message.

A linear geometry is used to model the RTs position between source and destination. In the theoretical examples that follow, the RT is assumed to be half-way between the source and destination. A wireless path loss exponent of 3 is further assumed.

Design example

Rate-compatible Low Density Parity Check (LDPC) codes are constructed for use in the above TDMA Relay framework. In the example, the source encoder chooses a rate near the source-RT link capacity. The degree distribution employed by RT encoder is optimized for the joint channel as observed by the destination receiver, which is parameterized by the source-destination and RT-destination link Signal-to-Noise Ratios (SNRs). The optimization technique is based on an adaptation of Extrinsic Information Transfer (EXIT) charts [8].

In order to evaluate any benefit for using the relay, a total power budget, P, used by the source and RT transmitter, is fixed, and comparisons are made to a point-to-point (non-cooperative) link with the same source power, P. This yields the same average SNR for both the cooperative and non-cooperative systems. This is done to facilitate a link layer comparison of the relay system. Additional constraints including limiting the total amount of excess interference contribution to other cells are for further study and are more appropriately handled with detailed system level studies.

The time sharing parameter (between BC and MAC mode) and power sharing parameter (between source and RT) are determined by the capacity maximization for the TDMA Relay code. Graph 600 shows the capacity results, including the constrained capacities for different modulation alphabets, for both TDMA and Multi-Hop (MH) Relay codes. The results show a large gain in spectral efficiency for the TDMA codes over MH for a given modulation alphabet. This is because the MH code does not use any cooperation between the source and RT encoders, and the MH capacity is given by the minimum of the two links. In contrast, by allowing the RT to cooperate with source encoder, a full multiplexing benefit is achieved. The TDMA Relay code shows as much as 5 dB improvement from non-cooperative capacity.

Graph 500 shows a performance example using rate-compatible LDPC codes with BPSK modulation, as measured at a BER of 0.0001. The encoder matrix used by the RT has been optimized using EXIT charts, according to the above framework, and constructed using the EG/PS algorithm for rate-compatible parity matrices [7].

Proposed implementation

We propose a control signaling mechanism for use with the TDMA Relay coding protocol. We consider the specific case of a Downlink (DL) channel in which BC mode is specified as the DL eNB transmission mode and the MAC mode is specified as the DL RT transmission mode. The proposed feedback scheme is termed “coordinated” since channel state information must be exchanged between eNB and RT, in addition to RT and UE. In the proposed scheme, RT sends CQI to eNB regarding the eNB-RT channel. The eNB then chooses a code rate near the eNB-RT link capacity. In order to maximize the spectral efficiency, RT requires CQI regarding the joint channel to UE, namely the eNB-UE link SNR and the RT-UE link SNR. Note that this scheme requires that the eNB have access to CQI regarding both the eNB-UE and eNB-RT links. Note further that the eNB does not require explicit CQI regarding the RT-UE link. Given the above feedback, the RT encoder is able to choose a compatible code word that maximizes the overall rate within TDMA framework.

Interaction with H-ARQ frame error protection would work as follows. The eNB first sends H-ARQ code words, during DL eNB transmission mode, until RT acknowledges the successful decoding. Then, during DL RT transmission mode, RT takes on the role of transmitting H-ARQ code words until the UE acknowledges a successful decoding.

Conclusion

An error coding protocol that enables faster communication rates and/or lower power consumption and/or lower interference contributions in a half-duplex cooperative relay system is described herein.

More particularly, the description includes: (1) a TDMA cooperative relay protocol, which can be viewed as a constrained version of a more general half-duplex relay model, (2) the application of rate-compatible error correcting codes for the purpose of determining source and relay transmitted code bits, and (3) the adaptation of the EXIT chart analysis techniques for the purpose of optimizing rate-compatible irregular LDPC codes for use in the TDMA relay protocol.

Some embodiments involve a rate-compatible LDPC code that is constructed according to the Edge Growth and Parity Splitting (EG/PS) algorithm. The example code is optimized to maximize the communication rate within the TDMA relay framework for a given power budget.

Embodiments may also include (1) the use of an optimal time-sharing parameter (i.e., a ratio of the first to the second coding interval) for a fixed total coding interval (which is the first + second coding interval) length; (2) the use of an optimal power sharing parameter, for a fixed total power budget, between source and relay nodes; (3) maximizing a communication rate within the constraints of either a fixed total coding interval length (which is the first + second coding interval) or a fixed total power budget between source and relay nodes; and/or (4) choosing the signals used by source and relay nodes from a rate-compatible code (representing the same source message) (also, the rate-compatible code may or may not be optimized for the specific relay configuration of the particular embodiment in question).

The detailed and, at times, very specific description above is provided to effectively enable a person of skill in the art to make, use, and best practice the present invention in view of what is already known in the art. In the examples, specifics are provided for the purpose of illustrating possible embodiments of the present invention and should not be interpreted as restricting or limiting the scope of the broader inventive concepts.

Aspects of embodiments of the present invention can be understood with reference to FIGs. 7-9. FIG. 7 is a logic flow diagram of relay functionality in accordance with various embodiments of the present invention. In the method depicted in diagram 700, signaling is received (701) during a first coding interval, the signaling being encoded at a first coding rate to convey information from a source node. During a second coding interval, subsequent to the first coding interval, signaling is received (702) from a relay node. The signaling from the relay node is based on signaling received at the relay node from the source node. The information from the source node is then recovered (703) using the signaling received from the source node and the signaling received from the relay node.

FIG. 8 is a logic flow diagram of relaying information in accordance with various embodiments of the present invention. In the method depicted in diagram 800, signaling is received (801) from a source node during a first coding interval and then decoded (802). During a second coding interval, subsequent to the first coding interval, relay signaling based on the decoded signaling is transmitted (803). Information from the source node is then recovered (804) using the signaling received from the source node and signaling received from a relay node. In some embodiments, transmitting the relay signaling may involve encoding based on a source-to-destination link quality and a relay-to-destination link quality.

FIG. 9 is a logic flow diagram of relaying information in accordance with various embodiments of the present invention. In the method depicted in diagram 900, a code rate is selected (901) to maximize a source-to-relay link capacity based on at least one resource constraint and a link quality between a source node and a relay node. Information encoded at the selected coding rate is then broadcast (902) to both a relay node and the destination node during a first coding interval. In some embodiments, the at least one resource constraint includes transmit power allocated to broadcasting the information.

Benefits, other advantages, and solutions to problems have been described above with regard to specific embodiments of the present invention. However, the benefits, advantages, solutions to problems, and any element(s) that may cause or result in such benefits, advantages, or solutions, or cause such benefits, advantages, or solutions to become more pronounced are not to be construed as a critical, required, or essential feature or element of any or all the claims.

As used herein and in the appended claims, the term “comprises,” “comprising,” or any other variation thereof is intended to refer to a non-exclusive inclusion, such that a process, method, article of manufacture, or apparatus that comprises a list of elements does not include only those elements in the list, but may include other elements not expressly listed or inherent to such process, method, article of manufacture, or apparatus. The terms a or an, as used herein, are defined as one or more than one. The term plurality, as used herein, is defined as two or more than two. The term another, as used herein, is defined as at least a second or more. Unless otherwise indicated herein, the use of relational terms, if any, such as first and second, top and bottom, and the like are used solely to distinguish one entity or action from another entity or action without necessarily requiring or implying any actual such relationship or order between such entities or actions.

The terms including and/or having, as used herein, are defined as comprising (i.e., open language). The term coupled, as used herein, is defined as connected, although not necessarily directly, and not necessarily mechanically. Terminology derived from the word “indicating” (e.g., “indicates” and “indication”) is intended to encompass all the various techniques available for communicating or referencing the object/information being indicated. Some, but not all, examples of techniques available for communicating or referencing the object/information being indicated include the conveyance of the object/information being indicated, the conveyance of an identifier of the object/information being indicated, the conveyance of information used to generate the object/information being indicated, the conveyance of some part or portion of the object/information being indicated, the conveyance of some derivation of the object/information being indicated, and the conveyance of some symbol representing the object/information being indicated.

What is claimed is:

CLAIMS

1. A method for relaying information, the method comprising:

receiving, during a first coding interval, signaling encoded at a first coding rate to convey information from a source node;

receiving, during a second coding interval, signaling from a relay node, wherein the signaling from the relay node is based on signaling received at the relay node from the source node and wherein the second coding interval is subsequent to the first coding interval;

recovering the information from the source node using the signaling received from the source node and the signaling received from the relay node.

2. A method for relaying information, the method comprising:

receiving, during a first coding interval, signaling from a source node;

decoding the signaling;

transmitting, during a second coding interval, relay signaling based on the decoded signaling, wherein the second coding interval is subsequent to the first coding interval;

recovering information from the source node using the signaling received from the source node and signaling received from a relay node.

3. The method of claim 2, wherein transmitting the relay signaling comprises

encoding based on a source-to-destination link quality and a relay-to-destination link quality.

4. A method for relaying information, the method comprising:

selecting a code rate to maximize a source-to-relay link capacity based on at least one resource constraint and a link quality between a source node and a relay node;

broadcasting information encoded at the selected coding rate to both a relay node and the destination node during a first coding interval.

5. The method of claim 4, wherein the at least one resource constraint comprises transmit power allocated to broadcasting the information.

6. An apparatus comprising:

means for receiving, during a first coding interval, signaling encoded at a first coding rate to convey information from a source node;

means for receiving, during a second coding interval, signaling from a relay node, wherein the signaling from the relay node is based on signaling received at the relay node from the source node and wherein the second coding interval is subsequent to the first coding interval;

means for recovering the information from the source node using the signaling received from the source node and the signaling received from the relay node.

7. An apparatus comprising:

means for receiving, during a first coding interval, signaling from a source node;

means for decoding the signaling;

means for transmitting, during a second coding interval, relay signaling based on the decoded signaling, wherein the second coding interval is subsequent to the first coding interval;

means for recovering information from the source node using the signaling received from the source node and signaling received from a relay node.

8. The apparatus of claim 7, wherein the means for transmitting the relay signaling comprises

means for encoding based on a source-to-destination link quality and a relay-to-destination link quality.

9. An apparatus comprising:

means for selecting a code rate to maximize a source-to-relay link capacity based on at least one resource constraint and a link quality between a source node and a relay node;

means for broadcasting information encoded at the selected coding rate to both a relay node and the destination node during a first coding interval.

10. The apparatus of claim 9, wherein the at least one resource constraint comprises transmit power allocated to broadcasting the information.

FIG. 1

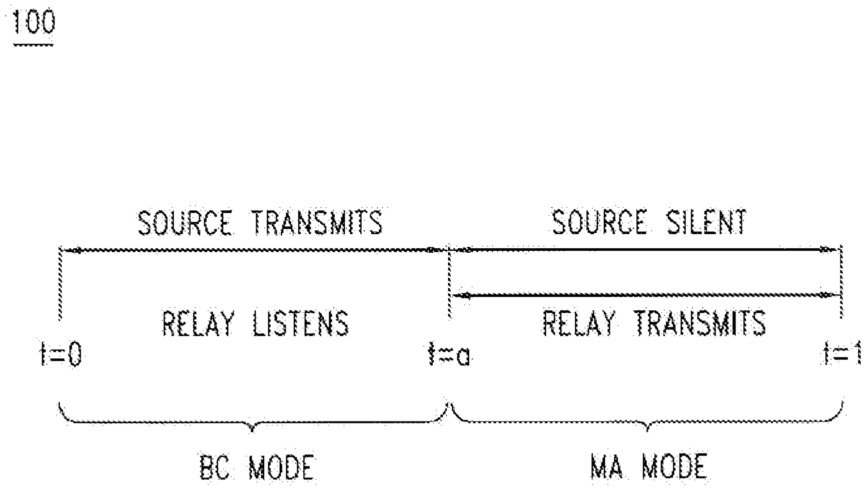

100
SOURCE TRANSMITS
SOURCE SILENT
RELAY LISTENS
RELAY TRANSMITS
t=0
t=a
t=1
BC MODE
MA MODE

FIG. 2

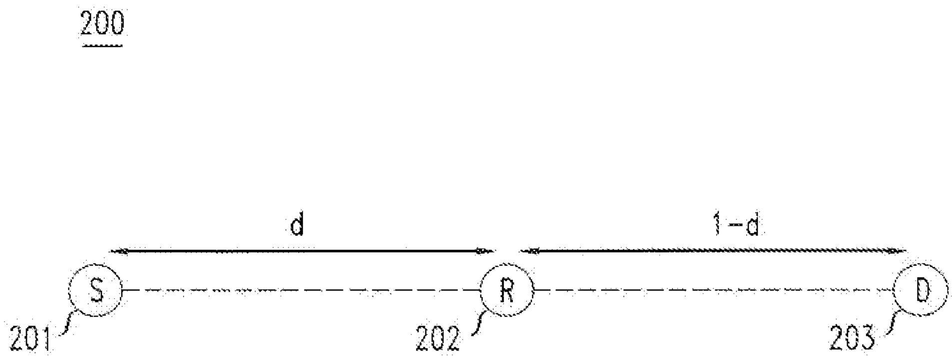


FIG. 3

300

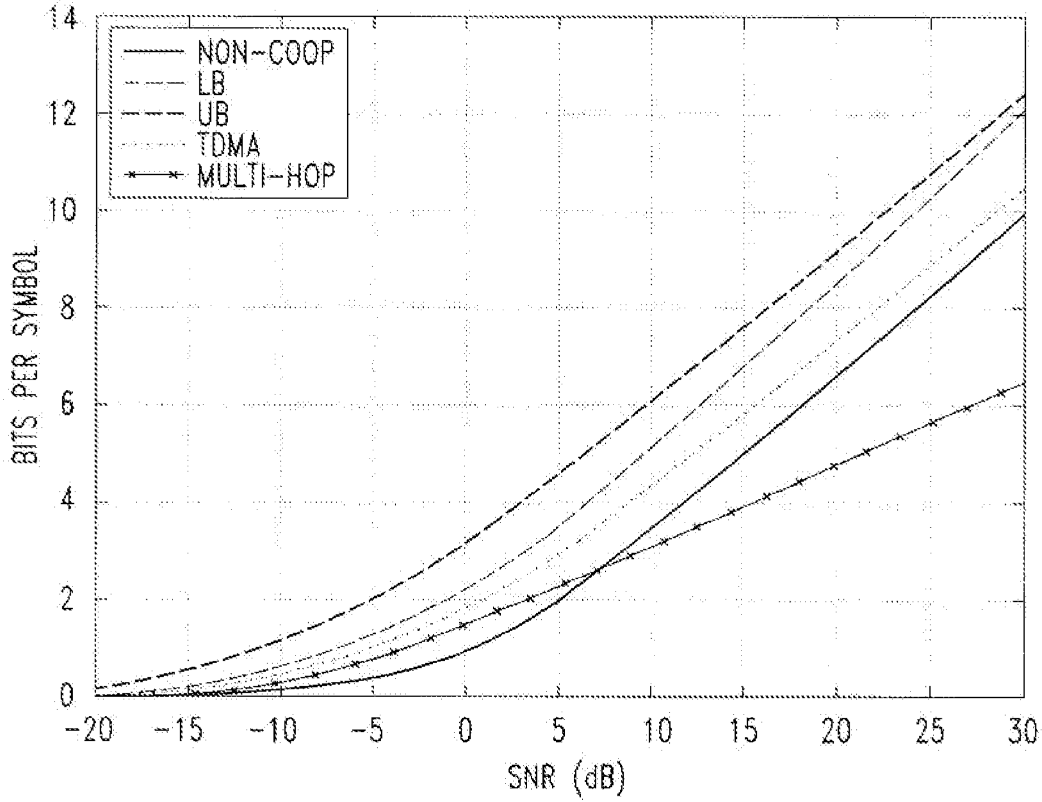

NON-COOP
LB
UB
TDMA
MULTI-HOP
BITS PER SYMBOL
14
12
10
8
6
4
2
0
-20
-15
-10
-5
0
5
10
15
20
25
30
SNR (dB)

FIG. 4

400

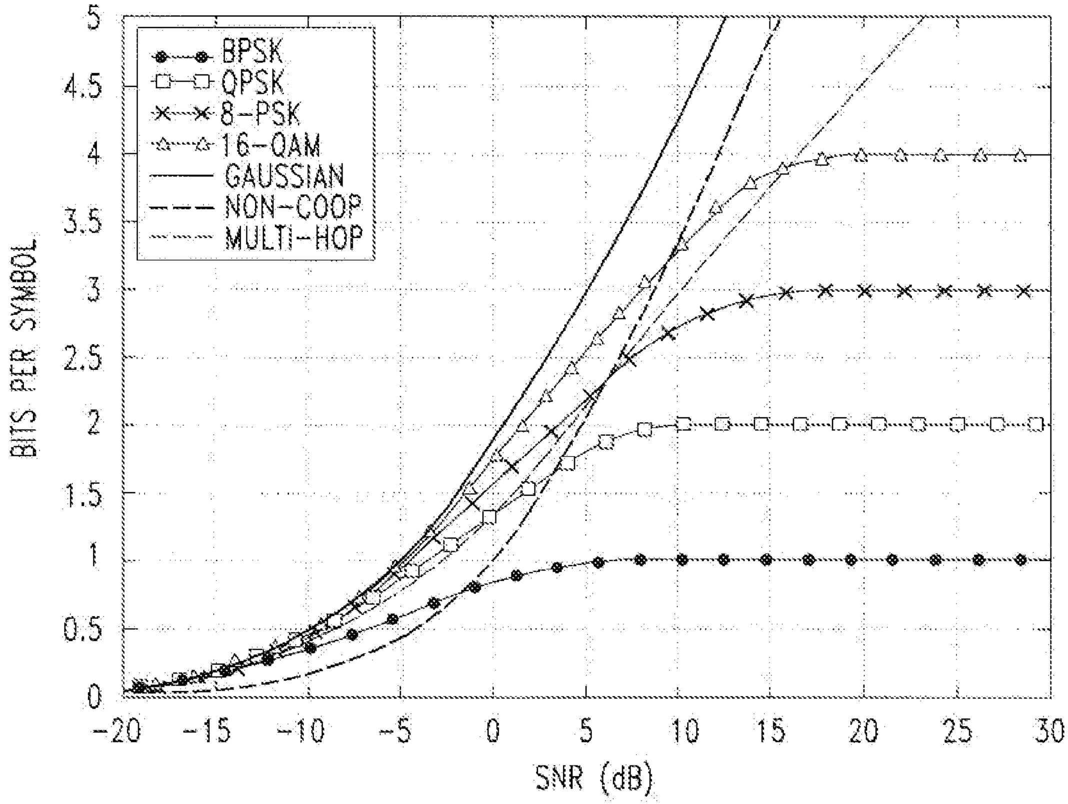

BPSK
QPSK
8-PSK
16-QAM
GAUSSIAN
NON-COOP
MULTI-HOP
BITS PER SYMBOL
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
-20
-15
-10
-5
0
5
10
15
20
25
30
SNR (dB)

FIG. 5

500

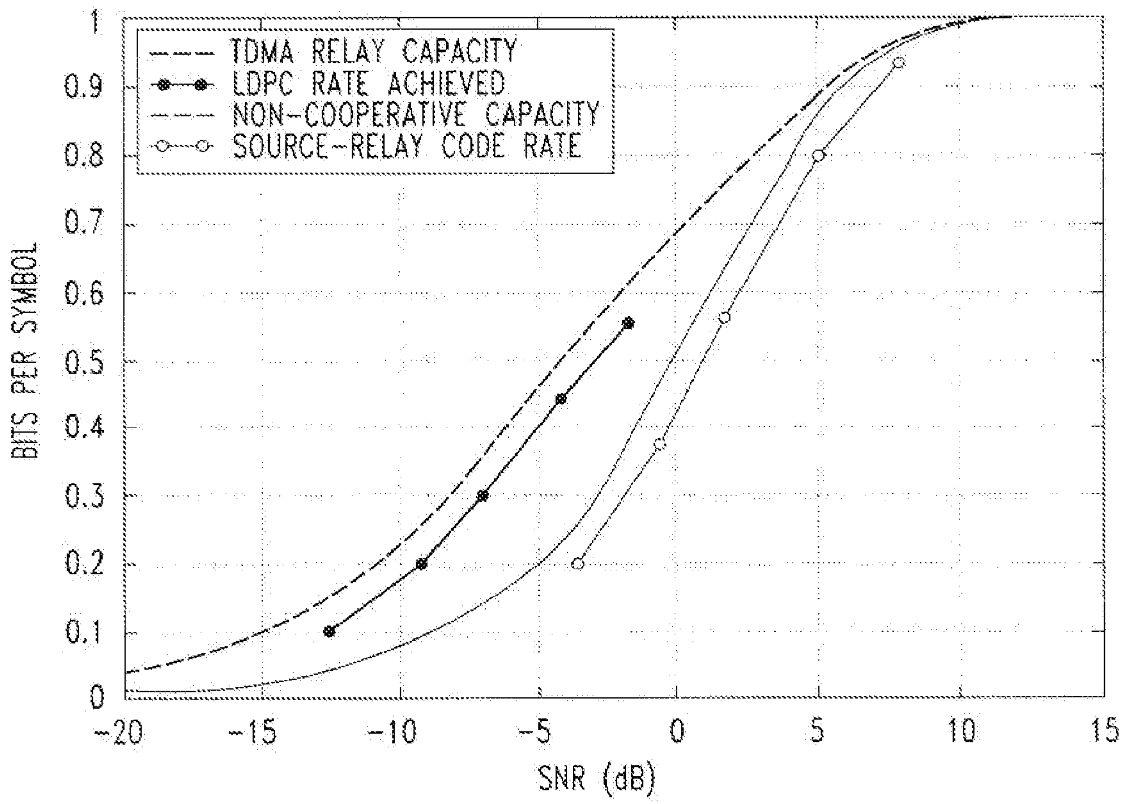

TDMA RELAY CAPACITY
LDPC RATE ACHIEVED
NON-COOPERATIVE CAPACITY
SOURCE-RELAY CODE RATE
BITS PER SYMBOL
SNR (dB)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-20
-15
-10
-5
0
5
10
15

FIG. 6

600

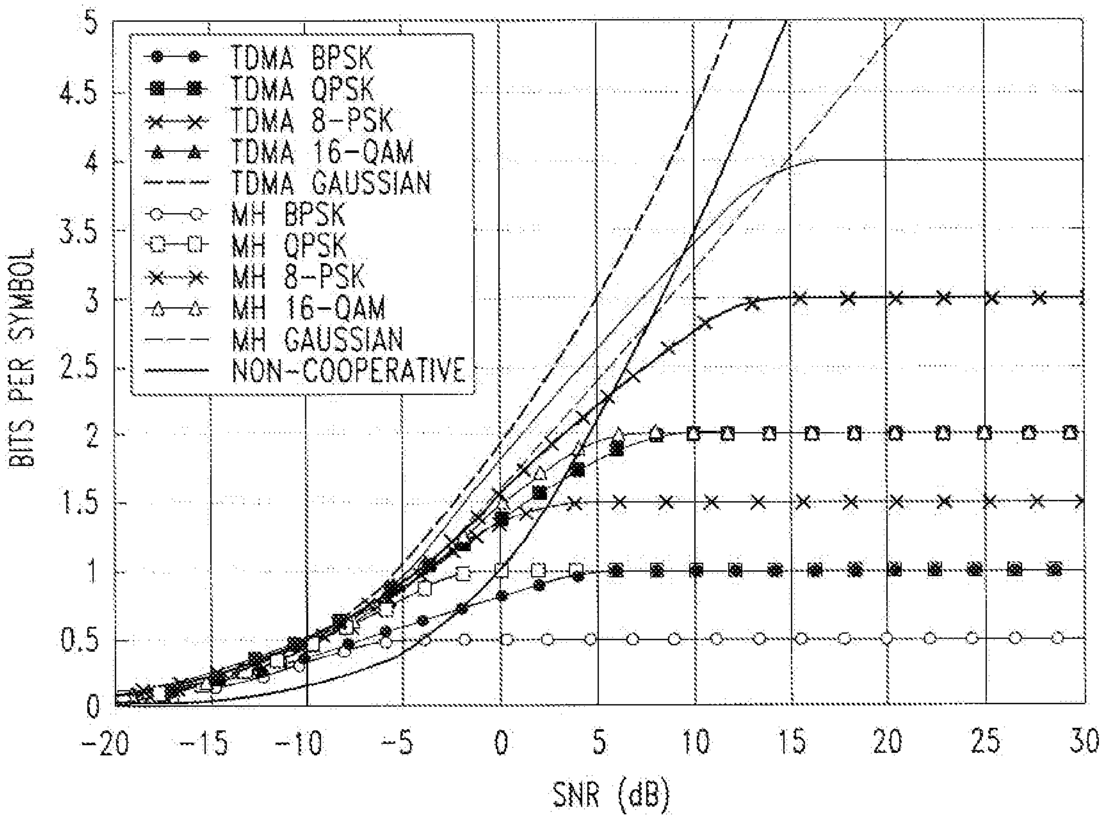

TDMA BPSK
TDMA QPSK
TDMA 8-PSK
TDMA 16-QAM
TDMA GAUSSIAN
MH BPSK
MH QPSK
MH 8-PSK
MH 16-QAM
MH GAUSSIAN
NON-COOPERATIVE
BITS PER SYMBOL
SNR (dB)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
-20
-15
-10
-5
0
5
10
15
20
25
30

FIG. 7

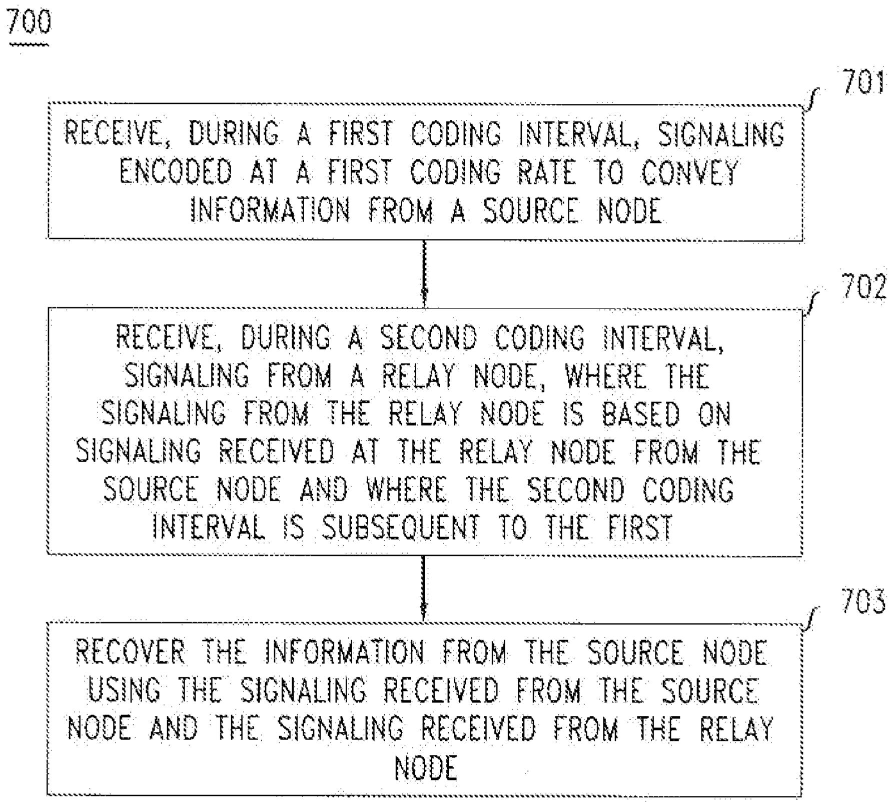

700
701
RECEIVE, DURING A FIRST CODING INTERVAL, SIGNALING ENCODED AT A FIRST CODING RATE TO CONVEY INFORMATION FROM A SOURCE NODE
702
RECEIVE, DURING A SECOND CODING INTERVAL, SIGNALING FROM A RELAY NODE, WHERE THE SIGNALING FROM THE RELAY NODE IS BASED ON SIGNALING RECEIVED AT THE RELAY NODE FROM THE SOURCE NODE AND WHERE THE SECOND CODING INTERVAL IS SUBSEQUENT TO THE FIRST
703
RECOVER THE INFORMATION FROM THE SOURCE NODE USING THE SIGNALING RECEIVED FROM THE SOURCE NODE AND THE SIGNALING RECEIVED FROM THE RELAY NODE

FIG. 8

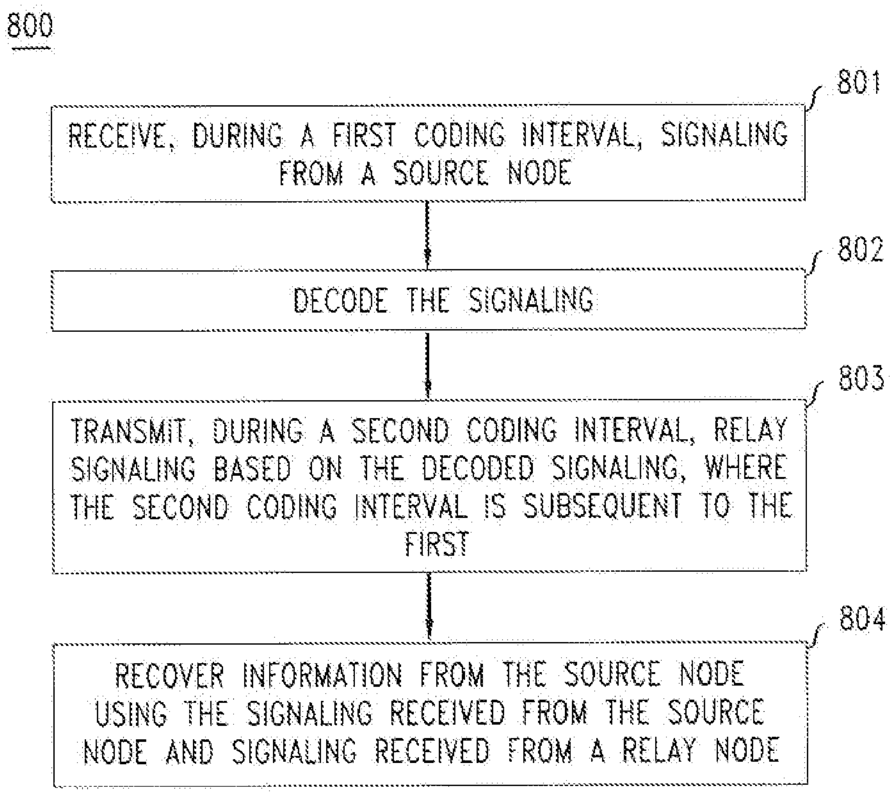
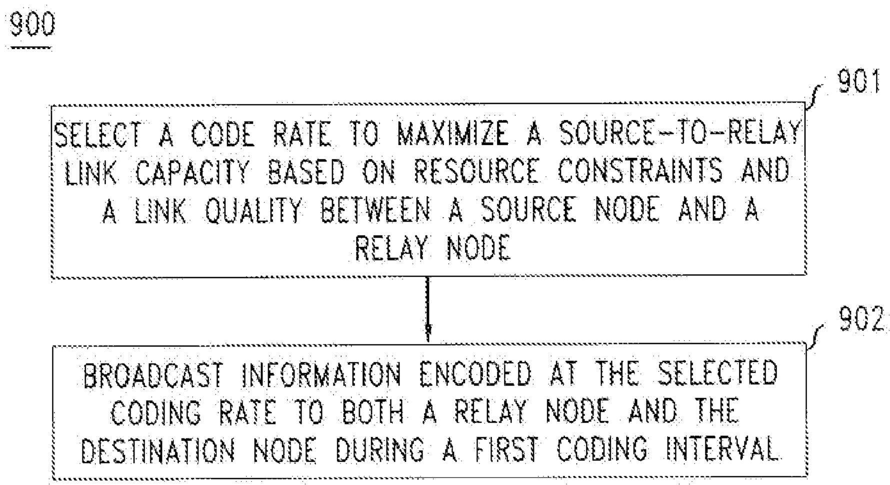

800
801
RECEIVE, DURING A FIRST CODING INTERVAL, SIGNALING FROM A SOURCE NODE
802
DECODE THE SIGNALING
803
TRANSMIT, DURING A SECOND CODING INTERVAL, RELAY SIGNALING BASED ON THE DECODED SIGNALING, WHERE THE SECOND CODING INTERVAL IS SUBSEQUENT TO THE FIRST
804
RECOVER INFORMATION FROM THE SOURCE NODE USING THE SIGNALING RECEIVED FROM THE SOURCE NODE AND SIGNALING RECEIVED FROM A RELAY NODE

FIG. 9


900
901
SELECT A CODE RATE TO MAXIMIZE A SOURCE-TO-RELAY LINK CAPACITY BASED ON RESOURCE CONSTRAINTS AND A LINK QUALITY BETWEEN A SOURCE NODE AND A RELAY NODE
902
BROADCAST INFORMATION ENCODED AT THE SELECTED CODING RATE TO BOTH A RELAY NODE AND THE DESTINATION NODE DURING A FIRST CODING INTERVAL