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SPHERE DECODER FOR NETWORK CODED COOPERATIVE COMMUNICATIONS

Usama Sayed Mohammed [1,*], Taha Khalf [2] and Safwat M. Ramzy [3]

[1,2] *Staff in Electrical Engineering Department, Faculty of Engineering, Assiut University, Egypt*
[3] *Electrical Engineering Department, Faculty of Engineering, Assiut University, Egypt*

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ABSTRACT

In cooperative communications, multiple sources communicate with a single destination in the presence of relay nodes. Network coding in cooperative communications allows the relay nodes to combine the data received from the sources and send the linear combination to the destination. The difference in complexity, reliability and overhead is a critical issue when we compare among the different decoders. In this paper, soft-decision maximum a posterior (MAP) decoder that has an optimal reliability and neglected overhead is proposed. Moreover, the Sphere decoder is used to reduce the complexity of the proposed MAP decoder. The proposed implementation proves that the sphere decoder can be used to reduce the complexity of the MAP decoder to about 3% related to the original complexity of the decoder.

Keywords: Cooperative communication, Network coding, Sphere decoder, MAP decoder

1. Introduction

Cooperative communications is a strategy where users, besides transmitting their own encoded information, also relay re-encoded versions of other users' information to a common destination. Cooperative communication was proved by many papers about the improvement of packet-reception-rate (PRR), transmitting speed, interference reduction and other multiple input multiple output (MIMO) benefits by taking advantage of intermediate nodes to gain spatial diversity.

For conventional cooperation approaches, each cooperating device uses orthogonal channels to relay different messages for mitigating co-channel interference and avoiding transmission collisions, but the bandwidth efficiency will significantly reduce. One method to tackle this issue is to use the network coding, in which different messages are combined at cooperating devices to save the channel use of data relying. Recently Cooperative

[*] Corresponding author.
Email address:Usama@aun.edu.eg

communication and network coding (NC) [1] have been shown as strong candidate technologies for many future wireless applications, such as relay-aided cellular networks [2] and vehicular ad hoc networks [3].Cooperative relaying has been introduced to improve the performance and reliability of wireless networks in spite of loss of system throughput. Cooperative relays can extend the coverage; reduce network energy consumption by exploiting neighbors' resources [4]. The basic idea of network coding in multiple access relay networks is to combine the information along the direct path from the source with the information received from the relays, where information from multiple sources are encoded (mixed), to enhance the reliability of decoding at the destination. Information theoretic studies on the multiple access relay channel (MARC) was first introduced in [5]. Several decoding schemes have been proposed in the literature to estimate and find the data transmitted by the sources at the destination, but they differ in complexity, reliability and overhead. In [6], the authors proposed a decoding scheme called a cooperative maximal ratio combiner (C-MRC). This combiner is used with the traditional cooperative diversity techniques where the relay nodes follow the decode-and-forward relaying protocol. A channel-aware decoder was proposed in [7]. This decoder is based on the maximum likelihood sequence estimation criterion. The decoding process occurs in two steps. In the first step, the destination estimates the data sent from the sources and relay nodes individually. Then, the destination uses the hard-decision decoded data of step one to find the closest codeword to the transmitted one based on the weighted distance decoder. In this paper, the maximum a posterior (MAP) decoder for cooperative communication networks [14] is used as a decoding device in which the relay nodes combine the data received from the sources to generate and forward parity bits to the destination. Unlike all other proposed decoding schemes, the MAP decoder minimizes the end-to-end error probability (i.e., the probability that the source bit is received in error at the destination after utilizing the data received from relay nodes). The main problem of MAP is its complexity which grows exponentially with the number of sources and relays. The Sphere Decoder [8]is a promising approach to overcome this obstacle. The Sphere Decoder uses the fact that the transmitted and received sequence of digital symbols can be represented with the help of lattice theory. Sphere decoding is widely used in communication applications [9]. It is a method for solving the integer least squares problem:

$$\min_{s\in Z^m}\|Hs-y\|^2 \tag{1}$$

Where, in this paper, $s\in\Re^M$ denotes the data vector sent from all sources and relays where, $y\in\Re^M$ is the signal received at the destination and $H\in\Re^{M\times M}$ is the channel gain. That is to find an integer vector s minimizing $\|Hs-y\|^2$. In this paper the sphere decoder [8] is implemented for the MAP decoding scheme.

The remaining part of this paper is organized as follows: The system model and MAP decoding scheme are described in Section 2. Description of the related decoders is stated in Section 3. Fundamentals of Sphere decoder are described in Section 4. Sphere decoder implementation of the MAP is described in Section 5. Section 6 presents the simulation results. Finally, the conclusions are drawn in Section7.

2. System model and the MAP decoding scheme

We consider a multiple, one destination, access relay network composed of M sources, L relays, and as shown in Figure 1. The transmission occurs over two phases. In the first phase, each source is assigned an orthogonal channel (time or frequency) and sends its symbol to the destination. Due to the broadcast nature of the wireless medium, the relays also receive the sources' data (possibly with some errors). Each relay node decodes the data received from the sources and then encodes (linearly combines) the decoded data to generate a parity symbol. In the second phase, each relay is assigned an orthogonal channel to forward its parity symbol to the destination. It is assumed that all data are sent using binary phase shift keying (BPSK) modulation scheme and each source generates its bits with equal probability, i.e. $P(0) = P(1) = .5$. All channels are assumed independent Rayleigh fading channels with additive white Gaussian noise and path loss. In BPSK, bit 0 is mapped to +1 and bit 1 is mapped to −1. Therefore, +1 is the additive identity element under "$\oplus$" (modulo-2) addition, e.g. $+1 \oplus s_m = s_m$, and −1 is the multiplicative identity element under "$\otimes$" (modulo-2) multiplication, e.g. $-1 \otimes s_m = s_m$. Let $s = [s_1, s_2, ..., s_M, s_{M+1}, ..., s_{M+L}]^T$ denotes the data vector sent from all sources and relays where $s_1, s_2, ..., s_M$ represent the sources' symbols and $s_{M+1}, ..., s_{M+L}$ represent the relays' symbols, $s_i \in \{+1, -1\}$. The signal received at the destination from the $i-th$ (source node for $i = 1, ..., M$ and relay node for $i = (M+1, ..., M+L)$ is given by

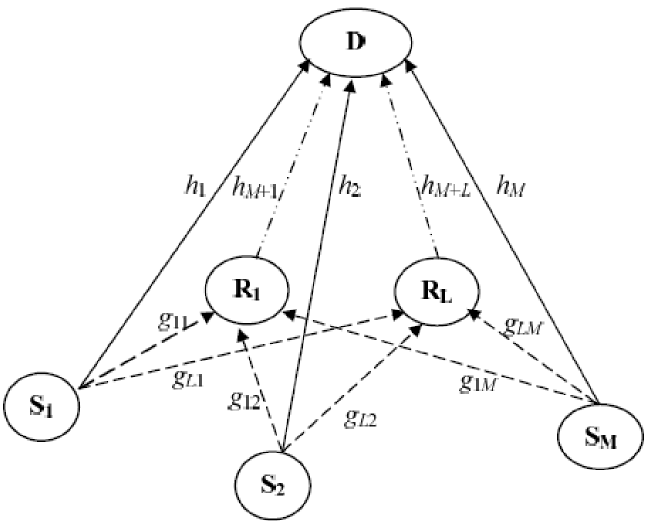

Fig. 1. M sources, L relays, and single destination wireless relay network

$$y_i = h_i s_i \sqrt{d_i^{-v} E_i} + n_i \tag{2}$$

and that are received at the $l-th$ relay, $l = 1, ..., L$ from the $m-th$ source, $m = 1, ..., M$ is given by

$$r_{lm} = g_{lm} s_m \sqrt{d_{lm}^{-v} E_m} + n_{lm} \qquad (3)$$

Where

h_i is the channel gain between the $i-th$ node and the destination and it follows a Rayleigh distribution with $E[h_i^2] = 1$.

d_i is the distance between the $i-th$ node and the destination.

d_{lm} is the distance between the $m-th$ source and the $l-th$ relay.

v is the path loss exponent.

E_i is the transmit energy of the $i-th$ node symbol.

g_{lm} is the channel gain between the $m-th$ source and the $l-th$ relay and it follows a Rayleigh distribution with $E[g_{lm}^2] = 1$.

n_i, n_{lm} is zero mean additive white Gaussian noise (AWGN) components with power Spectral densities $N_0/2$ and $N_{r0}/2$, respectively.

Each relay linearly combines the decoded symbols and produces a coded (parity) symbol. The parity symbol generated by the $l-th$ relay, $l = 1,2,.......,L$ is given by

$$s_{M+l} = \bigoplus_{m=1}^{M} s_{ml} \qquad (4)$$

Where s_{ml} is the decoded symbol at the $l-th$ relay sent by the $m-th$ source. The received signals at the destination can be written in the matrix form as follows:

$$y = Hs + n \qquad (5)$$

where the received vector $y = [y_1, y_2, ..., y_{M+L}]^T$,the noise vector $n = [n_1, n_2, ..., n_{M+L}]^T$, and

$$H = \begin{bmatrix} h_1\sqrt{d_1^{-v}E_1} & 0 & .... & 0 \\ 0 & h_2\sqrt{d_2^{-v}E_2} & .... & 0 \\ . & . & . & . \\ . & . & . & . \\ 0 & 0 & .... & h_{M+L}\sqrt{d_{M+L}^{-v}E_{M+L}} \end{bmatrix} \qquad (6)$$

Where $d_i^{-v} E_i / N_0 = \gamma_i$ is the average received signal-to-noise (SNR) ratio of the link from node i to destination. The MAP algorithm searches for the codeword $\hat{c}$ from 2^{M+L} codewords inside the codebook that maximizes the a posteriori probability $P(c_k \mid y)$.

$$\hat{c} = \arg\max_{c_k} P(c_k \mid y) \\ = \arg\max_{c_k} P(y \mid c_k) P(c_k) \tag{7}$$

$$\hat{c} = \arg\max_{c_k} \frac{1}{(\pi N_0)^{(M+L)/2}} e^{\frac{-\|y - Hc_k\|^2}{N_0}} P(c_k) \tag{8}$$

Equation (8) is the assumption of the orthogonality of channels and the joint distribution of random white Gaussian variables [15].

$$\hat{c} = \arg\min_{c_k} (\|y - Hc_k\|^2 - N_0 \log(P(c_k))) \tag{9}$$

Where $k = 1, \ldots\ldots, 2^{M+L}$

So, the MAP should calculate the decision function in (9) 2^{M+L} times, and it chooses the codeword that minimizes (9). Let $e_{ml} \in \{+1, -1\}$ be the error value between the $m-th$ source and the $l-th$ relay. Let $P_{lm} = P(e_{lm} = -1)$ be the average probability of symbol error between the $m-th$ source and the $l-th$ relay [10].

$$P_{lm} = \frac{1}{2}\left[1 - \sqrt{\frac{\gamma_{lm}}{1+\gamma_{lm}}}\right] \tag{10}$$

Where $\gamma_{lm} = d_{lm}^{-v} E_m / N_{r0}$ is the average received SNR of the link between the $m-th$ source and the $l-th$ relay. Let z_l captures the error events on the channels between all sources and the $l-th$ relay.

$$z_l = \bigoplus_{m=1}^{M} e_{lm} \tag{11}$$

Where $z_l = +1$ means that the relay decodes the source bits correctly, i.e. the generated symbol of $l-th$ relay is $s_{M+l} = \bigoplus_{m=1}^{M} s_m$.

$$P(c_k) = P(c_{k1}, c_{k2}, \ldots\ldots, c_{kM}) \times P(c_{k(M+1)}, c_{k(M+2)}, \ldots\ldots, c_{k(M+L)} \mid c_{k1}, c_{k2}, \ldots\ldots, c_{kM}) \tag{12}$$

$$P(c_{k(M+1)}, c_{k(M+2)}, \ldots\ldots, c_{k(M+L)} \mid c_{k1}, c_{k2}, \ldots\ldots, c_{kM}) = \prod_{l=1}^{L} P(c_{k(M+l)} \mid c_{k1}, c_{k2}, \ldots\ldots, c_{kM}) \tag{13}$$

$$P(c_{k(M+l)} \mid c_{k1}, c_{k2}, \ldots\ldots, c_{kM}) = P\left(z_l = (\bigoplus_{m=1}^{M} c_{km}) \oplus c_{k(M+l)}\right) \tag{14}$$

$$P(c_k) = \frac{1}{2^M} \prod_{l=1}^{L} P\left(z_l = (\bigoplus_{m=1}^{M} c_{km}) \oplus c_{k(M+l)} \right) \quad (15)$$

In simple notation $P(c_k)$ may be written as

$$P(c_k) = \frac{1}{2^M} \prod_{l=1}^{L} P(z_l) \quad (16)$$

3. Description of related decoders

Nasri et.al [11] generalized C-MRC scheme to work with relay networks in which the relay node forwards a linear combination of the data received from the sources. Although the generalized C-MRC scheme reduces the complexity of the decoding process, it is not optimal in some sense. The proposed generalized C–MRC metric is given by

$$\hat{c} = \underset{c_k}{\arg\min} \left\| y_{sd} - H_{sd} c_k \right\|^2 + \psi \left\| y_{M+1} - h_{M+1} \tilde{s} \right\| \quad (17)$$

Where $k = 1,....,2^M$, $y_{sd} = [y_1, y_2,......., y_M]^T$ and $\tilde{s} = \bigoplus_{m=1}^{M} c_{km}$, The weighting factor $\psi = \frac{\min(\gamma_{eq}, \gamma_1)}{\gamma_1} \in [0,1]$, and γ_{eq} is the minimum instantaneous SNR of sources to relay link , $\gamma_1 = h_{M+1}^2 d_{M+1}^{-v} E_{M+1} / N_0$ is instantaneous SNR of relay to destination link, and

$$H_{sd} = \begin{bmatrix} h_1 \sqrt{d_1^{-v} E_1} & 0 & .... & 0 \\ 0 & h_2 \sqrt{d_2^{-v} E_2} & .... & 0 \\ . & . & . & . \\ . & . & . & . \\ 0 & 0 & .... & h_M \sqrt{d_M^{-v} E_M} \end{bmatrix} \quad (18)$$

It is clear that this decoder needs to know all channel state information (CSI) of sources to relay link which means the large overhead information is needed. It means that the complexity increases exponentially with M, i.e. the number of computations will be 2^M .

Iezzi et.al [12] generalized the A channel-aware decoder that was proposed in [7]. It has the same complexity as the decoder in [11] and also it needs to know all CSI of sources to relay link which means a large overhead.

4. Fundamentals of sphere decoder

In this section the fundamentals of sphere decoder [8] is illustrated for the general minimum least square error (MLSE) problem. The idea of sphere decoding is very simple: We attempt to search over only lattice points that lie inside a certain sphere with radius around the given vector, thereby reducing the search space and, hence, the required computations.

Sphere decoding, introduced originally by Finke [13], enumerates all lattice points in a sphere centered at a given vector. It searches a lattice point in a sphere of radius d and centered at y in (1) that is closest, in Euclidean distance, to the center point as shown in Figure 2. Therefore, by restricting the search area, it can reduce the computational complexity of solving (1).

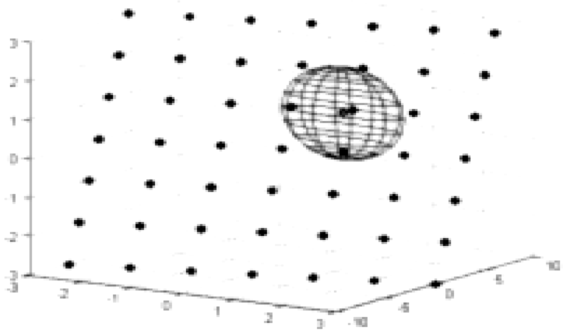

Fig. 2. Geometric interpretation of a hyper sphere in a lattice

The Sphere Decoder is based on the following concepts:

1. The search through the lattice can be done recursively.
2. Given a sphere around the received vector, only a subset of the lattice has to be searched to find the closest lattice.
3. The complexity of the decoder relies on the size of the search space which is the number of code words of the system and the radius d of the sphere.

If d is too large, the sphere contains too many lattice points, then the search complexity may be exponential to M. If d is too small, the sphere may contain no lattice points. The value of d depends on the application. We can determine all lattice points in a sphere of dimension M and radius d by successively determining all lattice points in spheres of lower dimensions $1,2,.........,M$ and the radius d. Such an algorithm for determining the lattice points in an M-dimensional sphere essentially constructs a tree where, the branches in the $k-th$ level of the tree correspond to the lattice points inside the sphere of radius d and dimension k as shown in Figure 3 .

4.1. Sphere Decoding Algorithm

The sphere of radius d and centered at y in (1) can be defined as

$$\hat{s} = \{s \mid \|Hs - y\| \leq d \tag{19}$$

If H isn't the upper triangular matrix, it is reduced into an upper triangular matrix using orthogonal transformations, such as the Householder transformation, to obtain the QR decomposition.

$$H = QR \tag{20}$$

where R is an $M \times M$ upper triangular matrix, and Q is an $M \times M$ orthogonal matrix. Then,

$$\|Hs - y\|^2 = \|Rs - Q^T y\|^2 \tag{21}$$

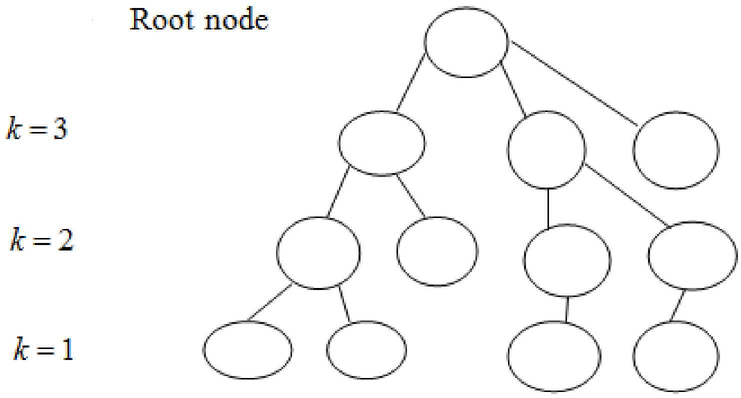

Fig. 3. Sample tree generated to determine lattice points in a three-dimensional Sphere.

Now (1) is equivalent to

$$\hat{s} = \arg\min_{s} \|\bar{y} - Rs\|^2 \tag{22}$$

Where $\bar{y} = Q^T y$

$$\|Rs - \bar{y}\| \le d^2 \tag{23}$$

$$\sum_{i=1}^{M} \left(\bar{y}_i - \sum_{j=1}^{M} R_{i,j} s_j \right)^2 \le d^2 \tag{24}$$

where $R_{i,j}$ denotes an (i, j) entry of R. We can rewrite (24) as follows:

$$d^2 \ge (\bar{y}_M - R_{M,M} s_M)^2 + (\bar{y}_{M-1} - R_{M-1,M} s_M - R_{M-1,M-1} s_{M-1})^2 + \ldots\ldots\ldots\ldots \tag{25}$$

Where the first term relies only on s_M , the second term on $\{s_M, s_{M-1}\}$, and so on. Therefore, a necessary condition for Hs to lie inside the sphere is that $d^2 \ge (\bar{y}_M - R_{M,M} s_M)^2$. This condition is equivalent to s_M belonging to the interval.

$$\left\lceil \frac{-d + \bar{y}_M}{R_{M,M}} \right\rceil \le s_M \le \left\lceil \frac{d + \bar{y}_M}{R_{M,M}} \right\rceil \tag{26}$$

Where $\lceil\ \rceil$ denotes rounding to the nearest larger element in the set of numbers that spans the lattice.

For every s_M satisfying (25), define

$$\bar{y}_{M-1,M} = \bar{y}_{M-1} - R_{M-1,M} s_M \text{ and } d^2_{M-1} = d^2 - (\bar{y}_M - R_{M,M} s_M)^2$$

a stronger necessary condition can be found by looking at the first two terms in (25), which leads to s_{M-1} belonging to the interval

$$\left\lceil \frac{-d_{M-1} + \bar{y}_{M-1,M}}{R_{M-1,M-1}} \right\rceil \le s_{M-1} \le \left\lceil \frac{d_{M-1} + \bar{y}_{M-1,M}}{R_{M-1,M-1}} \right\rceil \tag{27}$$

Continuing in a similar for s_{M-2}, s_{M-3} and so on until s_1.Thereby, obtaining all lattice points belonging to (22).

5. Sphere decoder implementation for the MAP

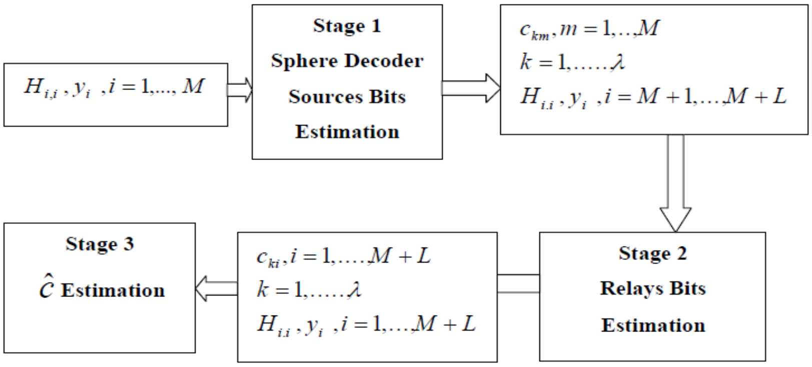

Fig. 4. The Block Diagram of the Proposed Decoding Scheme

Now the problem is to find the codeword that minimizes (9) with less computation using the sphere decoder. The codeword probability $P(c_k)$ relies on the all bits formed the codeword. This problem can be solved by rewriting the codeword probability as a number of probabilities; each one relies on only the relay bit and sources bits. Substituting from (16) into (9) yields

$$\begin{aligned} \hat{c} &= \arg\min_{c_k} \sum_{i=1}^{M+L} (y_i - H_{i,i} c_{ki})^2 - N_0 \log\left(\frac{1}{2^M} \prod_{l=1}^{L} P(z_l)\right) \\ &= \arg\min_{c_k} \sum_{i=1}^{M} (y_i - H_{i,i} c_{ki})^2 + \sum_{i=M+1}^{M+L} \left((y_i - H_{i,i} c_{ki})^2 - N_0 \log(P(z_{(i-M)})) \right) \end{aligned} \tag{28}$$

where $H_{i,j}$ denotes an (i, j) entry of H.

The last step is to convert the multiplication to summation of parts, each part depends on the source bits and the relay bit reduces the binary tree from $M + L$

levels into M levels that reduces the complexity of the decoder because this reduces the search space from 2^{M+L} codewords to 2^M codewords.

The decoding process consists of three stages as shown in Figure 4.

5.1. Stage 1

In this stage, we shall estimate the sources's bits of the codewords that have minimum decision function using the sphere decoder; this can be summarized as follows:

1- Determining the initial sphere radius by hard-decision estimation for both relays and sources's symbols. Let $\bar{c}$ is the estimated codeword by hard-decision for each symbol individually; the sphere radius is given by

$$d_M^2 = (\left\| y - H\bar{c} \right\|^2 - N_0 \log(P(\bar{c}\ )) \quad (29)$$

2- Beginning with the highest level M . Let $k = M$, each node in the level k and in the test order is tested according to the following rule:

$$\text{If } \; d_k^2 \geq (y_k - s_k H_{k,k})^2 \text{ then } d_{k-1}^2 = d_k^2 - (y_k - s_k H_{k,k})^2 \;,\; s_k \in \{+1,-1\}$$

If the node passes the test, this means that the node is inside the sphere and its off-spring in the next level will be tested, else it will be a leaf node and the test will go to adjacent node in the same level. If the two nodes are tested and neither of them passes the test, the test will go back to the upper level for further testing until all branches in the binary tree are tested, as shown in Figure 5. The scanning order is depth-first searching.

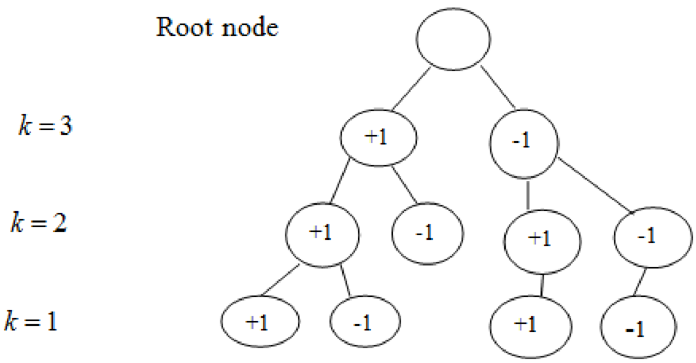

Fig. 5. Sample binary tree generated to determine lattice points in a three-dimensional sphere.

5.2. Stage 2

In this stage we estimate the relays bits of the codewords found by stage 1, this stage is as follows:

1- For each codeword c_k of sources' bits lie in the sphere, $k = 1,.....,\lambda$

Where λ is the number of the codewords that are found inside the sphere from stage 1.Let us define $x_0 = \bigoplus_{m=1}^{M} c_{km}$, $x_1 = 1 \oplus x_0$

2- For every relay bit l of every codeword inside the sphere determined from stage one we decide the relay bit 0 or 1 according to which one of them minimizes $(y_{M+l} - H_{M+l,M+l} c_{k(M+l)})^2 - N_0 \log(P(z_l))$.

So, If

$$(y_{M+l} - H_{M+l,M+l})^2 - N_0 \log(P(z_l = x_0)) < (y_{M+l} + H_{M+l,M+l})^2 - N_0 \log(P(z_l = x_1))$$

The relay bit is estimated as 0 else it is estimated as 1.

5.3. Stage 3

After determining λ codewords that we make sure that the required codeword $\hat{c}$ is one of them. We get the required codeword $\hat{c}$ that minimizes (9) from λ codewords.

6. Simulation results

In this section, the simulation results for the proposed decoding scheme are presented. In this simulation, we assume that the multiple access relay network composed of 4 sources, 4 relays, number of generated random data and noise samples is 10^5 bit/sample and the signals received at the destination have equal SNR's, γ. The simulation results shown in Figure 6 illustrate the comparison between the complexity of the MAP with the Sphere decoder and with the Brute Force (MAP without sphere decoder). It is clear that using sphere decoder reduces the complexity by 97 %.

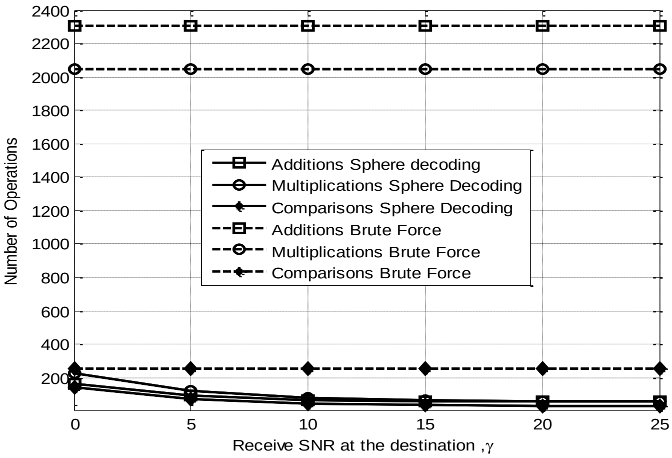

Fig. 6. The Sphere decoder performance for MAP.

Also the complexity decreases as the signal to noise ratio increases due to increasing the minimum distance between the two symbols +1 and −1. Figures 7, 8 show the performance of different decoding schemes when the number of relays is 2 and 4 respectively. No cooperation scheme means no relays nodes are available in the network. ML decoder (Maximum likelihood) neglects the error in source-to-relay links and assumes that no error in source-to-relay links. We also find that the ML decoder provides an error floor which can be intuitively interpreted as follows. At high receive SNR at the destination, the performance will be dominated by the receive SNR at the relay nodes. Since the destination neglects the error in source-to-relay links, increasing the receive SNR at the destination will not enhance the overall end-to-end error probability, more details about ML performance are found in [16]. This problem is addressed in the MAP decoder by considering all possible codewords with different probabilities. The recently proposed GC-MRC [11] scheme has complexity of 2^M and high overhead since all instantaneous SNR of sources to relays links should be sent to the destination. This overhead is not required by the MAP decoder because it relies on the average error probabilities of these links. These error probabilities rely on the average SNR's which can be sent to the destination using a negligible overhead compared to that used in GC-MRC.

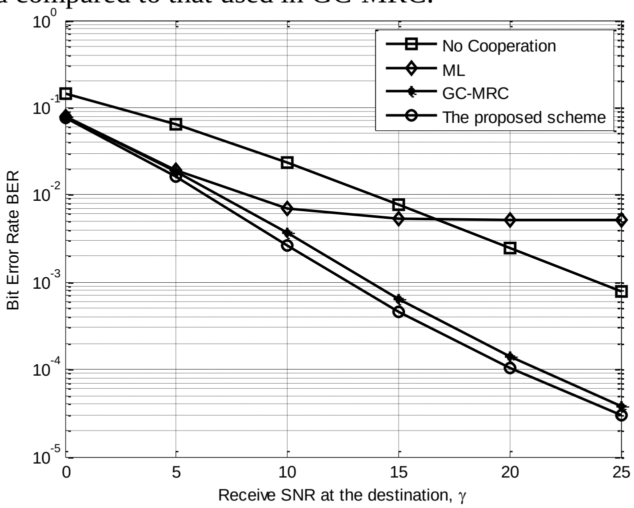

Fig.7. BER Comparison for different decoding schemes M=2,L=2.

Table 1
Comparison between the Proposed Scheme and the state of art Schemes

Number of Operations/Overhead	**Comparing**	**Multiplication**	**Addition**	**Overhead**	
GC-MRC **[11]**		16	128	144	Large (instantaneous Sources-Relays SNR's)
M. Iezzi[12]		16	128	144	Large instantaneous Sources-Relays SNR's)
The Proposed Scheme		25	55	50	Neglected (Average Sources-Relays SNR's)

In Table 1, we compare between the proposed scheme and the other decoding schemes in terms of the computational complexity and the overhead. From previous result, it is clear that our proposed scheme outperforms the recently proposed GC-MRC scheme in terms of the complexity, the overhead and the bit error rate performance.

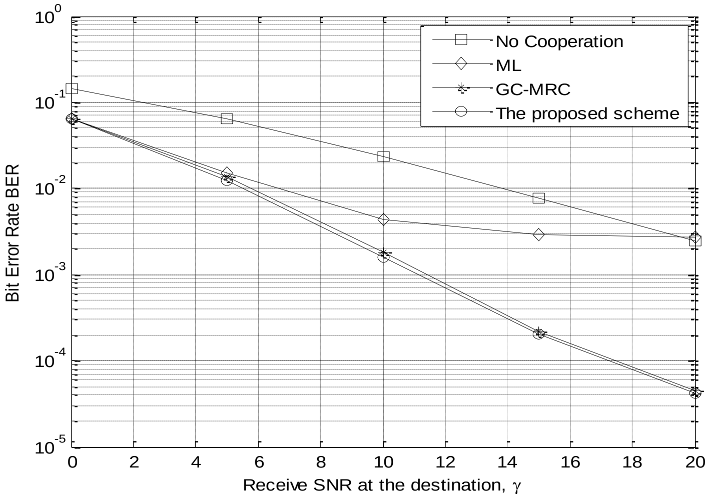

Fig. 8. BER Comparison for different decoding schemes M=2, L=4..

7. Conclusions

In this paper, we proposed the sphere decoder for the MAP decoder of the multiple access relay network to solve the complexity problem of this decoder. After using the sphere decoder the system has less complexity in addition to less overhead and achieved optimal bit error rate performance. The cooperation protocol considered in this network is the parity forwarding protocol where the relay nodes decode the data received from the sources and then combine the decoded data to generate and forward a parity bit to the destination. The results show that although the BER performance of the GC-MRC is good, the GC-MRC requires a considerable amount of overhead to forward the gain from the source-to-relay links to the destination.

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"الديكودر الكروي في الشبكات المتعددة الدخل المشفرة شبكيا ذات نقاط الترحيل"

الملخص العربى

في الشبكات ذات الدخل المتعدد المشفرة شبكيا ذات نقاط الترحيل يتصل اكثر من مصدر مع هدف واحد.التشفير الشبكي بيسمح لنقطة الترحيل بخلط البيانات الواردة من اكثر من مصدر وارسالها للهدف. الاختلاف في احتمالية الخطأ والبيانات الجانبية وحجم العمليات مسألة هامة عندما نقارن بين مختلف الديكودرات. في هذه المقالة تم فرض ديكودر MAP الذي له اداء مثالي في كمية البيانات الجانبية واحتمالية الخطأ ولكنه يعاني من حجم العمليات الحاسبية .لذا تم أستخدام الديكودر الكروي للعمل مع MAP والذي قلل حجم العمليات الحاسبية الي نسبة 3 في المائة من حجم العمليات بدون الديكودرالكروي.