Journal of Theoretical and Applied Information Technology
10th June 2013. Vol. 52 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

THE THROUGHPUT FOR MULTI-HOP RELAY WIRELESS SENSOR NETWORKS BASED ON COOPERATIVE DIVERSITY

[1]YU GENJIAN, [2]WENG KUNPENG

[1] Ph.D, Department of Computer Science, Minjiang University, Fuzhou, CHN

[2]Senior Engineer, Fuchun Communications Co., Ltd, Fuzhou, CHN

E-mail: [1]genjianyu@126.com, [2]53014448@qq.com

ABSTRACT

This paper studied the problem of the throughput of multi-hop multi-relay wireless sensor networks based on the cooperative diversity technology. At first, the paper established the cooperative diversity model for multi-source, multi-sink and multi-relay sensor networks, on which the specific expression of throughput of wireless sensor networks was deduced, it not only prove that the throughput performance of multi-hop multi-relay wireless sensor networks would be increased by the cooperative diversity technology, but also gave the criterion for discussing further the application effect of the technical scheme such as the cooperative selection strategy and so on in actual multi-hop multi-relay wireless sensor networks. In the other hand, the paper theoretically proved that cooperative diversity could improve the throughput of multi-hop multi-relay wireless sensor networks.

Keywords: *Wireless Sensor Networks, Diversity Cooperative Technology, Throughput Capacity, Multi-Hop, Multi-Relay*

1. INTRODUCTION

Wireless communication went through the development from analog to digital, fixed to mobile and centralization to distributed. With multiple antenna elements equipped both in transmitter and receiver, the structure of MIMO channel could be formed by the existing Multiple Input Multiple Output (MIMO) technology, and then the capacity of channel greatly improved with the full use of airspace resources[1]. But the existing antenna technology was mainly applied in the the base station, and it was difficult to install multiple antennas in mobile terminal, because for realizing the transmit diversity, the space between neighboring antenna was greater than the wavelength and the transmission channel between several transceiver antennas was independent or irrelevant at least, and the requirement of mobile terminal for volume, quality and power were extremely exacting, so it was difficult to realize the uplink transmit diversity in mobile terminal[2].

As it was made of multi-user in existing communication system of wireless sensor network, so cooperative diversity, which the transmit diversity was realied in mobile terminal, was caused with it[3]. The basic idea is to share their antenna between mobile terminal, transmit information by virtual multi-antenna array composed of themselves and other mobile nodes terminal, so as to achieve diversity way of launch diversity gain. As to reduce the effect of fading and instability of wireless channel, cooperative diversity may evidently reduce the bit error ratio, piece error ratio and interrupt possibility, and It could also improve the reliability, data transfer rate and throughput of network[4]. Many techniques of cooperative diversity have obtained in recent years[5,6].

Wireless sensor network is an un-center multi-hop wireless network, the information transmission beginning from source node arrives at its destination by multi-formal relay. Many researchers have written a lot of articles about relay channel theory and cooperation relay theory[7-16], in which, the classic relay channel theory proposed by Cover and Ei Gamal is founded further investigation base for the work.

The major reasons, which may prevent increasing the capacity of channel and improve the quality of service, were multi-path fading, shadow fading, path loss and interference of the channel of wireless sensor network. As to possess evident superiority in the aspect of repel channel multi-path

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

fading, and significantly improve the capacity of channel and the throughput of network below the premise that has not increased power and frequency, MIMO technology based on the idea of spatial diversity was gradually adopted by mainstream protocol of the next generation wideband wireless communication. The perfect MIMO technology may move haltingly in the process of practice because of many problems, especially challenge of setting multi-antenna in mobile wireless sensor terminal. So, cooperative diversity, which is a new technology of space diversity, is proposed by Sendonaris and others, as shown in Figure 1. The basic idea is to create virtual multi-antenna array by the form of sharing antenna and other network resources between multi-user construction, and achieve certain spatial diversity gain through the distributed processing. In this sense, cooperative diversity provides a new path in order to apply MIMO technology to engineering practice.

As far as wireless networks are concerned, cooperative diversity has been an attractive way of anti-fading[13,14]. The cooperation performance of multi-hop relay asynchronous network and the validity of cooperative diversity at the level of MAC were studied in [2] and [19], respectively. A robustness MAC protocol based on cooperative diversity, a coding cooperative scheme based on MISO in sensor network, a self-adapting cooperative coding algorithm, a cross-layer collaborated system and a judgment method were proposed in [4], [5],[15],[16]and[18], respectively. In [20], a cross-layer design project was devised. The technology of sensor network and Internet of things based on cooperative diversity have already raised great attention. The cooperative diversity, which the idea is based on the Classic relay channel theory proposed by Cover and Ei Gamal, is different from the traditionary relay communication. To the traditional relay communications, the role of relay node is to form main channel, it is only exists as relay, node itself has no messages to deliver, so in relay communications the diversity gain is zero. But to cooperative communications based on cooperative diversity, every user needs not just to transfer the message of partner but to send itself message , In the time , the role of relay node is to assist and enhance main channel, it has the diversity gain.

Different from the traditional point-to-point communications, coordination communication mode and networking technology based on cooperative diversity allow different users or nodes to share the antenna and network resources of each other in wireless sensor networks, the wireless sensor network throughput and multiplexing gain are expected to greatly improve , it is benefit of reducing the complexity of the problem and realizing the seamless wireless networking, so it has huge application value to wireless sensor network. At present, the studies of cooperative diversity and coordination communication have been confined to the simple model of single-source node, single-destination node and single/ multi-relay, but the model, which has great contributions to the study of cooperative diversity technology and the establishment of related theory, is far from the practical network environment, so we can't expand the model to whole network. There are still many problems to be resolved, which the cooperative communication theory is applied to the actual cooperation network. One of the key problems is how to extend simply model to the actual multi-source, multi-destination and multi-relay network model for realizing cooperative diversity on the network side.

Based on above considerations, this article focuses on the study of throughput in the model of cooperative diversity sensor network that is multi-source, multi-destination and multi-relay.

This paper is organized as follows. In section 2, cooperative diversity technology of wireless network is given. In section 3, the cooperative diversity model of multi-hop multi-relay wireless sensor networks is presented. The code technology and decode relay in this paper are also presented in section 4. In section 5, the throughput of multi-hop relay sensor networks is analyzed. Finally, our works of this paper is summarized in the last section.

2. COOPERATIVE DIVERSITY TECHNOLOGY OF WIRELESS NETWORK

As the instability of the wireless sensor networks link, the main goal of adopting cooperative diversity technology in sensor network is to improve the quality of data transmission and the throughput when some link fault occurs or the quality of communication was poor, which another wireless node forward the information as a relay, and the information from the sender node and the relay node were joined together by the receiver node. The principle of cooperative diversity is shown in Fig. 1. A simple diversity cooperation system is formed by source node, relay node and destination node. The specific process is divided

Journal of Theoretical and Applied Information Technology
10th June 2013. Vol. 52 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

into two steps: first, source node send the information to relay nodes and destination node, and relay node process the received information; next, source node and relay node send the information to destination node, then destination node combined the received information by some method of combining.

The way, which the information sent from source node and processed by relay node is forwarded to the base station, is divided into the following several kinds: amplify forward, decode forward and coding cooperative, according to the original coding method, the information gained from judgment is transferred to the destination node in the second step. In this process, the performance is improved by the retransmission of redundant information in different space. In coding cooperative, corporate users decode the received signal in perspective, and then pass to destination after coding. Its basic idea is: every user try best to send redundancy increment of information for its partners. The process is to add the different redundant information to sign by code in order to gain double redundant of space with code and achieve double diversity of air-space with code-space. Coding Cooperative mode can be divided into CC(Coding Cooperative) and STCC(Space Time Coded Cooperation). The user in CC only send message from itself Multi-access channels, and the user in STCC send message from itself and corporate users Multi-access channels, The user in CC only send message from itself Multi-access channels, and the user in STCC send message from itself and corporate users Multi-access channels.

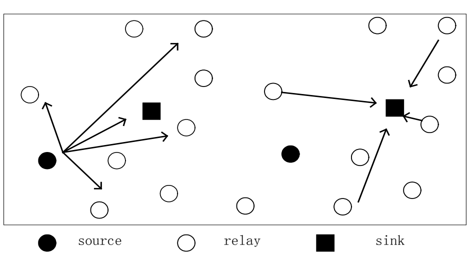

Fig.1 diversity of wireless networks

Firstly, the studies of cooperative diversity technology are concentrated on how to generate the diversity combating fading at the moment, and the classic relay channel theory proposed by Cover and Ei Gamal mainly analyze the capacity of channel and throughput under Additive White Gaussian Noise channel17. Secondly , the purpose of relay is to help main channel in the relay channel, but the resources of whole system are constant in cooperative communication, the user acts as information source and the relay. Besides AF(Amplify Forward), DF(Decode Forward) and CC mentioned above, another important treatment method for cooperation is Detection Relay, which is pretty close to the traditionary relay method. In detection relay, the user first attempts to detect bit of partner specified by base station and some technologies, then resend the detected bit. Depending on the condition of cooperation between two users, then in practice, each user has a partner to provide the second path for it, and so diversity is formed. The distribution of the partners is becoming a hot topic at present. We can refer to the case in the book written by Sendonaris, which bring more inspiration and enlightenment to the researcher. In addition, the cooperation mechanism of decode forwarding under CDMA, which the nodes of two users had teamed up in pairs, was analyzed in the book. Each user node had its own spreading codes. The data bit of two user were the functions of time, the distribution of signal power was reflected in the range of the signal, and each signal cycle included 3 bit interval. Each user sent itself bit information and detected the second bit of other users in the first and second interval. Two users sent the linear combination involving the second bit of itself and its partners in the third interval. To the first, second and third interval, the power was variable, According to the condition between uplink and user channel, the related transmission power is optimized, the method had self-adaptability for the state of channel. The power is allocated by $a_{i,j}$, which the average transmit power is invariant. In short, when the channel status was good, more power will be allocated for collaboration, otherwise the power will be decreased. This kind of signal processing mechanism is very simple and had self-adaptability. But to the clumping type sensor network, the mechanism had the following questions: first, the signal detection might be fail, the cooperation was unfavorable for the last detection made by the signal in the cluster head. Next, in order to have the optimal decoding, the cluster head needed to know the error characteristics of channel between nodes. In order to avoid the problem of error transmission mentioned above, a kind of mixed decoding forward method was developed by Laneman13, the user node could decode the data of its partner when the fading channel had higher SNR (Signal Noise Ratio), but when the channel had lower SNR, the user node returned to the non-collaboration.

In AF mechanism, each user receive the signal with noise from the partner, and then resend the

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

signal after the amplification. Base station combine the data from the user and its partners and make a decision. Although when the cooperation magnify the signal, the noise is also magnified, but the base station receive two independent declined signal, finally can make better decision. AF mechanism, which was developed by Laneman, was detailed analyzed13. The result shows that the diversity order of AF is two at high signal to noise power ratio region (SNR) under the conditions of two users. In AF, granted the Channel coefficient between user, we can get the optimum decoding, so AF must have necessary channel estimation and exchanges of information. It is not a simple technology for sample, amplification and retransmission of analog signal to AF. But overall, according to a simple cooperation mechanism that is easy for analyzing, it will be very helpful to further understand the later coordination communication system.

CC was integrated the channel coding idea and coordination. CC send the different code word of each user by two independent fading channel. The basic idea is that each user send the redundant information increase to its partners. CC will return elastically to non- cooperation model when the channel between them is very poor. The outstanding characteristics of CC is to achieve coordination by designing channel coding Without the feedback between users. The source data sent from user includes value information and CRC information. Data sending cycle of each user is divided into two stages In CC. We call each stage for a frame.

In first frame, the code word sent form user includes N_1 bits. Each user attempts to decode correctly on the data of partner. In second frame, if the decoding is correct, the user will calculate and send the second part of its partner, which includes N_1 bits. Otherwise, the user will send the second part of itself, which also includes N_1 bits. So the user send $N = N_1 + N_2$ bits in each cycle. Usually, all kinds of channel coding method can be used for coding cooperation network. For example the code words can be block code, convolution code or both of two. In Rate Compatible Punctured Convolution(RCPC)24, for example, the first frame can be obtained by hewing N_1 out of N, and the second frame is composed of bits that was poked.

The monograph, which was published by Sendonaris, analysed the cooperation mechanism of DF under CDMA. In this mechanism, as a pair, two users support each other. Each user has its own spreading code $C_1(t)$ and $C_2(t)$. The data bits of two users are $b_i(n)$, in which, $i = 1,2$ is index number of user, n is expressed as time mark of information. Each signal cycle includes three bits space. $X_1(t)$ and $X_2(t)$ are expressed as the signal of user 1 and user 2, respectively, so the signal is

$$X_1(t) = \left[a_{11} b_1^{(1)} C_1(t),\ a_{12} b_1^{(2)} C_1(t),\ a_{13} b_1^{(2)} C_1(t) + a_{14} \hat{b}_2^{(2)} C_2(t) \right] \quad (1)$$

$$X_2(t) = \left[a_{21} b_2^{(1)} C_2(t),\ a_{22} b_2^{(2)} C_2(t),\ a_{23} \hat{b}_1^{(2)} C_1(t) + a_{24} b_2^{(2)} C_2(t) \right] \quad (2)$$

Each user sent itself bit information and detected the second bit of other users in the first and second interval. Two user sent the linear combination involving the second bit of itself and its partners in the third interval. To the first, second and third interval, the power was variable, According to the condition between uplink and user channel, the related transmission power is optimized, this method had self-adaptability for the state of channel.

The power is allocated by $a_{i,j}$, which the average transmit power is invariant. In short,, when the channel status was good, more power will be allocated for collaboration, otherwise the power will be decreased.

3. THE COOPERATIVE DIVERSITY MODEL OF MULTI-HOP RELAY WIRELESS SENSOR NETWORK

Consider a multi-hop relay wireless sensor networks $\Omega(N)$, the number of node was N.

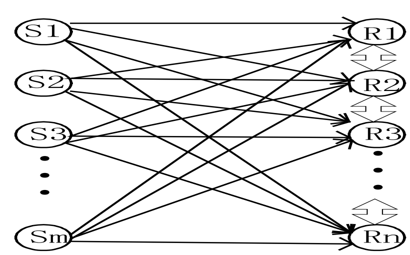

Fig.2 Network Model Based On Cooperative Diversity

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

As shown in Figure 2, the source (or relay) node sent the sign z_i to the destination (or relay) node R_j ($j=1,2,...,n$) at the rate of $\grave{u}_i$, respectively ,expressed as $S_i \xrightarrow{z_i} R_j$, in which, $z_i \hat{I}$ A_i .

To be more specific, the node S_i 、 R_j ($i=1,2,...,m$, $j=1,2,...,n$) could be configured for sending out complex value base-band signal flow a_{ik} 和 b_{jk} ($k=1,2,...N$), respectively , which were satisfied the conditions of node power in the average significance:

$$\frac{1}{N}\sum_{k=1}^{N}|\alpha_{ik}|^2„ \ P(S_i) \quad , \quad \frac{1}{N}\sum_{k=1}^{N}|\beta_{jk}|^2„ \ P(R_j) \tag{3}$$

When the source (or relay) node S_i send the signal to the destination (or relay) node R_j at the rate of p_{S_i} , the other destination (or relay) node $R_w (w \neq j)$ could listen and assist the distribution process by relay cooperation. Noted the signal received by the destination (or relay) node R_j ($j=1,2,...,n$) as $¡ (R_j)$, the channel was rayleigh fading, noted the fading index as r_j ($j=1,2,...,n$), noted Additive Gaussian White Noise with zero mean and one variance as C ,which was the circle symmetrical IDD complex random variable. The channel gain between S_i and R_j was g_{ij} , the cooperative diversity gain between R_j and R_w was $G(\cos\theta_{jw}+i\sin\theta_{jw})$, in which, i was the unit of imaginary number, the range G was constant, the phase θ_{jw} was the random variable distributed in $[-\pi,\pi]$, thus, based on $S_i \xrightarrow{z_i} R_j$, the model of receiving signal of source (or relay) node was

$$¡ (R_j) = g_{ij} z_i + G\sum_{w=1,2,...m,w\neq j}(\cos\theta_{jw}+i\sin\theta_{jw})z_j^w + C_j \tag{4}$$

$$j=1,2,...n$$

In which, z_j^w was sent by R_w in $S_i \xrightarrow{z_i} R_j$, C_j was Additive Gaussian White Noise. The formula (4) could be noted as

$$¡ (R_j,k) = g_{ij}\alpha_{ik} + G\sum_{w=1,2,...,n,w\neq j}(\cos\theta_{jw}+i\sin\theta_{jw})\beta_{wk} + C_{jk} \tag{5}$$

$$j=1,2,...n, \quad k=1,2,...N$$

The fading channel, which carried the information sent and receive by many sender and receiver, was a degenerate gaussian radio channel in this paper, in which, each sender and receiver had the different SNR that was depent on the state of the channel. In addition, unlike in the past, the transmitter sent many information flows with different rate and power, not sent simple information flow with constant rate and interrupt possibility. Then, many information flows were decoded when the condition of channel is poor, and more information could obtain more reliable decoding when the condition of channel is good.

4. CODING TECHNOLOGY AND DECODE RELAY

Which way do Code Word transfer depent on receiving node. According to the information of receiving node, Code Word transferred many kind of information, supposed the sender node sent the information

$$z_1 \in \{1,2,...,2^{k\grave{u}_1}\} \quad , \quad z_2 \in \{1,2,...,2^{k\grave{u}_2}\} \quad , \quad ..., \quad z_m \in \{1,2,...,2^{k\grave{u}_m}\} \tag{6}$$

So the sender node would form a generalized information matrix, which was $2^{k\grave{u}_1}\times 2^{k\grave{u}_2}\times\cdots\times 2^{k\grave{u}_m}$, matrix elements was random gaussian code, noted as $X(\zeta_1,\zeta_{2,}\cdots\zeta_m)$. if channel capacity was $C … \grave{u}_1+\grave{u}_2+\cdots+\grave{u}_m$, then the information z_1 , z_2 , …, z_m were decoded by the receiver node. If $z_{i_1},...,z_{i_j}$, $1„ \ i_1,...,i_j „ \ m$, and $C … \sum_{k\neq i_1,i_2,...,i_j} z_k$, then the receiver node decoded z_k $(k\neq i_1,...,i_j,1„ \ k„ \ m)$ by the generalized information matrix.

If the wireless channel, which the information was choose, according to a uniform probability by the information set in (6) and sent from the source (or relay) node to the destination (or relay) node, was point-to-point. For the wireless relay channel, Block Markov Coding was first developed by Madsen in the [3]. A signal, which would be sent, was divided into several blocks, each block of signal was encoded alone, supposed the signal z_i

Journal of Theoretical and Applied Information Technology
10th June 2013. Vol. 52 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

was divided into M blocks $z_i(1), z_i(2), \ldots, z_i(M)$, The encoding function of the source (or relay) node was $X_{S_i}(\zeta_i(1))$, $X_{S_i}(\zeta_i(2))$, …, $X_{S_i}(\zeta_i(M))$. In the model of received signals above, the relay node $R_w\ (w \neq j)$ decoded the Code Book $X_{S_i}(\zeta_i(l))$ of l block.. When $\grave{u}_i < \log(1+|g_{ij}|^2 \cdot P(S_i))$, the biggest misunderstanding code probability would be so small. After obtaining the signal of Decode Block, the relay node sent the signal series 0, $X_{R_w}(\zeta_i(1))$, $X_{R_w}(\zeta_i(2))$,…, $X_{R_w}(\zeta_i(M))$ which was decoded in the next Block Slot. The transport method of block code signal was called Decode Relay. To the model architecture of System in this paper, the target (or relay) nodes used parallel decoding technology12.

Supposed the destination (or relay) node had received the signal $z_i(k)$ of k block, and Meanwhile, the Code Book $X_{S_i}(\zeta_i(k-2))$ was decoded by the small misunderstanding code probability, then the form of parallel decoding signal based on the model of received signals in the target (or relay) nodes was

$$\Big[X_{S_i}(\zeta_i(k)) + G \sum_{w=1,2\ldots m, w\neq j} (\cos\theta_{jw} + i\sin\theta_{jw}) X_{R_w}(\zeta_i(k-1)) + C_j, \quad X_{S_i}(\zeta_i(k-1)) + C_{j-1}\Big] \qquad (7)$$

If the source (or relay) node $S_i\ (i = 1,2,\ldots,m)$ sent a code word that described the information received by the destination (or relay) node. Based on the discussion mentioned above, the relay node $R_w\ (w \neq j)$ would decode the information before R_j. So when the information was decoded successfully, every receiver node began to use another scheduled code word and sent the same information in the average power conditions. Supposed that the decoding time of the node R_j in a code block cycle was represented in the time slot t_j. Then, t_j means a period of a fading code block cycle when the node R_j decoded and realied the information to the node $R_w\ (w \neq j)$. According to the condition of right decoding, there was $\grave{u}_i \big/ \log(1+|g_{ij}|^2 \cdot P(S_i)) < 1$.

Based on the actual physical channel and decoding conditions, we supposed that the node R_j would neither decode nor send information when $t_j \geq 1$.

Let p_j to represent the probability which the node R_j was decoded successfully. In addition, the mutual information related to node S_i, R_j was

$$I_j = \sum_{l=1}^{j} (t_l - t_{l-1}) \log(1+|g_{ij}|^2 \cdot P(S_i) + G^2(l-1))$$

(8)

In which $t_0 = 0$, by solving a equation $I_j = \grave{u}_i$, $j = 1,2,\ldots,n$, we have:

$$t_1 = \frac{\grave{u}_i}{\log(1+|g_{i1}|^2 \cdot P(S_i))},$$

$$t_2 = \frac{\grave{u}_i + t_1 \log\dfrac{1+|g_{i2}|^2 \cdot P(S_i) + G^2}{1+|g_{i2}|^2 \cdot P(S_i)}}{\log(1+|g_{i2}|^2 \cdot P(S_i) + G^2)}, \quad \ldots,$$

$$t_n = \frac{\grave{u}_i + t_1 \log\dfrac{1+|g_{i2}|^2 \cdot P(S_i) + G^2}{1+|g_{i2}|^2 \cdot P(S_i)}}{\log(1+|g_{in}|^2 \cdot P(S_i) + (n-1)G^2)} + \frac{t_2 \log\dfrac{1+|g_{i3}|^2 \cdot P(S_i) + 2G^2}{1+|g_{i3}|^2 \cdot P(S_i) + G^2}}{\log(1+|g_{in}|^2 \cdot P(S_i) + (n-1)G^2)} + \cdots + \frac{t_{n-1} \log\dfrac{1+|g_{in}|^2 \cdot P(S_i) + (n-1)G^2}{1+|g_{in}|^2 \cdot P(S_i) + (n-2)G^2}}{\log(1+|g_{in}|^2 \cdot P(S_i) + (n-1)G^2)} \qquad (9)$$

$$(i = 1,2,\ldots,m)$$

Naturally, when $t_j < 1$ and $t_{j+1} \geq 1$, then $p_j > 0$, $p_{j+1} = 0$, $(j = 1,2,\ldots,m)$, and vice versa. So

$$p_j = \Pr\{t_j < 1\}$$

(10)

Through the analysis (node decoding, cooperation and relay) mentioned above and the literature[15], in the sense of probability expectations, the throughput of mulit-hop relay sensor network based on cooperative diversity was expressed as

Journal of Theoretical and Applied Information Technology
10th June 2013. Vol. 52 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

$$C_{throughput} = \sum_{i=1}^{m}\sum_{j=1}^{n}\frac{\omega_i}{n}p_{S_i}p_j$$

(11)

In which, the probability, which the source (or relay) node sent information was p_{S_i}.

5. THROUGHPUT ANALYSIS

Now we analyse the throughput of multi-source sink relay sensor network.

Throughput of sensor network when $m = n = 1$

There is only a source (or relay) node S_1 and a target (or relay) node R_1, $i = j = 1$, so it is a situation of unicast and non-cooperation diversity. Because the probability density function of gain $|g_{ij}|^2$ is $p_{|g_{ij}|^2}(x) = e^{-x}$, and in here $i = j = 1$, so from the formula (9) and (11), we have:

$$C_{throughput,m=n=1} = \omega_1 p_{S_1}\Pr\{t_1 < 1\}$$

$$= \omega_1 p_{S_1}\Pr\left\{\frac{\omega_1}{\log(1+|g_{11}|^2\cdot P(S_1))} < 1\right\}$$

$$= \omega_1 p_{S_1}\Pr\left\{\frac{e^{\omega_1}-1}{P(S_1)} < |g_{11}|^2\right\} = \omega_1 p_{S_1}\int_{\frac{e^{\omega_1}-1}{P(S_1)}}^{+\infty} e^{-x}dx$$

$$= \omega_1 p_{S_1}\exp\left\{-\frac{e^{\omega_1}-1}{P(S_1)}\right\} \qquad (12)$$

From（12）, if the source (or relay) node S_1 sent the information to R_1 with the nonzero probability p_{S_1} and the rate ω_1, $C_{throughput,m=n=1}$ reached the maximum. Hence, when the level of node power and the possibility of sending information are to achieve a dynamic balance, the throughput was maximum.

Throughput of sensor network when $m = 2$, $n = 2$

There were two source (or relay) nodes and target (or relay) nodes, respectively, and the network was based on the cooperative diversity model, radio strategy and decoding technology mentioned above in this paper. Because the Joint probability density function16 of gain $|g_{i1}|^2$ and $|g_{i2}|^2$ $(i = 1,2)$ was

$$p_{|g_{i1}|^2,\ |g_{i2}|^2}(x,y) = e^{-x}e^{-y}, (i = 1,2),$$

and the conditional probability density function was $p_{|g_{i1}|^2\ |\ |g_{i2}|^2}(x\,|\,y) = e^{y-x}$, $(i = 1,2)$. We have the theorem 1.

Theorem 1 Based on the cooperative diversity model, radio strategy and decoding technology mentioned above, the parameters were described as following: the path index was $|g_{ij}|^2$, the cooperation index was Γ^2, the power of source node was $P(S_i)$, the rate of sending information was ω_i, $i, j = 1,2$. Then the throughput of sensor network was：

$$C_{throughput,m=n=2} = \sum_{i=1}^{2}\frac{\omega_i p_{S_i}}{2}\times\Big(1 + e^{\Lambda} - e^{-\Lambda} +$$

$$+\exp\left\{-\frac{e^{\omega_1}-1}{P(S_1)}\right\} + \exp\left\{-\frac{e^{\omega_2}-1}{P(S_2)}\right\}\Big) \qquad (13)$$

In which

$$\Lambda = \frac{\exp\{\omega_i / L(\Gamma, g_{i2}, \omega) - 1\}}{P(S_i)}, \text{ and}$$

$$L(\Gamma, g_{i2}, \omega) = \frac{\log\left(1+|g_{i2}|^2 P(S_i) + \Gamma^2\right) - \omega_i}{\log\left(\frac{1+|g_{i2}|^2 P(S_i) + \Gamma^2}{1+|g_{i2}|^2 P(S_i)}\right)}$$

The proof of thoerem 1 see appendix.

Obviously, it included the throughput under the condition of non-cooperation relay in the formula (23), this emphasizes the fact that the throughput could be improved by cooperative diversity. For the common m and n, similar to the mark mentioned above, we have $L(\Gamma, g_{i2}, g_{i3}, \omega)$,…, $L(\Gamma, g_{i2}, g_{i3}, ..., g_{ij}, …, \omega)$ and $\Lambda_1, ..., \Lambda_{j-2}$, thereby, we have the following corollary.

Corollary: For the other m and n, Under the condition of theorem 1, the calculation formula of throughput of multi-hop relay sensor network based on cooperative diversity technology was

$$C_{throughput} =$$

$$\sum_{i=1}^{m}\frac{\omega_i}{n}p_{S_i}\left(1 + e^{\Lambda} - e^{-\Lambda} + \sum_{j=1}^{n}\exp\left\{-\frac{e^{\omega_j}-1}{P(S_j)}\right\} + \right.$$

Journal of Theoretical and Applied Information Technology
10th June 2013. Vol. 52 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

$$+\sum_{j=3}^{n}\int_{\text{L}_{j-2}}\int_{\text{L}_{j-1}}\cdots\int_{\text{L}_1}\Upsilon\, dy_3\cdots dy_j\Bigg)$$

$$\Upsilon=\Pr\left\{|g_{i,j-1}|^2>\text{L}_{j-2}\,\Big\|\, g_{i,j}|^2=y_j\right\}p_{|g_{i,j}|^2}(y_j)\quad(14)$$

6. CONCLUSIONS

In this paper we mainly studied the throughput of multi- source relay wireless sensor network based on cooperative diversity, a cooperative diversity model of sensor network, which was multi-source relay, was set up. Based on the model, the formulae of throughput was derived. So the quantitative calculation for the throughput performance of multi-source relay sensor network under cooperative diversity would provide us theoretical judging rule for discussing farther the application of technical proposal such as cooperative selection scheme in the actual network environment of multi-hop relay sensor network. On the other hand, it was proved theoretically that throughput performance of multi-source relay sensor network would be improved by cooperative diversity.

According to the conclusions of throughput and the simulation based on cooperative diversity, a valuable judgment scale was given in the application environment of multi-hop relay wireless sensor network for balancing the relationship between the throughput and network cost.

APPENDIX

Prove of theorem 1: for $\forall i,j,i\neq j$, A_i and A_j are independent of each other. Combined with the formula (9), we have:

$$\Pr\{t_1<1\}=\Pr\left\{\frac{\grave{u}_1}{\log(1+|g_{11}|^2\cdot P(S_1))}<1\right\}$$

$$+\Pr\left\{\frac{\grave{u}_2}{\log(1+|g_{21}|^2\cdot P(S_2))}<1\right\}\quad(15)$$

$$=\Pr\left\{\frac{\grave{u}_1}{\log(1+|g_{11}|^2\cdot P(S_1))}<1\right\}$$

$$+\Pr\left\{\frac{\grave{u}_2}{\log(1+|g_{21}|^2\cdot P(S_2))}<1\right\}\quad(16)$$

$$=\exp\left\{-\frac{e^{\grave{u}_1}-1}{P(S_1)}\right\}+\exp\left\{-\frac{e^{\grave{u}_2}-1}{P(S_2)}\right\}$$
(17)

But

$$\Pr\{t_2<1\}=\Pr\{t_1<L(G,g_{i2},\grave{u})\}$$

$$=\int_0^\infty\Pr\left\{t_1<L(G,g_{i2},\grave{u})\,\Big|\,|g_{i2}|^2=y\right\}p_{|g_{i2}|^2}(y)\,dy$$

$$=\int_0^\infty\Pr\left\{|g_{i1}|^2>\frac{\exp\{\grave{u}_i/L(G,g_{i2},\grave{u})-1\}}{P(S_i)}\,\Big\|\, g_{i2}|^2=y\right\}p_{|g_{i2}|^2}(y)\,dy$$
(18)

$$=\int_0^\infty\Pr\left\{|g_{i1}|^2>\text{L}\,\Big\|\, g_{i2}|^2=y\right\}p_{|g_{i2}|^2}(y)\,dy$$
(19)

$$=\begin{cases}\int_0^\infty\int_{\text{L}}^\infty p_{|g_{i1}|^2\,|\,|g_{i2}|^2}(x\,|\,y)\,p_{|g_{i2}|^2}(y)\,dx\,dy & if\ \ y<\text{L}\\ \int_0^\infty p_{|g_{i2}|^2}(y)\,dy & if\ \ y\geq\text{L}\end{cases}$$
(20)

in which

$$L(G,g_{i2},\grave{u})=\frac{\log\left(1+|g_{i2}|^2P(S_i)+G^2\right)-\grave{u}_i}{\log\left(\frac{1+|g_{i2}|^2P(S_i)+G^2}{1+|g_{i2}|^2P(S_i)}\right)},$$

$$\text{L}=\frac{\exp\{\grave{u}_i/L(G,g_{i2},\grave{u})-1\}}{P(S_i)}$$
(21)

Combined with the conditional probability density function, we easy to know that

$$\Pr\{t_2<1\}=\int_0^{\text{L}}\int_{\text{L}}^\infty e^{y-x}\,dx\,dy+\int_{\text{L}}^\infty e^{-y}\,dy$$

$$=1-e^{-\text{L}}+e^{\text{L}}$$
(22)

So we have

$$C_{throughput,m=n=2}=\sum_{i=1}^{2}\frac{\grave{u}_i p_{S_i}}{2}\left(\Pr(t_1<1)+\Pr(t_2<1)\right)$$

$$=\sum_{i=1}^{2}\frac{\grave{u}_i p_{S_i}}{2}\times\Bigg(1+e^{\text{L}}-e^{-\text{L}}+$$

$$+\exp\left\{-\frac{e^{\grave{u}_1}-1}{P(S_1)}\right\}+\exp\left\{-\frac{e^{\grave{u}_2}-1}{P(S_2)}\right\}\Bigg)$$
(23)

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

ACKNOWLEDGMENT

This work is supported by the special project funds of college of Fujian Province under Grant No. JK2010045 and the funds of Department of Education of Fujian Province under Grant. No. JA11199 and funds of Fuchun communication Co.,Ltd.

REFRENCES:

[1] Jakllari G., Krishnamurthy S V., Faloutsos M., "On broadcasting with cooperative diversity in multi-hop wireless networks", *IEEE Journal on Selected Areas in Communications*, Vol. 25, No. 2, 2007,pp.484-496.

[2] Nahas, M.; Saadani, A.; Hachem, W.; Performance of asynchronous two-relay two-hop wireless cooperative networks. *IEEE Transactions on Wireless Communications*, Vol. 9 , No. 3, 2010, pp.1086-1096.

[3] Host-Madsen A., "Capacity bounds for Cooperative diversity", *IEEE Trans. on Inform. Theory*, Vol.52, No.4, 2006, pp.1522-1544.

[4] Sangman Moh; Chansu Yu; "A Cooperative Diversity-Based Robust MAC Protocol in Wireless ad hoc Networks", *IEEE Transactions on Parallel and Distributed Systems*, Vol. 22, No.3, 2011, pp.353-363.

[5] Asaduzzaman; Hyung Kong, "Coded diversity for cooperative MISO based wireless sensor networks", *IEEE Communications Letters*, Vol.13, No. 7, 2009, pp.516-518.

[6] Mahinthan V., Mark J W., "A simple cooperative diversity scheme based on orthogonal signaling mobile radio applications", *IEEE Wireless Communications and Networking Conference*, Vol.2, Hongkong, July 23-26, 2005, pp.1012-1017.

[7] Li Y., Xia X G., "A Family of Distributed Space-Time Trellis Codes With Asynchronous Cooperative Diversity", *IEEE Transactions on Communications*, Vol.55, No.4, 2007, pp.790-800.

[8] Yue Shang, Xiang Gen Xia, "Shift-full-rank matrices and applications in space-time trellis codes for relay networks with asynchronous cooperative diversity", *IEEE Trans. on Inform. Theory*, Vol.52, No.7, 2006, pp.3153-3167.

[9] Yýlmaz A O., "Cooperative Diversity in Carrier Frequency Offset", *IEEE Communications Letters*, Vol.11, No.4, 2007, pp.307-309.

[10] Mehrpouyan, Hani; Blostein, Steven D.; "Bounds and Algorithms for Multiple Frequency Offset Estimation in Cooperative Networks", *IEEE Transactions on Wireless Communications*, Vol.10, No.4, 2011, pp.1300 -1311.

[11] Lei Xiao, Fuja T E., Kliewer J., Costello D J., "Cooperative Diversity Based on Code Superposition", *IEEE International Symposium on Information Theory*, Vol.12, No.5, Nov. 12-15, 2006, NewYork, pp.2456-2460.

[12] Nicholas J, Laneman, Martinian E, et.al., "Source–Channel Diversity for Parallel Channels", *IEEE Trans. on Inform. Theory*, Vol.51, No.10, 2005, pp.3518-3539.

[13] J. N. Laneman, D. N. C. Tse, and G.W.Wornell, "Cooperative diversity in wireless networks: Efficient protocols and outage behavior," *IEEE Trans. Inf. Theory*, Vol. 50, No.12, 2004, pp.3062–3080.

[14] A. Sendonaris, E. Erkip, and B. Aazhang, "User cooperation diversity Part I: System description," *IEEE Trans. Commun*., Vol. 51, No. 11, 2003, pp.1927–38.

[15] Li Li; Honglin Hu; Xia Chen; Hsiao-Hwa Chen, "Adaptive cooperative coding with power allocation in wireless relay networks", *IEEE Transactions on Wireless Communications*, Vol.8, No.9, 2009, pp,4604 -4615.

[16] Wei Chen; Lin Dai; Ben Letaief, K.; Zhigang Cao, "A Unified Cross-Layer Framework for Resource Allocation in Cooperative Networks", *IEEE Transactions on Wireless Communications*, Vol.7, No.8, 2008, pp.3000-3012.

[17] Cover T M., EI Gamal A A., "Capacity theorems for the relay channel", *IEEE Trans. Inform. Theory*, Vol.25, No.2, 1979, pp.572-584.

[18] Srinivasan V., Nuggehalli P., Chiasserini C F., et al., "An analytical approach to the study of cooperation in wireless ad hoc networks", *IEEE Transactions on Wireless Communications*, Vol.4, No.2, 2005, pp.722-733.

[19] Zheng H., "On the effectiveness of cooperative diversity in ad hoc networks: A MAC layer study", *Proc. ICASSP05*, Vol.3, Japan, March 3-5, 2005, pp.509-512.

[20] Lin D., "Cross-layer design for combining cooperative diversity with truncated ARQ in ad hoc wireless networks", *Proc.*

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

GLOBECOM'05, Sept. 24-26, 2005, Beijing, pp.3175-3179.

[21] Dongwoo Lee, Jae Hong Lee, "Adaptive Amplify-and-Forward Cooperative Diversity using Phase Feedback", *IEEE 65th Vehicular Technology Conference*, Oct. 12-14, 2007, Taiwan, pp.1633-1637.

[22] Luo J., Blum R.S., "Decode-and-Forward Cooperative Diversity with Power Allocation in Wireless Networks", *IEEE Transactions on Wireless Communications*, Vol.6, No.3, 2007, pp.793-799.

[23] Bletsas A., Khisti A., Reed D.P., "A simple Cooperative diversity method based on network path selection", *IEEE Journal on Selected Areas in Communications*, Vol.24, No.3, 2006, pp.659-672.

[24] Hagenauer J. "Rate-compatible punctured convolution codes (RCPC Codes) and their applications", *IEEE Trans on Communications*, Vol.36, No.4, 1988, pp.389-400.