ENERGY – BALANCED MULTI – HOP – AWARE COOPERATIVE GEOGRAPHIC ROUTING FOR WIRELESS AD HOC NETWORKS

Wentong Fan [1] – Song Zhang[2*] – Linhua Ma[1] – Le Ru[1] – Hong Tang [1] – Yu Tian [3]

[1]Aeronautics and Astronautics Engineering College, Air Force Engineering University, 710038 Xi'an, China
[2]Unit 95980 of the People's Liberation Army, 441100 Xiangyiang, China
[3]Unit 95876 of the People's Liberation Army, 734100 Zhangye, China

ARTICLE INFO

***Article history*:**
Received: 14.11.2014.
Received in revised form: 26.3.2015.
Accepted: 27.3.2015.

Keywords:
Cooperation communication
Energy balanced
Power saving
Geographic routing
Wireless ad hoc network

Abstract:

Since the cooperative communication can reduce the transmitted power and extend the transmission coverage, minimum energy routing protocols are considered to reduce the total energy consumption in a multi-hop wireless Ad Hoc network. In this paper, an Energy-balanced Multi-hop-aware Cooperative Geographic Routing (EMCGR) algorithm is proposed. We firstly formulate the outage probability and construct the minimum power route in Multi-hop-aware Cooperative Transmission (MCT) mode. The MCT mode can fully exploit the merit of the relay broadcasting characteristics to achieve the aim of saving the total transmitted power. Then an improved Energy-Balanced Geographic Routing (EBGR) algorithm is designed. The EBGR algorithm selects the next hop forwarding node by combining the geographic position information and energy information. The goal of this strategy is to balance the energy consumption among nodes so that the lifetime of the whole network can be prolonged. The route of the proposed EMCGR algorithm is based on EBGR algorithm. Simulation results show that in the same computer simulation scene, the power saving of the EMCGR algorithm with respect to the MPCR algorithm and EBGR algorithm can achieve 15.2% and 67.1%, respectively. Besides, the EMCGR algorithm does well in balancing the energy consumption among nodes in the wireless Ad Hoc network.

1 Introduction

Recently, wireless networks have been drawn more and more attention in various applications. As the wireless nodes are often powered merely by batteries, energy saving is a major concern of routing algorithms for different wireless networks such as wireless sensor networks and ad hoc networks [1].

* Corresponding author. Tel.: +86 029 8478 7514; fax: +86 029 8478 7514;

Cooperative communication for wireless networks can gain much interest, because it can enable lower power over multi-path fading channels and enhance the channel capacity. S. Alamouti has proved that Multi-Input Multi-Output (MIMO) systems require less transmission energy than Single Input Single Output (SISO) systems for the same throughput requirement in the fading channel [2]. In previous work, the advantages of the cooperative communication in the physical layer were sufficiently explored. Energy efficiency of cooperative transmissions over a single hop was investigated and compared with traditional SISO transmission [3] [4]. The capacity of ergodic MIMO channels with finite dimensions was investigated in [5]. In [6], C. Jiang jointly optimized the transmit power, the number of active antennas, and the antenna subsets at the transmitter and receiver to maximize the energy efficiency.

Now, there has been much interest in studying the energy consumption of cooperative communication at the network layer. In [7], A. Khandani firstly formulated the problem of finding the minimum energy cooperative route for the wireless network. Then he presented a dynamic programming-based algorithm as well as two polynomial-time heuristic algorithms. In [8], a minimum power cooperation routing (MPCR) algorithm was proposed to construct the minimum-power route. As the technical trend of data center design poses new challenges for efficient and scalable multicast routing, an efficient and scalable multicast routing scheme for data center networks was proposed in [9].

However, these methods mainly focus on minimizing the total energy consumption of route from the source node to the destination node. It is well known that consistently using the minimum cost path for routing may lead to uneven energy distribution among nodes, which substantially reduces the network lifetime [15].

In this paper, we propose an Energy-balanced Multi-hop-aware Cooperative Geographic Routing (EMCGR) algorithm. We formulate the outage probability and construct the minimum power route in multi-hop-aware cooperative transmission (MCT) mode. The MCT mode can fully exploit the merit of the relay broadcasting characteristics and achieve the aim of saving the total transmitted power. Then we design an improved Energy-Balanced Geographic Routing (EBGR) algorithm, so we can deal with the inanition problem in the geographic routing algorithm more effectively. After one route is built on the basic of the EBGR algorithm, the EMCGR algorithm adopts the MCT mode to achieve the aim of saving energy. In order to prolong the lifetime of the whole wireless network, the EMCGR algorithm selects the forwarding node and relay node by combining the geographic position information with the energy information.

2 Network model

In this section, we introduce the network model in our paper and describe the rudimental scenario in network model [8] [12]. Then, we present the direct transmission mode and multi-hop-aware cooperative transmission mode.

We consider a graph $G(N,E)$ with N nodes and E edges. Given any source-destination pair (S,D), our motivation is to find the route *S*-*D* to minimize the total transmitted power, while satisfying a specific throughput. For a given source-destination pair, define Ω as the set of all possible routes. Each route is defined as a set consisting of its hops. For a route $\check{n}\in\Omega$, define $\check{n}_i$ as the *i-th* hop of this route. Thus, the problem can be formulated as

$$\min_{\check{n}\in\Omega}\sum_{\check{n}_i\in\check{n}} W_{\check{n}_i} \qquad s.t. \qquad \eta_{\check{n}} \ge \eta_0 \tag{1}$$

where $W_{\check{n}_i}$ represents the total transmitted power of the *i-th* hop, $\eta_{\check{n}}$ is the end-to-end throughput, and η_0 denotes the desired value of the end-to-end throughput. Let $\eta_{\check{n}_i}$ represent the throughput of the *i-th* hop, which is defined as the number of successfully transmitted bits second per hertz (bit/s/Hz) of a given hop. So, it is obviously obtained as follows that the end-to-end throughput of a given route $\check{n}$ is the minimum of each throughput values of the hops constituting this route.

$$\eta_{\check{n}} = \min_{\check{n}_i\in\check{n}} \eta_{\check{n}_i} \tag{2}$$

2.1 Rudimental scenario

In this paper, fast quasi-static fading channel is considered. All the channel terms are independent complex Gaussian random variables with zero mean and unit variance. The noise terms are modeled as zero mean, complex Gaussian random variables with equal variance N_0. Each node can change its transmitted power to adjust the transmission radius.

2.2 Direct transmission (DT) mode

In Fig. 1, a direct transmission link is presented by the link (i, j), where node i is the sender and node j is the receiver.

Figure 1. Direct transmission mode.

The gain coefficient of wireless channel between the sender node i and the receiver node j is presented by $\alpha_{i,j} = \sqrt{d_{i,j}^{-k}} \cdot h_{i,j}$, where $d_{i,j}^{-k}$ is the distance between node i and node j , k is the path loss exponent, $h_{i,j}$ is the channel coefficient. In the fast quasi-static fading channel, the probability density function of channel gain $|h_{i,j}|^2$ is $p(|h_{i,j}|^2) = \exp(|h_{i,j}|^2)$ [13]. For the direct transmission link (i, j), the received symbols can be modeled as

$$r_{i,j}^D = \sqrt{W_i} \cdot \alpha_{i,j} \cdot s + n_{i,j} \tag{3}$$

Where W_i is the transmitted power of node i, s is the transmitted symbols, and $n_{i,j}$ is a complex Gaussian random noise with zero mean and equal variance N_0.

2.3 Multi-hop-aware cooperative transmission (MCT) mode

As depicted in Fig. 2, a cooperative transmission link (x, R_1, y) includes the sender node x, the relay node R_1 and the receiver node y.

For the cooperative transmission, the transmission process can be divided into two slots as shown in Fig. 3. The sender node x sends its symbols to the relay node and the receiver node in the first slot. In the second slot, the relay node R_1 sends its symbols to the receiver node y if the received symbols of relay node R_1 are correctly received. We assume that both the relay node and the receiver node can decode the received symbols correctly if the received Signal-to-Noise Ratio (SNR) is greater than a certain threshold.

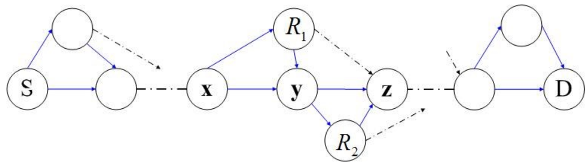

Figure 2. Multi-hop-aware cooperative transmission mode.

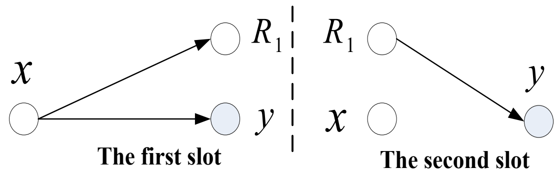

Figure 3. The usage of time slots for cooperative transmission mode.

Finally, the receiver node y combines the received symbols from the sender node x and the relay node R_1 by Maximum Ratio Combining (MAC) [14]. The signals combined are calculated as

$$r_{x,R_1,y}^D = (\alpha_{x,y})^* r_{x,y}^D + (\alpha_{R_1,y})^* r_{R_1,y}^D \tag{4}$$

Where $r_{x,y}^D = \sqrt{W_x} \cdot \alpha_{x,y} \cdot s + n_{x,y}$, $r_{R_1,y}^D = \sqrt{W_{R_1}} \cdot \alpha_{R_1,y} \cdot s + n_{R_1,y}$ are the received symbols of node y from the sender node x and the relay node R_1, respectively. And W_x is the transmitted power of the sender node x, W_{R_1} is the transmitted power of the relay node R_1 in cooperative transmission.

In [8], an MPCR algorithm adopts the cooperative transmission scheme mentioned above. We define it as CT mode. In this scheme, transmission from x to y and from y to z, respectively, is supported only by R_1 and R_2. Cooperative transmission of the relay only occurs in the current hop. The merit of the broadcasting characteristic of the wireless medium has not been explored adequately.

As depicted in Fig. 2, when the relay node R_1 sends its symbols to the receiver node y, the next-hop receiver node z can receive the symbols from R_1, if node z is in the transmission coverage range of R_1. And the received symbols of node z from R_1 can be modeled as

$$r^D_{R_1,z} = \sqrt{W_{R_1}} \cdot \alpha_{R_1,z} \cdot s + n_{R_1,z} \tag{5}$$

When the SNR between node z and R_1 is greater than a certain threshold, the next hop receiver node z can decode the symbols from R_1 correctly. Then node z sends an Acknowledgment (ACK) to current hop receiver node y to inform that node y does not need to send the symbols to node z in the next slot. Otherwise, it sends a Negative Acknowledgment (NACK) to inform the current hop receiver node y and the next hop relay node R_2 to transmit the symbols to it in their own slots. The combined signals of node z are calculated as

$$r^D_{y,R_2,z} = (\alpha_{y,z})^* r^D_{y,z} + (\alpha_{R_2,z})^* r^D_{R_2,z} + (\alpha_{R_1,z})^* r^D_{R_1,z} \tag{6}$$

3 Link analysis

Since the throughout is a continuous monotonously increasing function of the transmitted power, the optimization problem in (1) has the minimum value only in the condition of $\eta_{ň} = \eta_0, \forall ň \in \Omega$. In order to achieve a desired throughput η_0 along the route $ň$, the optimum power allocation should force the throughput of all hops $\eta_{ņ̌}$ to be equal to the desired one.

$$\eta_{ņ̌} = \eta_0, \quad \forall ņ̌ \in ň \tag{7}$$

Define $W_{ņ̌}$ as the required power of the $i-th$ hop on a route when $\eta_{ņ̌} = \eta_0$ for $i = 1,\ldots,n$, where n represents the number of a certain route hop. However, the end-to-end throughput does still not change based on equation (2). So, there is no need to increase the throughput of any hop over η_0, which is demonstrated in (7).
Since the throughput of a given link ņ̌ represents the number of successfully transmitted bits per second per Hertz, it can be calculated as follows:

$$\eta_{ņ̌} = p^S_{ņ̌} \times R_{ņ̌} \tag{8}$$

where $p^S_{ņ̌}$ represents the per-link probability of success and $R_{ņ̌}$ represents transmission rate. While we assume that the desired throughput can be calculated as follows:

$$\eta_0 = p^S_0 \times R_0 \tag{9}$$

where p^S_0 and R_0 represent the desired per-link probability of success and the desired transmission rate, respectively.
So the goal in this paper is to calculate the required transmitted power in order to achieve the desired per-link probability of success and desired transmission rate for both DT mode and MCT mode.

3.1 Direct transmission link

As depicted in Fig. 2, for the direct transmission link in [8], the input SNR of receiver is calculated as

$$SNR_D = \frac{W_i}{N_0} \left|\alpha_{i,j}\right|^2 \tag{10}$$

Therefore, the mutual information between the sender node i and the receiver node j can be calculated as

$$I_{i,j} = \log(1 + \frac{W_i}{N_0}\left|\alpha_{i,j}\right|^2) = \log(1 + \frac{W_i d_{i,j}^{-k} \left|h_{i,j}\right|^2}{N_0}) \tag{11}$$

Without loss of generality, we assume unit bandwidth in (11). If the mutual information $I_{i,j}$ is less than the required transmission rate R_0, we think that the communication of the link (i, j) is in outage. Thus, the outage probability of the direct transmission link (i, j) is calculated as

$$p^O_{i,j} = \Pr(I_{i,j} \le R_0) \tag{12}$$

Based on equation (11) and (12), we can get

$$p^O_{i,j} = \Pr(\left|h_{i,j}\right|^2 \le \frac{(2^{R_0} - 1) N_0 d^k_{i,j}}{W_i}) = 1 - \exp(-\frac{(2^{R_0} - 1) N_0 d^k_{i,j}}{W_i}) \tag{13}$$

If an outage occurs, the data packet is considered to be lost. So we can get the per-link probability of success $p_{i,j}^{S}=1-p_{i,j}^{O}$ in DT mode. In order to achieve the desired p_0^S and desired transmission rate R_0, the required transmitted power in DT mode is

$$W_i^{DT}=W_i=\frac{(2^{R_0}-1)N_0 d_{i,j}^k}{-\log(p_0^S)} \tag{14}$$

By equation (13) and (14), obviously, the result that the outage probability of link (i,j) is inversely proportional to the transmitted power of node i can be reached.

3.2 Multi-hop-aware cooperative transmission link

For a cooperative transmission link (x,R_1,y) shown in Fig.2, the outage of link (x,R_1,y) can be divided into two types. The first type is that both the sender-receiver link (x,y) and the relay-receiver link (R_1,y) are in outage but the sender-relay (x,R_1) link is not. The second type is that both the sender-receiver link (x,y) and the sender-relay link (x,R_1) are in outage. So the outage probability of link (x,R_1,y) in CT mode is obtained by

$$\begin{aligned} p_{x,R_1,y}^{O} &= \Pr(I_{x,y}\le R_C)\cdot(1-\Pr(I_{x,R_1}\le R_C))\cdot\Pr(I_{R_1,y}\le R_C) \\ &\quad +\Pr(I_{x,y}\le R_C)\cdot\Pr(I_{x,R_1}\le R_C) \end{aligned} \tag{15}$$

where R_C represents the transmission rate for each time slot.

The minimum total power $W_x+W_{R_1}$ of link (x,R_1,y) is derived in [16]. If the outage probability $p_{x,R_1,y}^{O}$ is equal to the required outage probability threshold, W_x, W_{R_1} can respectively be calculated as

$$W_x=\frac{1}{d_{R_1,y}^k}\cdot\sqrt{\frac{M+1}{K}},\quad W_{R_1}=\frac{1}{2M\cdot d_{x,R_1}^k}\cdot\sqrt{\frac{M+1}{K}} \tag{16}$$

where $K=\dfrac{-\log(p_0^S)}{(2^{R_0}-1)^2 {N_0}^2 d_{x,y}^k d_{x,R_1}^k d_{R_1,y}^{2k}}$, $\gamma=\dfrac{d_{R_1,y}^k}{2d_{x,R_1}^k}$, $M=\dfrac{\gamma+\sqrt{\gamma^2+8\gamma}}{2}$.

By equation (16), we can get

$$\frac{W_x}{W_{R_1}}=\frac{2Md_{x,R_1}^k}{d_{R_1,y}^k}=\frac{1+\sqrt{1+\frac{8}{\gamma}}}{2}>1 \tag{17}$$

However, by equation (13) and (14), we can see that the higher the transmitted power of relay node R_1, the higher the probability that the next hop receiver node z decodes the symbols from link (R_1,y) correctly. So, we set that both the sender and the relay send their data by using the same power: $W_x=W_{R_1}=W_0$.

By equation (15), we can get that the successful probability of link (x,R_1,y) in CT mode is calculated as

$$\begin{aligned} p_{x,R_1,y}^{S} &= 1-p_{x,R_1,y}^{O} \\ &= \exp(-gd_{x,y}^k)+\exp(-g(d_{x,R_1}^k+d_{R_1,y}^k)) \\ &\quad -\exp(-g(d_{x,R_1}^k+d_{R_1,y}^k+d_{x,y}^k)) \end{aligned} \tag{18}$$

where $g=\dfrac{(2^{R_C}-1)N_0}{W_0}$.

We set the successful probability $p_{x,R_1,y}^{S}$ of link (x,R_1,y) as the desired per-link probability of success p_0^S. By approximating the exponential functions in equation (18) as $\exp(-x)\approx 1-x+\dfrac{x^2}{2}$, we can obtain

$$g\approx\sqrt{\frac{1-p_0^S}{\xi}} \tag{19}$$

where $\xi=(d_{x,R_1}^k+d_{R_1,y}^k)d_{x,y}^k$.

The probability that the sender transmits without the relay cooperative transmission, denoted by $\Pr(\phi)$, is calculated as

$$\begin{aligned} \Pr(\phi) &= 1-\Pr(I_{x,y}\le R_C)+\Pr(I_{x,y}\le R_C)\cdot\Pr(I_{x,R_1}\le R_C) \\ &= 1-\exp(-gd_{x,y}^k)+\exp(-g(d_{x,y}^k+d_{x,R_1}^k)) \end{aligned} \tag{20}$$

Therefore, the probability that the relay cooperates with the sender is calculated as

$$\overline{\Pr(\phi)} = 1 - \Pr(\phi) \quad (21)$$

Thus, the average transmission rate of cooperative transmission mode can be calculated as

$$R = R_C \cdot \Pr(\phi) + \frac{R_C}{2}\overline{\Pr(\phi)} \quad (22)$$

where R_C corresponds to the transmission rate if the sender transmits only, while $R_C/2$ corresponds to the transmission rate if the relay participates in the cooperative transmission.

We set the average transmission rate as $R = R_0$, Thus, we can obtain R_C by (20) and (22) as

$$\begin{aligned} R_C &= \frac{2 \cdot R_0}{1 + \Pr(\phi)} \\ &\approx \frac{2 \cdot R_0}{2 - \exp(-g d_{x,y}^k) + \exp(-g(d_{R_1,y}^k + d_{x,y}^k))} \end{aligned} \quad (23)$$

The required power per-link can be calculated as

$$W_0 \approx (2^{R_C} - 1) \cdot N_0 \sqrt{\frac{\xi}{1 - p_0^S}} \quad (24)$$

So, the total transmitted power of link (x, R_1, y) in CT mode can be calculated as

$$W_{x,R_1,y}^{CT} \approx W_0 \cdot \Pr(\phi) + 2W_0 \cdot \overline{\Pr(\phi)} = W_0(2 - \Pr(\phi)) \quad (25)$$

As depicted in Fig. 2, the receiver node z may receive the symbols from R_1 correctly in the process of cooperative transmission if node z is in the transmission coverage range of R_1. Multi-hop-aware cooperative transmission can be adopted. When the relay node R_1 participates in the transmission between node y and node z, the outage probability of link (y, R_2, z) in MCT mode is calculated as

$$p_z^O = p_{y,R_2,z}^O \cdot p_{R_1,z}^O \quad (26)$$

If the outage probability $p_{R_1,z}^O$ is less than the required outage probability threshold, the receiver node z can decode the symbols from R_1 correctly, so that the last hop receiver node y and the current hop relay node R_2 need not transmit its symbols to node z . And the outage probability of link (y, R_2, z) is $p_{y,R_2,z}^O = 0$ right now. Therefore, the transmitted power of the sender node y and the relay node R_2 will be $W_y = W_{R_2} = 0$, respectively.

If the outage probability $p_{R_1,z}^O$ is more than the required outage probability threshold, we can get

$$p_{y,R_2,z}^O = \frac{p_z^O}{p_{R_1,z}^O} \quad (27)$$

By (18), the success probability of link (y, R_2, z) is calculated as

$$\begin{aligned} p_{y,R_2,z}^S &= 1 - p_{y,R_2,z}^O = 1 - \frac{p_z^O}{p_{R_1,z}^O} \\ &= \exp(-g d_{y,z}^k) + \exp(-g(d_{y,R_2}^k + d_{R_2,z}^k)) \\ &\quad - \exp(-g(d_{y,z}^k + d_{y,R_2}^k + d_{R_2,z}^k)) \end{aligned} \quad (28)$$

We set the probability of success as $p_z^S = 1 - p_z^O = p_0^S$ in (28). By approximating the exponential functions in equation (28) as $\exp(-x) \approx 1 - x + \frac{x^2}{2}$, we can obtain

$$g \approx \sqrt{\frac{1 - p_0^S}{p_{R_1,z}^O \cdot \xi}} \quad (29)$$

In (23), the average transmission rate of MCT mode can be divided into two types. One type is that the last hop relay participates in the current hop cooperative transmission. The other type is that it does not participate.

The probability that the current hop receiver node z can decode the symbols form R_1, denoted by $\Pr_1(\omega)$ is calculated as

$$\Pr_1(\omega) = \overline{\Pr(\omega)'} \cdot p_{R_1,z}^S \quad (30)$$

The probability that the sender transmits only for multi-hop-aware cooperative transmission, denoted by $\Pr_2(\omega)$, is calculated as

$$\Pr_2(\omega) = \Pr(\omega)' \cdot \Pr(\phi) + \overline{\Pr(\omega)'} \cdot p_{R_1,z}^O \cdot \Pr(\phi) \quad (31)$$

Accordingly, the probability that the current hop relay does not participate in multi-hop-aware cooperative transmission, denoted by $\Pr(\omega)$, is calculated as

$$\Pr(\omega) = \Pr_1(\omega) + \Pr_2(\omega) \tag{32}$$

While the probability that the relay participates, denoted by $\overline{\Pr(\omega)}$, can be calculated as

$$\begin{aligned}\overline{\Pr(\omega)} &= 1 - \Pr_1(\omega) - \Pr_2(\omega) \\ &= \Pr(\omega)' \cdot \overline{\Pr(\phi)} + \overline{\Pr(\omega)'} \cdot p^{O}_{R_1,z} \cdot \overline{\Pr(\phi)}\end{aligned} \tag{33}$$

where $\Pr(\omega)'$ is the probability that the sender transmits only in the last hop. $\overline{\Pr(\omega)'}$ is the probability that the relay participates in the cooperative transmission in the last hop. $\Pr(\phi)$ can be calculated by (20). It is the probability of link (y,R_2,z) that the sender transmits only in the current hop and the last-hop relay is not taken into account. It is derived that if the receiver node z is not in the transmission range of last hop relay, we can get $p^{S}_{R_1,z} = 0$ and $p^{O}_{R_1,z} = 1$. Then we can calculate $\Pr(\omega) = \Pr(\phi)$ and $\overline{\Pr(\omega)} = \overline{\Pr(\phi)}$ in this condition.

Thus, the average transmission rate of MCT mode can be calculated as

$$R = R_C{}' \Pr_1(\omega) + R_C \Pr_2(\omega) + \frac{R_C}{2}(1 - \Pr(\omega)) \tag{34}$$

where $R_C{}'$ is the transmission rate of the last hop.

We also set the average transmission rate as $R = R_0$, Thus, R_C can be calculated as

$$R_C \approx \frac{R_0 - R_C{}' \Pr_1(\omega)}{\Pr_2(\omega) + \dfrac{1 - \Pr(\omega)}{2}} \tag{35}$$

So, the required power per-link of MCT mode is derived as

$$W_0 \approx (2^{R_C} - 1) \cdot N_0 \sqrt{\frac{\xi \cdot p^{O}_{R_1,z}}{1 - p^{S}_{y}}} \tag{36}$$

Hence, the total transmitted power of link (y, R_2, z) in MCT mode can be calculated as

$$W^{MCT}_{y,R_2,z} = 0 \cdot \Pr_1(\omega) + W_0 \cdot \Pr_2(\omega) + 2W_0(1 - \Pr(\omega)) \tag{37}$$

4 The EMCGR algorithm

In this section, firstly, we design an improved EBGR algorithm. Then we introduce the selection strategy of the cooperation relay in this paper. Finally, we summarize the detailed description of the proposed EMCGR algorithm.

4.1 The EBGR algorithm

In order to prolong the lifetime of the whole wireless network, the improved EBGR algorithm selects the next hop node by using the geographic position information and the energy information. Firstly, it sets a forwarding area. If there are candidate nodes in the forwarding area, the EBGR algorithm adopts the greedy mode strategy. In the greedy mode, the EBGR algorithm selects the node with the minimum Dynamic Forwarding Backoff Time (DFBT) value. The DFBT value is calculated based on the distance information and the energy information. If not, the EBGR algorithm adopts the inanition mode strategy. In the inanition mode, the geographic position information switches from the distance information into the angle information.

4.1.1 Precondition and scenario

In the whole wireless network, each node only knows its own geographic location. This can be done by using a global positioning technique like GPS. The location information of destination node can be obtained by the source via location service. Besides, the transmission range of each node is the same. Their links are also bidirectional.

4.1.2 Competitive strategy in greedy mode

In order to achieve the successful transmission of competitive strategy in greedy mode, we introduce a forwarding area. This area is to satisfy several conditions as follows:

1. The selected next-hop forwarding node is closer to the destination than the current-forwarding node in the forwarding area.

2. The forwarding area should be big enough to make sure that it is possible to find the optimum forwarding node.

3. Each node can communicate with each other in order to avoid having more than one optimum candidate forwarding node in the competition.

According to the conditions above, the forwarding area adopted is the shadow sector area of 60 degrees as shown in Fig. 4.

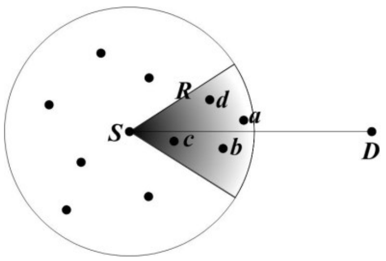

Figure 4. Multi-hop-aware cooperative transmission mode.

When a node (the source node or one forwarding node) needs to send its data packets, it firstly writes its geographic position information and the destination node into the header of data packets, then broadcasts theirs to all neighbor nodes. After receiving the data packets, each neighbor node picks up the geographic position information to judge whether it is in the forwarding area. If not, it discards the data packets. Otherwise, it needs to calculate its DFBT value. The DFBT value in greedy mode is calculated as follows:

$$DFBT = [\beta \cdot \frac{r}{Dis} + (1-\beta) \cdot \frac{E-e}{E}] \cdot T_0 \qquad (38)$$

where $\beta \in [0,1]$ is an alterable coefficient, Dis is the distance between the current forwarding node and the destination node, and r is the distance between the candidate forwarding node and the destination node. E is the total energy. e is the residuary energy, T_0 is the maximum waiting time before it sends the feedback data packets to reply to the sender.

In Fig.4, the node a is closer than the node b, but if the residuary energy of node b is much higher than that of node a, while the DFBT value of node b is less than that of node a, the node b will win the competition alternatively.
Based on the DFBT value, each candidate forwarding node can get its backoff time. The node with the minimum DFBT value in the forwarding area is bound to be the first to send the feedback data packets to reply to the sender, and win the competition. The node with the minimum DFBT value will be selected as the next-hop sender. Since each node in the forwarding area can communicate with each other, the other nodes can listen to the feedback data packets of the node with the minimum backoff time. Then the other nodes withdraw from the competition. Such a process will be cycled until the data packets are sent to the destination node.

4.1.3 Inanition mode strategy

If the current forwarding node does not receive any feedback data packets after a maximum waiting time, it indicates that there are no candidates forwarding nodes in the forwarding area. Then the sender node adopts the inanition mode strategy.
The conventional Greedy Perimeter Stateless Routing (GPSR) protocol adopts boundary forwarding strategy to deal with the inanition problem. Its process is as follows:

1. The whole wireless network is modeled as a geometric graph where the geographical position of each node defines a point in the planar graph.

2. When the sender fails in the greedy mode, it will apply the well-known right hand rule to search the next-hop node in turn until the destination node receives the data packets or current forwarding node switches back the greedy mode.

However, this strategy which applies right hand rule from first to last may not get the optimum routing.
As depicted in Fig. 5, the node S fails in forwarding in data packets in the greedy mode. It switches into the inanition mode, and applies the right hand rule to find the next-hop node b. Obviously, the path from node S to node a is shorter than that from node b to node a. The node b is not the optimal forwarding node. It is due that

the conventional GPSR protocol only applies right hand rule from first to last [16]. So, this forwarding protocol needs to be improved.

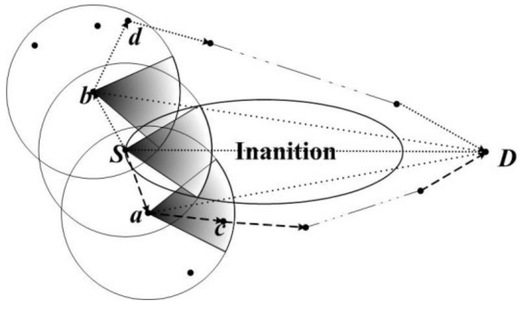

Figure 5. The sketch map of boundary forwarding strategy.

The proposed inanition mode strategy is as follows:

1. Firstly, the whole wireless network is also modeled as a geometric graph.

2. When the sender fails in the greedy mode, the sender will apply the right hand rule and left hand rule to search several candidate next-hop nodes, calculate their DFBT values by equation (39), respectively.

3. Based on the DFBT value, each candidate forwarding node can calculate his back-off time. The node with the minimum DFBT value must be the first to send the feedback data packets to reply to the sender, and win the competition, which is selected as the next-hop sender.

4. Since the node can not listen to other nodes outside the forwarding area, it needs the sender S to broadcast a data packet to inform other nodes to quit the competition. And another candidate node cancels the data packets.

Here, we define forwarding angle as $\angle N_iSD$ where N_i is the $i-th$ neighbor node of node S. Evidently, if $\angle N_iSD$ of candidate node N_i is small, as soon as possible, it, as the next-hop forwarding node, can bypass the inanition as quickly as possible. According to the scenario above, the DFBT value in inanition mode is calculated as

$$DFBT = [\beta \cdot \frac{\theta}{180^0} + (1-\beta) \cdot \frac{E-e}{E}] \cdot T_0 \qquad (39)$$

where θ is the angle value of forwarding angle $\angle N_iSD$.

If $\beta = 1$ in (38) and (39), the EBMCGR algorithm transfers the pure geography routing. The candidate node with smallest forwarding angle in (39) or r in (38) is sure to win the competition. If $0 < \beta < 1$, the energy information is introduced into competitive strategy.

4.1.4 Detailed description of EBGR algorithm

A node (the source node or one forwarding node) needs to send its data packets in the wireless network.

1. Firstly, the node writes its node information and the destination node information into the header of data packets. Then it switches the mode into the greedy mode, and broadcasts the data packets to all neighbor nodes. Carry out 2.

2. The node with the minimum DFBT value should be the first to reply to the sender, and win the competition. If the other nodes in the forwarding area listen to the feedback data packets during a maximum waiting time, they withdraw from the competition and delete the stored data packets. Carry out 1. If not, carry out 3.

3. The sender switches the mode into the inanition mode, and broadcasts the data packets again. If the current node intercepts the feedback data packets of candidate forwarding nodes during a maximum waiting time after the second transmission, it selects the node with the minimum DFBT value as the next-hop forwarding node. Then it broadcasts a data packet to inform other nodes to end the competition. Carry out 1. If not, it indicates that the current node is an isolated node. So, the data packets fail to be sent.

4. Cycle such a process until the data packets are sent to the destination node.

4.2 Selection of the cooperation relay

In order to reduce the whole transmitted power, the EMCGR algorithm selects the node, which, as the current-hop relay is the closest to current-hop receiver in the distance.

In order to select the optimal relay quickly, we also introduce a shadow area for selection of relay as shown in Fig.6. The shadow area is also used to reduce the number of the candidate relay nodes and to avoid colliding, compared with the traditional flooding mechanism. The shadow area satisfies several conditions as follows:

1. The selected relay node should be close to the receiver node and as near as possible in the shadow area.

2. The shadow area should be big enough to make sure that it is possible to find the optimum relay node.

3. The candidate relay node should be in the transmission range of both the sender and the receiver, so that they could communicate with each other in the shadow area in order to avoid colliding.

When the sector angle $\vartheta = 60^0$ depicted in Fig. 6, the shadow area is maximum. Obviously in this area, the distances among candidate relay nodes are all less than transmitted radius R .

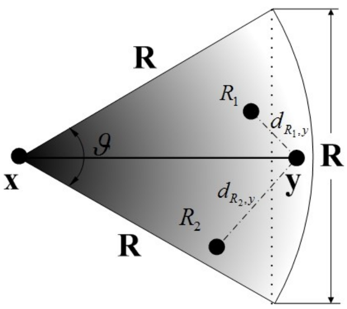

Figure 6. The sketch map of shadow area for selection of relay.

The choice of current-hop relay is achieved by the handle mechanism of RTS/CTS. Firstly, the sender node x writes its geographic position information and that of the receiver node y into the header of RTS data packets. Then it broadcasts them to all neighbor nodes. After receiving the RTS data packets, each neighbor node picks up the geographic position information to judge whether it is in the forwarding area for selection of relay. If not, discard the data packets. Otherwise, its dynamic relay backoff time $\mathrm{T_{backoff}}(\mathrm{i})$ value is to be calculated as follows:

$$\mathrm{T_{backoff}}(\mathrm{i}) = [\lambda \cdot \frac{d_{r_i,y}}{d_{x,y}} + (1-\lambda) \cdot \frac{E-e}{E}] \cdot T_0 \qquad (40)$$

where $\lambda \in [0,1]$ is an alterable coefficient, r_i is the $i-th$ candidate relay node. $d_{r_i,y}$ is the distance between candidate relay node r_i and the receiver node y .

The candidate relay node with the minimum backoff time is bound to be the node, which sends CTS data packets to reply to the sender node x firstly. And the other candidate relay nodes withdraw from the competition after listening to the CTS data packets. So, the node with the minimum backoff time will win the competition, and be selected to be current hop relay node. If the sender node x does not listen to any CTS data packets during a maximum waiting time after broadcasting the RTS data packets, it indicates that there is no candidate relay node in the shadow area. Then it will adopt direct transmission mode to transmit the data packets.

4.3 The Description of the EMCGR algorithm

The detailed description of our proposed EMCGR algorithm is as follows:

1. Firstly, a non-cooperative route is built based on the improved EBGR algorithm.

2. Then, the current-hop sender node x (the source node or one forwarding node) selects an optimum relay node among the candidate relay nodes in the shadow area for cooperative transmission. If there is no candidate relay node, it will adopt direct transmission mode to transmit the data packets. Otherwise, carry out 3.

3. Both the sender node x and optimum relay node send the data packets to the receiver node y . If the next-hop receiver node z is in the transmission coverage of the current-hop relay node, carry out 4. Otherwise, change the receiver node y to be the sender in the next hop. Carry out 2.

4. Using the data packets from its superior-hop relay node R_1 , the next hop receiver node z calculates the outage probability $p^O_{R_1,z}$ of link (R_1, z) by equation

(13). If the outage probability $p^{O}_{R_1,z}$ is less than the required outage probability threshold, the next hop receiver node z can decode the symbols from R_1 correctly. So, the current hop receiver node y and the next hop relay node R_2 does not need to transmit the data packets to node z, otherwise, change the receiver node y to be the sender in the next hop. Carry out 2.

5. Such a process will be cycled until the data packets have been sent to the destination node.

5 Simulation and analysis

In this section, we consider a 1000 m $\times$ 1000 m square network area in computer simulation scene. The nodes are randomly distributed. Set the noise variance as $N_0 = -70$ dBm, and path loss exponent k as 2. The maximum waiting time T_0 is 2ms. The size of each data packet is 256 bytes. The desired per-link probability of success p^S_0 is 0.925 and desired transmission rate R_0 is 2 bit/s/Hz.

For a given network topology in computer simulation scene, the source-destination pairs are chosen randomly. For each algorithm, we calculate the total transmitted power per-route. And our results represent the average of the measurements over 2000 routes with random source-destination pairs. In addition, we assume that all nodes can periodically broadcast a HELLO packet to its neighbors in one hop to update the topology information. The carrier sense multiple access with collision avoidance (CSMA/CA) [18] protocol is considered.

Fig. 7 depicts the required transmitted power comparison among the EMCGR, MPCR and EBGR algorithm under different node densities. Set the alterable coefficient λ, β as zero beforehand in order to validate the advantage of EMCGR algorithm in saving power directly. The simulation results show that the energy consumption does not change as the node density gets higher obviously. In other words, the transmitted power is obviously not affected by the node density. It is due that the node forwards the packets to its neighbor node which is geographically closest to the destination using the EBGR algorithm.

Here, let us define the power saving ratio of scheme 2 with respect to scheme 1 as

$$Powsaving = \frac{P_{scheme1} - P_{scheme2}}{P_{scheme1}} \times 100\% \qquad (41)$$

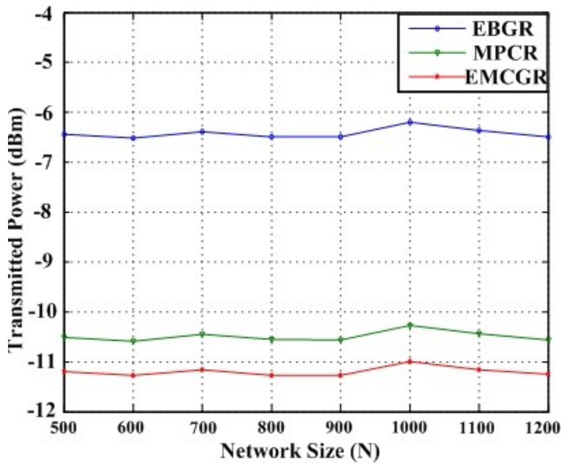

Figure 7. The required transmitted power per route versus the network size for $p^S_0 = 0.925$, *R*=150m *and* $\beta = \lambda = 0$.

Fig. 8 depicts the whole transmitted power per route by different routing algorithms for different transmitted radii. The simulation results show that the EMCGR algorithm requires the minimum transmitted power compared with the MPCR algorithm and EBGR algorithm. As shown in Fig.8, the energy consumption is decreased by reducing the transmitted radii.

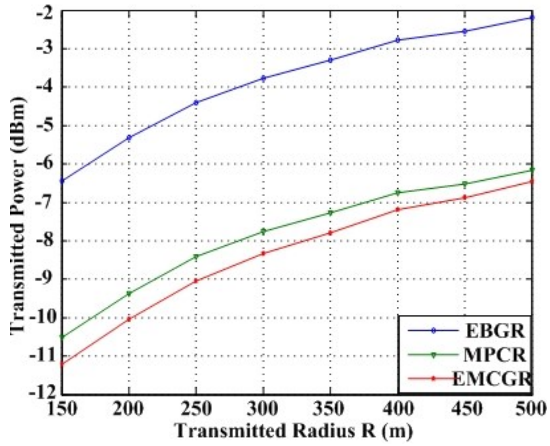

Figure 8. The required transmitted power per route versus the transmitted radius for $p^S_0 = 0.925$, *N=800 and* $\beta = \lambda = 0$.

Simultaneously, Figure 9 depicts the power saving versus the network size for the random wireless network. It is shown that the power saving of the EMCGR algorithm with respect to the MPCR algorithms and EBGR algorithm can be 15.2% and 67.1%, respectively. As depicted in Fig. 9, the power saving is decreased by increasing the transmitted radii. It is due to the fact that the number of hops is decreased by increasing the transmitted radii. So, the advantage of cooperation transmission is weakened with a decrease in the number of hops.

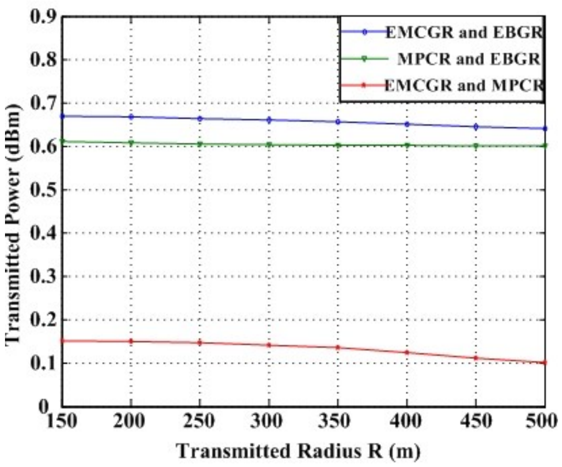

Figure 9. The power saving per route versus the transmitted radius for $p_0^S = 0.925$, N=800 and $\beta = \lambda = 0$.

Fig. 10 depicts the transmitted power comparison of one route by using three different routing algorithms for different hops. It is shown that the transmitted power of EMCGR algorithm is the same as that of MPCR algorithm in the first hop. They are both less than that of EBGR algorithm. It is due to the fact that both EMCGR and MPCR algorithm only adopt CT mode in the first hop. From the second hop, the transmitted power of EMCGR algorithm is less than that of MPCR algorithm. However, the EMCGR algorithm may start to adopt MCT mode from the second hop, so the required transmitted power of EMCGR algorithm is less than that of MPCR algorithm with an obviously increasing hop.

Based on the introduction in section 3, the desired throughput η_0 can be calculated by Equation (9). Here, we assume that the desired transmission rate R_0 is not changed. So, the desired throughput η_0 is proportional to the desired per-link probability of success p_0^S. Fig. 11 depicts the required transmitted power versus different desired throughput η_0 by three different routing algorithms. The simulation results show that all of the required energy consumption by three different routing algorithms are obviously decreased as the desired throughput η_0 gets lower. Undoubtedly, the EMCGR algorithm performs best.

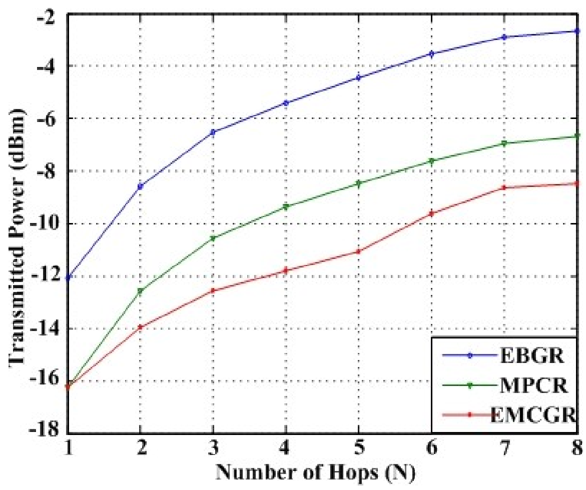

Figure 10. The required transmitted power in a random route versus the number of hops for N=800, $p_0^S = 0.925$, R=150m and $\beta = \lambda = 0$.

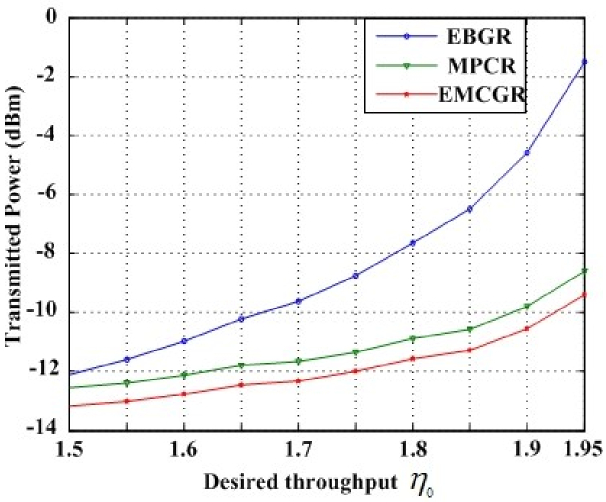

Figure 11. The required transmitted power in a random route versus desired throughput for N=800, R=150m and $\beta = \lambda = 0$.

Here, let us define the residuary energy and total energy ratio (RTR) as

$$RTR = \frac{e}{E} \times 100\% \tag{42}$$

We assume that the initial total energy E of the node $v_i (1 \le i \le N)$ is $E = C^0(i)$, and the current residuary energy after l routes is $e = C^l(v_i)$. When $C^l(v_i) = 0$, it means that the node v_i runs out of its energy[18] and the node v_i is a dead node. When the node v_i transmits data packets using transmitted power $P_C^D(v_i)$, its residuary energy $C^l(v_i) = C^{l-1}(v_i) - -P_C^D(v_i) \cdot \Delta P$, where ΔP is the time interval when the node transmits its data packets. If the node v_i does not participate in transmission, its residuary energy $C^l(v_i) = C^{l-1}(v_i)$. Here, we calculate the transmitted energy cost and ignore the receiving and listening energy cost in order to present the superiority of our proposed algorithm in saving the transmitted power. We assume that the number of transmitted data packets is the same every time.
In order to show the advantage of balancing the energy consumption among nodes, we set the alterable coefficient β, λ as 0.7, and 0.95 respectively as shown in Tab.1.We define Energy-Balanced Multi-Hop-Aware Cooperative Geographic Routing- Standard (EBMCGR-S) algorithm in order to distinguish the simulations above. We run 20000 routes in total in this topology and record the RTR of each node as shown in Fig.12.

Table 1. The alterable coefficient β and λ for different algorithms

Algorithm	EBGR	MPCR	EMCGR	EMCGR-S
β	0	0	0	0.7
λ	0	0	0	0.9

Fig. 13 depicts the RTR distribution of nodes intuitively. We calculate the mean and variance of RTR values for different algorithms as shown in Tab. 2. As shown in Tab. 2, the mean of RTR adopted by EBMCGR-S algorithm is more than that of the EBMCGR algorithm, but it is less than that of the MPCR algorithm. However, the variance of RTR values at given nodes by EBMCGR-S algorithm is the least among these four algorithms.

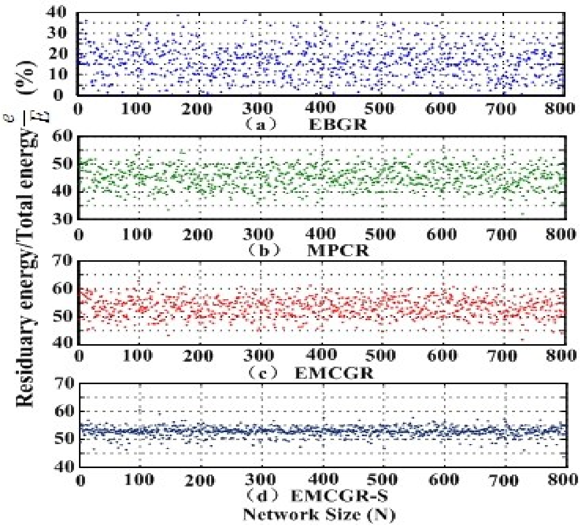

Figure 12. The distribution map of RTR versus per-network node for N=800, R=150m and $p_0^S = 0.925$.

Table 2. Mean and Variance of RTR value for different algorithms

Algorithm	EBGR	MPCR	EMCGR	EMCGR-S
Mean(%)	15.48	45.21	53.34	52.72
Variance	67.51	14.99	12.25	3.048

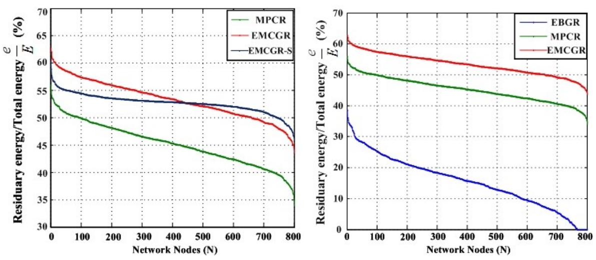

Figure 13. The distribution map of RTR versus per-network node sorted by size for each algorithm.

It is due to that the EBMCGR-S algorithm selects the node with the minimum DFBT value as the next-hop forwarding node, and the node with the minimum backoff time as the cooperative relay node. So, the forwarding node and the relay node may not be the optimal node in the distance, which will bring a little increase in energy consumption.

However, the strategy of the EBMCGR-S algorithm can bring the advantage of balancing the energy consumption among nodes. All simulation results show that the EBMCGR-S algorithm indeed does well in balancing the energy consumption among nodes in the wireless network.

6 Conclusion

In this paper, we analyze the merits of cooperation communication in the conventional transmission mode. Considering the merits of the node broadcasting characteristics, we formulate the outage probability and the total transmitted power in MCT mode. Then, we design an improved EBGR algorithm to deal effectively with the inanition problem in the geographic routing algorithm. The improved EBGR algorithm selects the next hop forwarding node by combining the geographic position information with the energy information. After establishing one route based on the EBGR algorithm, the EMCGR algorithm is proposed. The proposed EMCGR algorithm adopts the MCT mode to achieve the goal of saving energy. Simulations show that the EMCGR algorithm can do well in dealing with inanition problem, and is more suitable for random and dense wireless Ad Hoc networks. In the same simulation condition, the power saving of the EMCGR algorithm with respect to MPCR algorithms and EBGR routing algorithm are 15.2% and 67.1%, respectively. Besides, the EMCGR algorithm does indeed well in balancing the energy consumption among nodes in wireless Ad Hoc networks.

References

[1] Younis, M., Youssef, M., Arisha, K..: *Energy-aware management for cluster-based sensor networks*, Computer Networks, 43 (2003) 5, 539-694.

[2] Alamouti, S. M.: *A simple transmit diversity technique for wireless communications*, IEEE Journal on Selected Areas in Communications, 16 (1998) 8, 1451-1458.

[3] Cui, S., Goldsmith, A. J., Bahai, A.: *Cross-layer design of energy constrained networks using cooperative MIMO techniques*, EURASIP J. Applied Signal Processing, 86 (2006) 8, 1804-1814.

[4] Cui, S., Goldsmith, A. J., Bahai, A.: *Energy-efficiency of MIMO and cooperative MIMO techniques in sensor networks*, IEEE Journal on Selected Areas in Communications, 22 (2004) 6, 1089-1098.

[5] Hanlen, L., Grant, A.: *Capacity analysis of correlated MIMO channels*. IEEE Transactions on Information Theory, 58 (2012) 11, 6773 - 6787.

[6] Jiang, C., Cimini, L. J.: *Antenna selection for energy-efficient MIMO transmission*, IEEE Wireless Communications Letters, 1 (2012) 6, 577-580.

[7] Khandani, A. E., Abounadi, J., Modiano, E., Zheng, L.: *Cooperative routing in static wireless networks*, IEEE Transactions on Communications, 55 (2007) 11, 2185-2192.

[8] Ibrahim, A. S., Han, Z., Liu, K.: *Distributed energy-efficient cooperative routing in wireless networks*, IEEE Transactions on Wireless Communications, 7 (2008) 10, 3930-3941.

[9] Li, D., Li, Y., Wu, J., Su, S., Yu, J.: *ESM: Efficient and scalable data center multicast routing*, IEEE/ACM Transactions on Networking, 20 (2012) 3, 944-955.

[10] Zhang, W., Liu, K.: *Energy-efficient Location-based cooperative routing in wireless network*. Dianzi Yu Xinxi Xuebao/Journal of Electronics and Information Technology, 34 (2012) 1, 63-68.

[11] Kwon, S., Shroff N. S.: *Analysis of shortest path routing for large multi-hop wireless networks*, IEEE/ACM Transactions on Networking, 17 (2009) 3.

[12] Adam, H., Bettstetter, C., Senouci, S. M.: *Multi-hop-aware cooperation relaying*, IEEE Vehicular Technology Conference, 2009, VTC Spring 2009 - IEEE 69th Vehicular Technology Conference.

[13] Aguilar, T., Syue, S. J, Gauthier, V., Afifi, H. Wang, C.-L.: CoopGeo.: *A Beaconless Geographic Cross-Layer Protocol for Cooperative Wireless Ad Hoc Networks*, IEEE Transactions on Wireless Communications, 10 (2011) 8, 2554-2565.

[14] Coskun, A., Candan, C..: *Transmit precoding for flat-fading MIMO multiuser systems with maximum ratio combining receivers*, IEEE Transactions on Vehicular Technology, 60 (2011) 2, 710-716.

[15] Chen, S., Huang, M., Li, Y., Zhu, Y.: *Energy-balanced cooperative routing in multihop wireless ad hoc networks*, IEEE International Conference on Communications, ICC 2012.

[16] Sheng, D., Ding, Z., Leung, K. K.: *Distributed and power efficient routing in wireless cooperative networks*, IEEE International Conference on Communications, Dresden, Germany, 2009,1-5.

[17] Wang, G.: *An energy-aware and beaconless geographic routing for mobile ad hoc network*, Tien Tzu Hsueh Pao/Acta Electronica Sinica, 38 (2010) 7, 1547-1551.

[18] He, T., Guo, Y.: *Power consumption optimization and delay based on ant colony algorithm in network-on-chip,* Engineering Review, 33 (2013) 3, 219-225.

[19] Wang, F., Li, D., Zhao, Y.: *Analysis of CSMA/CA in IEEE 802.15.4*, IET Communications, 5 (2011) 15, 2187-2195.