Power-efficient Location-based Cooperative Routing with Sensor Power Upper Limit for Wireless Sensor Networks

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Abstract: Cooperative routing in Wireless Sensor Networks can improve performance in these types of networks. In our work, we propose a routing algorithm called Location-based Cooperative Routing with Sensor Power-upper-limit for Wireless Sensor Networks. The algorithm is based on the principle of minimum link power and aims to take advantage of nodes cooperation to make the link work well in Wireless Sensor Networks with a low transmission power. In the proposed scheme, with a determined sending power upper limit, nodes find the most appropriate next nodes and single-relay nodes with the proposed algorithm. Moreover, this proposal subtly avoids the nodes not working, because we add Bad nodes Avoidance Strategy. Simulation results show that, compared with other routing algorithm, the algorithm proposed in previous study, proposed algorithm with Bad nodes Avoidance Strategy can significantly improve the performance in reducing the overall link power, enhancing the transmission success rate and decreasing the retransmission rate.

Keywords: wireless sensor networks; power conservation; cooperative communication; bad nodes avoidance; power efficient.

1. INTRODUCTION

Cooperative routing has been identified as an effective and useful method of reducing the negative effects of fading in Wireless Sensor Networks (WSNs)

WSNs have numerous potential applications, e.g., environmental Monitoring, mineral survey, traffic control and disaster response. In practical applications, a set of QoS requirements (e.g., end-to-end delay, packet delivery ratio, and communication bandwidth) on network performance must be satisfied. However, due to the dynamic topology, time-varying wireless channel, and severe constraints on power supply, quality of service (QoS) provisioning is challenging in WSNs [2], [25].

Routing is an important part in improving WSNs' QoS. In the same hardware conditions, a reasonable routing protocol can not only improve the quality of data transmission, but also save power and energy consumption so as to extend sensors' life-time.

The routing protocol is an important part of the TCP / IP protocol suite in IP based architectures. Therefore, the quality of its process will affect the efficiency of the entire Internet network. The routing is divided into static routing and dynamic routing. Static routing table is established by administrators before selecting the router and can only be changed by the network administrator. So it is only suitable for network transmission whose status is relatively simple. In dynamic routing, with the changes in the network operation, the routers automatically calculate the best path for data transmission according to the data functions provided by the routing protocol, and then get the dynamic routing table. Dynamic routing can be divided into Interior Gateway Protocol (IGP) and Exterior Gateway Protocol (EGP). And IGP can be divided into distance vector routing protocol (DV) and link-state routing protocol (LS). The common DV include Route Information Protocol (RIP), Interior Gateway Routing Protocol (IGRP) and Enhanced Interior Gateway Routing Protocol (EIGRP). The common LS include Open Shortest Path First (OSPF) and Intermediate system to intermediate system (IS-IS). And EGP includes an advanced distance vector routing protocol, Border Gateway Protocol (BGP). Table 1 shows the relationship of and the advantages and disadvantages of the various routing protocols.

Table 1 Comparison of various routing protocols.

Classification		Feature	Protocol	Advantages and Disadvantages
IGP	DV	Using the number of hops or vector to determine the distance from one device to another without considering each hop's link rate.	RIP	Interconnect different routers; Simple configuration; High WAN bandwidth/CPU consumption.
			IGRP	Narrower bandwidth than RIP; Longer convergence time than RIP.
			EIGRP	Mixed metric; Non-equivalent load balancing technology; Rapid convergence.
	LS	Using graph theory algorithms or shortest path first algorithm without hop counts limit.	OSPF	Rapid convergence; High security; High accuracy rate; Low CPU and memory consumption
			IS-IS	Standard IS-IS is not appropriate for the IP network; Rapid convergence.
EGP		—	BGP	Requires the user to have a considerable understanding on the network structure.

Classical routing protocols in WSNs have been developed, greedy algorithm, ant colony optimization and opportunistic routing protocol [12].

Greedy Algorithm: The key to the greedy algorithm routing protocol is that the node packet forwarding data to the neighbor which is closer to the destination according to greedy forwarding strategy. The problem is that forwarding strategy will cause the phenomenon of temporary communication blindness resulted from fixed period beacon exchange in mobile WSNs, still, it cannot perceive the shape of the routing void. Though a number of scholars had improved this algorithm, greedy algorithm is a kind of local optimum algorithm, which forms unbalanced distance between nodes. It will cause unbalanced energy dissipation and make its first node rapidly die.

Ant Colony Optimization: Because of the energy of the node is limited in WSNs, ant colony optimization is proposed to extend the life circle of nodes and improve the performance of the network. However, it assumes that all nodes are static and the position of the node has to be known what it is not possible in practical mobile wireless sensor network.

Opportunistic Routing: In opportunistic routing, node exploits the best candidate to forward data after broadcasting the data. It takes great advantage of broadcast nature of the wireless channel to select the best candidate. However, the drawbacks are that each hop may provide extremely small progress towards the destination , and the signaling overhead for selecting the forwarding node may be too large.

The development trend of routing protocols in WSNs is that the routing protocol should save energy as much as possible. What is more, it is expected to balance the amount of information transmitted by a node and avoid reducing of the QoS. Another important aspect is that routing protocols must have security implemented, but this is out-of the scope of this work.

Challenges for developing routing protocols in WSNs, there still exists due to the three following reasons:

Smaller coverage, mainly in short-distance communication, the general communication range is a few meters to tens of meters, so the need of transmission power is low. Because the sending power, which is the largest part of the entire transmission power consumption in wireless nodes, is growing exponentially with increasing distance, 802.15.4 protocol is fundamentally determined as a low-power agreement. The sending power in 802.15.4 is generally recommended between - 3d bm-10dbm. With low power transmission it is difficult to ensure the quality of the transmission in a complex network environment. However, the research and development of high-power devices suitable for WSNs still takes longer.

Due to the large number of sense nodes, it is not possible to build a global addressing scheme for large number of sensors as the overhead ID maintenance is high. Thus traditional IP-based protocol may not be applied in WSNs. In WSNs getting data is more important than knowing the IDs for what every node in the networks must be self-organized as the ad hoc deployment. The core of the routing is to establish an automatic connecting mechanism for each node instead of a central deployment [3].

Topology changes are a very practical problem that occurs when nodes artificially or naturally fail or move. In case of topology changes, usually the new topology will not be timely informed to each node in the networks. This is seriously harmful to address -memory mode-based networks. This encounters nodes to have autonomous adaptability when topology change occurs.

New ideas on routing in WSNs, such as cooperative routing algorithm in WSNs can be used to solve the problems above to some extent. It is for that, reason that they draw more and more attention in WSNs researches.

In WSNs, multipath fading is a great challenge. Because of the serious fading, destination node cannot judge the signal sent by source node in fading channel. In this case, in order to make sure the success of the transmission, the power of the transmission must increase, which is different in WSNs. However, cooperation diversity is one of the ways against decline in a favorable channel. In recent years, more and more people begin to pay attention to and research on the location-based cooperative routing algorithms in WSNs. Because cooperative link can mitigate fading, achieve high spectral efficiency and improve transmission capacity for wireless networks by means of spatial diversity, and its easier realization than multiple- input multiple-output (MIMO) technique at small mobile terminals, it is theoretically possible to better adapt to the common WSNs where the node power is relatively low.

The basic idea of cooperation diversity is that every node has one or more cooperative relay nodes. Each node has response to transmit not only the own message, but also the cooperative relays', which makes the node exploit its own spatial channel and cooperative relay node's to gain a certain spatial diversity. The inherent spatial diversity enables nodes to cooperate their communication for successful delivery to a destination. The basic procedure of cooperation diversity is that the source node takes advantage of the broadcast nature of the wireless channel which allows multiple nodes to receive the same transmission. Then the relay node sends the signal which had been processed to the destination node. Finally, the destination node incorporates the signals sent by the source node and relay node according to certain rules.

At present, most cooperative routing are based on the purpose of improving the system performance on the transmission quality and efficiency. For cooperative routing research, relay node selection problem the most important issue. Currently, according to the purposes and the methods of selecting the relay node, the typical cooperative routing protocols in the wireless network can be divided into: cooperative routing protocol based on the channel quality, energy-based cooperative routing protocol, the opportunity cooperative routing protocols and distributed cooperative routing protocol. Table 2 shows the advantages and disadvantages of these four types of protocols.

Table 2 Comparison of various cooperative routing protocols.

Classification	Advantages and Disadvantages
channel quality-based	No multi-node resource allocation problems; Gain incremental decreases with the increasing of the number of relay nodes while the link cost increases
energy-based	Simultaneously reduce power consumption and energy consumption without no loss of QoS; Little coexistence between the efficiency of the overall link power and the fairness among nodes
opportunity	Ability to respond to random changes on network topology; Hard to ensure the selected path with feasible minimum power, energy consumption, and path length
distributed	Suitable for Ad Hoc networks and WSNs without a central information node; Challenge in getting nodes location information

On one hand, cooperative routing in WSNs has one unique feature distinguishing from conventional wireless networks. Node cooperation techniques in WSNs have recently been shown to be efficient in terms of energy saving and performance gain. Through cooperation the data transmissions from multiple sensor nodes to a common receiving node, the signals within the same channel from different nodes could be combined at the receiver to obtain stronger signal strength. Cooperation among sensor nodes provides a promising mechanism to exploit spatial diversity and mitigate channel fading. This fundamental difference from the traditional point-to-point transmission model requires new routing protocols that can fully utilize the benefits of the new technology [4].

On other hand, as a common routing protocol in WSNs, geographic routing has been widely hailed as the most promising approach to generally scalable wireless routing. Geographic routing does not need to establish global link state-based routing and storing routing table can avoid data flooding in the entire network and enable data directed transmission. It can save energy and reduce the node's memory by only storing the neighbor state information, which has a good network scalability and robustness. Combining cooperative routing algorithm and geographic routing protocol can be an integrated solution to several challenges in WSNs and this gradually attract people's attention.

In order to take advantages of the low link power and high channel gain of the cooperative routing in WSNs so that the node can work better under conditions of extremely low power , we propose a routing algorithm called Power-efficiency Location-based Cooperative Routing with Sensor Power-upper-limit (PLCR_SP). Node location information analysis and selection policy based on the RTS / CTS handshaking mechanism is the core part of the algorithm. The main idea of the algorithm can be summarized as follows. Each node uses its transmit power upper limit as its transmit power in order to ensure enough transmission distance in case of low power. In this case, the transmission distance and the outage probability will mutually influence each other, both of which can be calculated under the lowest link power, and then the sending node will use the calculated transmission distance as the basis for selecting the location of the next hop node. The algorithm adopts a single cooperative node strategy，and the cooperate link ensure to maintain a relatively low outage probability even under a long transmission distance. In addition, the algorithm further includes a bad node avoidance strategy. Therefore, the cooperative node will not drop packets until the transmission of this hop success so that it can replace the next node to continue transmission when the next hop node cannot receive or decode packets.

The remainder of the paper is organized as follows. Section 2 describes the related work. Then Section 3 defines the network model of the proposed algorithm. We explain our scheme, Power-efficiency Location-based Cooperative Routing with Sensor Power-upper-limit, in details in Section 4. In Section 5, we list the calculation method of the simulation parameters, whereas, in Section 6 we present our simulation results. Finally, Section 7 summarizes our conclusions.

2. RELATED WORK

Related studies have been gained some progress.

A novel geographic routing protocol that incorporates cooperative relaying and leapfrogging has been proposed [37]. This scheme of protocol does not insist on successful decoding data packet at next hop node. Instead, they recognize that after the initial retransmission (from a relay) in response to a RREQ from the next-hop node, there may be nodes that are further advanced towards the destination than the next-hop node that have successfully decoded the data packet. The concept of leapfrogging circumvents links with poor radio channel conditions and significantly reduces the number of retransmission. In the context of energy-constrained WSNs such an approach can potentially increase the network lifetime. Yet the selections of next hop nodes and leapfrogging nodes have not been proposed in details.

Robust Cooperative Routing Protocol (RRP) [6] is a cross-layer robust routing protocol based on node cooperation among nearby nodes for unreliable mobile WSNs. Inside the robust path expanded from an intended path, a reliable path is selected for packet delivery. Based on the path quality, the intended path is able to adapt to the varying topology. Utilizing path diversity in the robust path, the robust routing protocol is capable of selecting the best path in a wide zone for each packet. This is the difference of RRP from traditional routing protocols. Therefore, the robustness against path breakage is improved.

Cooperative-Aided Routing Protocol (CARP) [5] in mobile ad-hoc WSNs consists of two parts as follows. The first part is the decision of routing routes which are decided on route stability based on mobility of mobile nodes to increase the operational lifetime of routes; and the second part is the data forwarding via the cooperative-aided routes to increase packet delivery ratio with advanced SNR (Signal Noise Ratio).

Power Control based Cooperative Opportunistic Routing Protocol (PC-CORP) [8]for WSN provides robustness to the random variations in network connectivity while ensuring better data's forwarding efficiency in an energy efficient manner. Based on realistic radio model, it combines the region-based routing, rendezvous scheme, sleep discipline and cooperative communication to model data forwarding by cross layer design in WSN. At the same time, a lightweight transmission power control algorithm Additive Increase Multiplicative Decrease Power Control (AIMD-PC) is introduced to utilize the cooperation of relay nodes to improve the forwarding efficiency performance and increase robustness of the routing protocol. The performance of PC-COPR is investigated by means of simulation from perspectives of adaptation of variations in network connectivity and satisfying QoS requirements of application.

An energy efficient cooperative routing scheme with space diversity called Space-Time Block Codes (STBCs) protocol [9] uses space-time bloc codes as well as the link quality. In our solution, the selected multiple nodes act as multiple transmitting and receiving antennas. Full diversity from the orthogonal STBC is utilized to overcome multipath fading and to enhance power efficiency. The steady state network performance measures, such as network throughput and delay are analyzed via Markov chain modeling. Compared with the traditional single relay routing method and the single receiving diversity routing method, the proposed method outperforms the other two in low SNR environments and provides higher throughput and similar delay in high SNR environments.

Energy-efficient Cooperative Routing Protocol (ECRP) [10] is a distributive implementation of cooperative routing protocol. A minimal energy multi-nodes cooperative route can be found by the cooperative transmission of neighboring nodes and comparison of total power consumption. Under the assumption that nodes can know the relative location of neighboring nodes, the distributive routing scheme can be implemented by carrying information about power consumption of route and cooperative cluster in RREQ packet. There is a 30-50% energy saving compared with traditional non-cooperative routing. Meanwhile, using the selection strategy of cooperative nodes, the control expense and complexity of computation can be reduced, trading off a little decline in energy-efficiency.

Most of the works have not taken into account the nodes' power upper limit that may exist for limited energy supplies and equipment strength practical application and how the networks perform at such conditions. And they also did not give much thought to the topology mutation caused by the unknown bad nodes (stop as energy exhaust or damage).

In order to take advantages of the low link power and high channel gain of the cooperative routing in WSNs so that the node can work better under conditions of extremely low power , we propose a routing algorithm called Power-efficiency Location-based Cooperative Routing with Sensor Power-upper-limit (PLCR_SP). Node location information analysis and selection policy based on the RTS / CTS handshaking mechanism is the core part of the algorithm. The main idea of the algorithm is: Each node uses its transmit power upper limit as its transmit power in order to ensure enough transmission distance in case of low power; In this case, the transmission distance and the outage probability will mutually influence each other, both of which can be calculated under the lowest link power, and then the sending node will use the calculated transmission distance as the basis for selecting the location of the next hop node; the algorithm adopts a single cooperative node strategy，and the cooperate link ensure to maintain a relatively low outage probability even under a long transmission distance. In addition, the algorithm further includes a bad node avoidance strategy: The cooperative node will not drop packets until the transmission of this hop success so that it can replace the next node to continue transmission when the next hop node cannot receive or decode packets.

The importance of this work is providing an algorithm which can work stably and power-efficient with extremely low sending power. This algorithm can make WSNs woke in bad environments, for example, Eco-system detection，deep-water probe，micro-sensor in military, etc.

3. NETWORK MODEL

The used cooperative model for this study takes a single cooperative node mode which means that for each hop there are only one relay node and one next hop node to transmit to. The model includes two basic link models, direct link model and cooperative link model, with some basic assumptions described below. The transmission will automatically choose the cooperative link model when there is an appropriate relay node meeting the requirements, otherwise, direct link model will be used.

3.1. BASIC ASSUMPTIONS

In order to evaluate the proposed algorithm, some basic assumptions are done.

We assume that there are no two nodes locate at the same position. All sensor nodes are equipped with the same radio transceiver. Moreover, each node only knows its own location information, power limit and channel environment parameters. Through RTS / CTS mechanism only respective location information can be transmitted between nodes. So each node just follows its own parameters to calculate and select next hop node and relay node. Therefore, for each sending node, it seems that each subsequent node is just like itself.

The basis of the above assumptions is that usually the quality of the channel and the merits of the environment are not prone to change. That means that the changes in the propagation environment are usually smooth. Here we have chosen the path loss exponent k as the indicator representing merits of the network.

We use Unit Disk Graph communication model for analysis. In this model, any two nodes *i* and *j* can reliably communicate with each other if and only if

$$|i\ j| \leq R \qquad (1)$$

where $|i\ j|$ is the Euclidean distance between *i* and *j*.

Each node in WSNs has a unique node identification number and all the links between nodes are bidirectional, i.e. if there is a communication link from node *i* to *j*, so it is also one from *j* to *i*.

3.2. DIRECT LINK MODEL

Direct link model is shown in Figure 1. the link *(S, D)* is composed of the sending node *S* and the receiving node *D*.

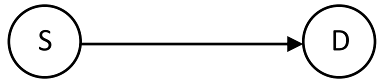

Figure 1 Direct link model.

The wireless channel between sending node *S* and receiving node *D* can be expressed by θ and α. θ is the phase-shift factor, and α is the gain factor which equals $h_{S,D}/d_{S,D}^{k/2}$, where *k is* the path loss exponent, and $d_{S,D}$ is the distance between the nodes. Assume that the channel attenuation coefficient $h_{S,D}$ is independent and identically distributed, and subject to a Gaussian distribution with zero mean and variance equal to 1. So for the direct link, the signal received at receiver *D* is:

$$\mathrm{r(t)} = \alpha_{\mathrm{S,D}} \mathrm{e}^{\mathrm{j}\theta} \mathrm{s(t)} + \mathrm{n(t)}, \quad (2)$$

where *s(t)* is the transmitted signal, and *n(t)* is the noise signal.

3.3 COOPERATIVE LINK MODEL

In cooperative link model shown in Figure. 2, Link *S*-*D* establishes collaborative sending mode. The collaborative link is formed by node *S* as a sender, node *R* as a cooperative node, and node *D* as a receiver. The process can be divided into two time slots. In the first time slot, the packet can be sent from source node S to forwarding node D and R directly. In the second time slot, the packet is sent through the relay node R to node D, and then the node D combines them optimally.

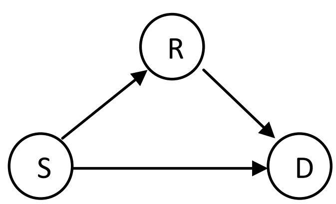

Figure 2 Cooperative link model.

Assuming that the receiver *D* both receives the data signals sent by *S* and the data signals relayed by *R* from *S*, and the transmission power of each node are equal for all of them, which are P_t, then the signal received by receiver *D* is:

$$\mathrm{r(t)} = \left(\alpha_{\mathrm{S,D}} + \alpha_{\mathrm{R,D}}\right) \mathrm{e}^{\mathrm{j}\theta} \mathrm{s(t)} + \mathrm{n(t)}, \quad (3)$$

4. PLCR_SP ALGORITHM

PLCR_SP ALGORITHM consists of two parts, one of which is the selection of the next hop node and the other is the bad node avoidance strategy. This algorithm is based on the principle of minimum link power. For a transmission hop, we have [19]

$$P_s = \frac{(2^{\mu_0}-1)N_0}{P_D^{out}} d^k \tag{4}$$

where P_s is sending power, P_D^{out} is outage probability and d is the transmission distance, that if P_s is determined by the node power upper limit, d and P_D^{out} have a negative correlation. Within a restricted range, we can find the optimal relation between these two parameters so that the overall link power reaches a minimum while ensuring the success rate of the transmission. The following section describes how to select the optimal distance d.

4.1. DIRECT LINK

For direct transmission between node S and D, the total power is [17]:

$$P_{S,D}=P_S+2P_e \tag{5}$$

where P_e is the power consumed by the transmitter and $2P_e$ counts a sending and a receiving power assumed. If the sending power has reached the maximum, the total direct power is:

$$P_{S,D}=P_S^{Lim}+2P_e \tag{6}$$

where P_S^{Lim} is the power upper limit of node S. The outage probability for this transmission is:

$$P_D^{out} = \frac{(2^{\mu_0}-1)N_0}{P_S^{Lim}} d^k \tag{7}$$

according to equation (4). As a statistical value, we can use the outage probability indirectly to indicate the expected sending times, n, in a hop. n is as follow:

$$n=\frac{1}{1-P_D^{out}}=\frac{1}{1-\frac{(2^{\mu_0}-1)N_0}{P_S^{Lim}}d^k} \tag{8}$$

As the node S just knows the parameter information (P_S^{Lim}, k) of itself and the location information of nodes who participate in the RTS / CTS within the transmission range, it must assume henceforth other hop conditions are equal to this hop. So in its view, the transmission distance of each hop, d, it is the same. L is the distance between S and D, so the total times, m, of hops is:

$$m = \frac{L}{d} \tag{9}$$

Consequently, the total power of the link calculated by node S is

$$P_{total} = P_{S,D} \times m \times n = P_{S,D} \times \frac{1}{1-\frac{(2^{\mu_0}-1)N_0}{P_S^{Lim}}d^k} \times \frac{L}{d} \tag{10}$$

Let

$$A = P_{S,D} \times L \tag{11}$$

and

$$B=\frac{(2^{\mu_0}-1)N_0}{P_S^{Lim}}, \tag{12}$$

then

$$P_{total} = A/(d-Bd^{k+1}). \tag{13}$$

We take the first derivative of P_{total} with respect to *d*, and let $\partial P/\partial d = 0$, at which time P_{total} reach the only minimum value. That

$$P'_{total} = -A[1-B\times(k+1)d^k]/(d-Bd^{k+1})^2=0 \tag{14}$$

And then we have the ideal transmission distance of this hop:

$$d=\sqrt[k]{\frac{1}{B\times(k+1)}}=\sqrt[k]{\frac{1}{\frac{(2^{\mu_0}-1)N_0}{P_S^{Lim}}\times(k+1)}} \tag{15}$$

Next-hop node's selection in direct link is realized by RTS / CTS handshaking mechanism. Nodes competition for next hop node will use the back of time as the indicator. The back off time before the node G_i replies CTS_1 message can be formulated as:

$$T_{delay}(i) = \left[\omega\left(\frac{d_{G_i,D_i}}{d}\right)^2 + R(1-\omega)\left(\frac{1-\cos\theta_i}{2}\right)^2\right]T_0 \tag{16}$$

where $d_{Gi,Di}$ is the distance between the node G_i and the ideal next-hop node D_i, d is the ideal distance, R ($0 \le R \le 1$) is a random number, ω ($0 \le \omega \le 1$) is the balance factor, θ_i is the angle between G_i and the destination node D with D_i as the vertex, and T_0 is the maximum waiting time of node G_i before it forwards the message. The node whose back off time is the least will win the competition and become the next hop node. More details refer to the previous study (2012, Juanfei Shi) [1].

4.2. COOPERATIVE LINK

4.2.1. NEXT HOP NODE SELECTION

Different from direct transmission, outage probability of cooperative transmission is a comprehensive result. It is affected by the relay node R's location, next hop node's location and the transmission power and so on [16]. For a single relay transmission, the determination of the location of the ideal relay node is based on the location of next hop node which, however, is unfortunately unknown. So the location of R must be assumed when S is to calculate d. Furthermore, it should assume R's parameter information (P_S^{Lim}, k) as well.

The same as direct transmission, S will assume that R has the same situation with S that they have the same parameter information (P_S^{Lim}, k) and thereby R's expected ideal transmission distance is also d [18]. In order to ensure the successful transmission, R must be within the sending radius of S and D must be in the emission radius of R, so R should be in the red area shown in Figure3. We choose the most 'remote' point for both S and D shown in Figure3 as the assumed location of R. In this cause the location of assumed R is the worst one in this area for relay so that hereafter wherever the final selected R actually is in the area it may competent to relay.

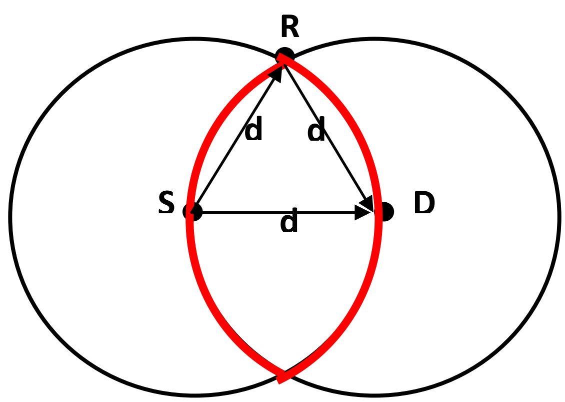

Figure 3 Assumption of the relay node position.

We assume that the sending and receiving processes are independent for every node. So for each group of sending and receiving processes the outage probability can be calculated according to equation (7). For cooperative transmission, an entire hop should contain 3 groups of sending and receiving processes: S to D, S to R and R to D. among these three, S to R then R to D is a continuous process. So the outage probability of an entire hop, $P_{S,R,D}^{out}$, can be calculated as follow:

$$P_{S,R,D}^{out} = P_{S,D}^{out}[1-(1-P_{S,R}^{out})(1-P_{R,D}^{out})] \tag{17}$$

where $P_{S,R}^{out}$ and $P_{R,D}^{out}$ are the outage probabilities from S to R and R to D. As S assumed that P_S=P_R=P_S^{Lim} and $d_{S,D}$=$d_{S,R}$=$d_{R,D}$=d, according to equation (7) we have $P_{S,R}^{out} = P_{S,R}^{out} = P_{S,R}^{out} = \frac{(2^{\mu_0}-1)N_0}{P_S^{Lim}} d^k$. So we can simplify the $P_{S,R,D}^{out}$ as:

$$P_{S,R,D}^{out} = \frac{(2^{\mu_0}-1)N_0}{P_S^{Lim}} d^k + 2\frac{(2^{\mu_0}-1)^2 {N_0}^2}{{P_S^{Lim}}^2} d^{2k} - \frac{(2^{\mu_0}-1)^3 {N_0}^3}{{P_S^{Lim}}^3} d^{3k}$$

$$= Bd^k + 2B^2 d^{2k} - B^3 d^{3k} \tag{18}$$

Where

$$B=\frac{(2^{\mu_0}-1)N_0}{P_S^{Lim}}. \tag{19}$$

And the expected sending times of a hop is

$$N=\frac{1}{1-P_{S,R,D}^{out}}=\frac{1}{1-Bd^k-2B^2d^{2k}+B^3d^{3k}} \tag{20}$$

In hop of packet cooperative transmission, at the first time slot according to the network model described in section 3, source node S broadcasts the data packet to the selected next hop forwarding node D and the selected relay node R in its communication area. And then at the second time slot, relay node R broadcasts the data packet received just recently to node D for data combination. Hence the power consumption contains two times of sending power limit, 2 sending power and 3 receiving power. Consequently, the total power of an entire cooperative hop is:

$$P_{S,R,D}=2\times P_S^{Lim}+5P_e \tag{21}$$

According to equation (10), the same to direct transmission, the total power of the link calculated by node S is:

$$P_{total} = P_{S,R,D} \times m \times n = P_{S,R,D} \times \frac{1}{1-Bd^k-2B^2d^{2k}+B^3d^{3k}} \times \frac{L}{d} \tag{22}$$

Let

$$AA = P_{S,R,D} \times L \tag{23}$$

Then

$$P_{total} = AA/(d - Bd^{k+1} - 2B^2d^{2k+1} + B^3d^{3k+1}). \tag{24}$$

We take the first derivative of P_{total} with respect to d, and let $\partial P/\partial d = 0$.

Then:

$$P'_{total} = -AA[1 - B(k+1)d^{k} - 2B^{2}(2k+1)d^{2k} + B^{3}(3k+1)d^{3k}]/(d - Bd^{k+1} - 2B^{2}d^{2k+1} + B^{3}d^{3k+1})^{2} = 0 \quad (25)$$

However, equation (25) is a transcendental equation that has not analytical solutions. So each sending node needs iterative computation. Here we ignore the extra power and time consumption caused by the iterative calculation [20]. More work it is needed to be done to find a suitable approximate analytical solution in future research.

When determining the ideal next hop node, S will assume that R is located at the point shown in Figure 3 in order to ensure the transmission. However, the ideal relay node is not at that point. It can be derivation from equation (7), (17) and (22) that, when the next hop node has been selected, if R is located in the mid-point between S and D, $P^{out}_{S,R,D}$ and P_{total} are both the least. So we choose mid-point between S and Das the location of ideal relay node. We use this location of ideal relay as a reference for the selection of the actual relay node [21].

Next-hop node's and relay node's selection is realized by RTS / CTS handshaking mechanism [14]. Nodes competition mechanism is the same to that mentioned in section 4.1.

4.2.2. 'BAD NODE' AVOIDANCE STRATEGY (BAS)

As shown in Figure 4, the source node S broadcasts the data packet to the selected next hop forwarding node D1 and the selected relay node R1. In this process, when S or R1 sent the data packet, they will start retransmission timers to account for the event that the node D1 cannot successfully decode the combined data packet. When the node D1 could successfully decode the combined data packet from the node S and R1, it will send an acknowledgement packet (ACK) to S and D1, otherwise, it issues a retransmission request (RREQ) to the node S and node R1. For S and R1, if the timers end without receiving the ACK or they receive the RREQ (then cancel the timer), both of them will start counters to record the Times of Transmission Failure (TTF). And the process will proceed again. However, if the times of transmission failure are more than one (TTF>2), the forwarding node D1 is believed a failed node. The node S will stop sending data packet and node R1 will replace node D1 as the forwarding node and continue the next hop transmission as shown in red line, so that it can reduce the times of retransmission to D1.

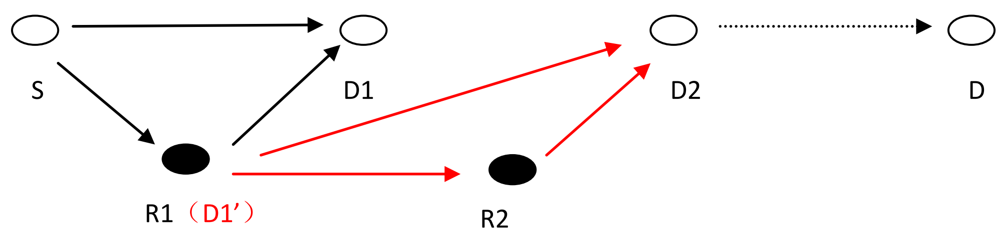

Figure 4 ‘bad node’ avoidance strategy.

5. PERFORMANCE EVALUATION

We chose three parameters: total link power, transmission success rate and retransmission rate respectively; as the algorithm performance evaluation indicators [22]. Correspondingly, the average total power of an entire link is chosen to test the pros and cons of the algorithm based on the principle of minimum link power; transmission success rate is an indicator that reflects the algorithm’s stability, reliability and scope of applications; retransmission rate is calculated to test the algorithm’s ability to respond to harsh transmission environments and bad nodes.

Total link power

The total link power P_{total}^{actual} for an entire link in PLCR_SP algorithm is:

$$P_{total}^{actual} = P_{S,D}(n_{ds} + n_{dr}) + P_{S,R,D}(n_{rs} + n_{rr}) = (P_S^{Lim} + 2P_e)(n_{ds} + n_{dr}) + \left(2P_S^{Lim} + 3P_e\right)(n_{rs} + n_{rr}) = P_S^{Lim}(n_{ds} + n_{dr} + 2n_{rs} + 2n_{rr}) + P_e(2n_{ds} + 2n_{dr} + 3n_{rs} + 3n_{rr}) \quad (26)$$

where n_{ds}, n_{dr}, n_{rs} and n_{rr} are, respectively, the total times of first-time transmission of direct hops, retransmission of direct hops, first-time transmission of relay hops and retransmission of relay hops.

Transmission success rate

The transmission success rate R_{succ}, reflecting the reliability of a link, is a kind of statistics calculated from multiple simulations. When the packet could be sent successfully from source node to the destination, we record link success once, otherwise, link error once. And the transmission success rate R_{succ} is:

$$R_{succ} = \frac{n_{succ}}{n_{succ} + n_{err}} \quad (27)$$

where n_{succ} is the total times of link success and n_{err} is the total times of link error.

Retransmission rate

Retransmission rate $R_{retrans}$ is the ratio of the times of retransmission to the times of the total transmission. This kind of statistics calculated from multiple simulations is an indicator used to test the performance of "bad node" avoidance strategy.

$$R_{retrans} = \frac{n_{dr} + n_{rr}}{n_{ds} + n_{dr} + n_{rs} + n_{rr}} \quad (28)$$

6. SIMULATION RESULTS

6.1. SIMULATION ENVIRONMENT

In WSNs, nodes are randomly distributed in a 500 × 500 rectangular plane area; the antenna type is omnidirectional; we use complex Gaussian white noise with variance is $N0$ =- 70dBm; the signal bandwidth B = 1MHz; balance factor ω = 0.78; forward angle region $\theta = 60^{o}$, $T0$ = $T1$ = 200μs. All the parameters above are according to the previous study [1] and the IEEE_802.15.4 protocol [30]. The source node will be located at coordinate (100,100) and destination node at (400,400), and then create routes, taking the average of 1000 different networks as the final simulation results.

When path loss k does not change as a control condition variable, in order to more realistically simulate the actual transmission environment, it is distributed as a fixed curved surface in the simulation area, which is shown in Figure 5 and described as:

$$k = \frac{1}{2}\left(\frac{x}{125} - 2\right) \times e^{\left(-\left(\frac{x}{125}-2\right)^2 - \left(\frac{y}{125}-2\right)^2\right)} \times e + 3 \quad (29)$$

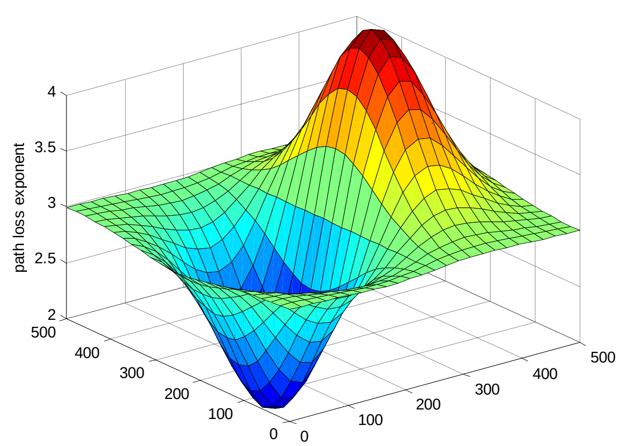

Figure 5 The distribution diagram of k in the simulation region.

where (x, y) are the coordinate of the area. In this area, the average k is 3 according to the IEEE_802.15.4 protocol for low power network. And a maxima peak exists at about (350, 250) while a minima peak at about (150, 250) in order to create a worse transmission environment area and a better one respectively to show how the algorithm works at poor and fine environments.

According to IEEE_802.15.4 protocol, the sending power of a node is recommended from -3dBm to 10dBm. However, in order to test our algorithm in an extremely low power as the final aim, after multi-times simulation we get a matching sending power condition that when the sending power upper limit does not change as a control condition variable it is 0.0001w (-10dBm) for each node.

When the bad node rate does not change as a control condition variable its value is 0.1 to all nodes. When the node density does not change as a control condition variable its value is 0.005.

6.2. Total Link Power

Figures6, 7 and 8, respectively, show the comparison of the total link power of PLCR_SP algorithm with and without BAS, and PLCR algorithm at different node density, path loss index and bad node rate.

These figures show that at the same abscissa the total link power of PLCR_SP algorithm with and without BAS are both much lower than that of PLCR algorithm. That indicates in the whole variation range of node density, path loss index and bad node rate in this simulation, the PLCR_SP algorithm is much more adaptable and power-efficient. The total link power of PLCR_SP algorithm with BAS shows a little lower than one without BAS. That indicates that BAS can reduce the “transfer resistance” and thereby reduce the total link power, which may be caused by avoiding multiple retransmissions to a bad node with poor ability to receive and decode. This part will be discussed in section 6.4.

Figure 6 shows the impact of different node density on total link power of the three algorithms. With the increase of node density, the total link power of three kinds of routing algorithms reduce gradually, which may be caused by the fact that the next hop nodes are more and more close to the ideal next node. For PLCR_SP with and without BAS, the total link power reduces quickly in the range of node density from 0.002/m^{-2} to 0.008/m^{-2}, while very slowly when higher than 0.008/m^{-2}, which indicates the PLCR_SP algorithm has the ability to determine the appropriate next node without being influenced by the node density even when the density is still low. On contrast, the total link power of PLCR is continuously reducing. The undulation of the total link power of PLCR is also caused by the low node density in which condition there is a significantly uncertainty of the distance between nodes.

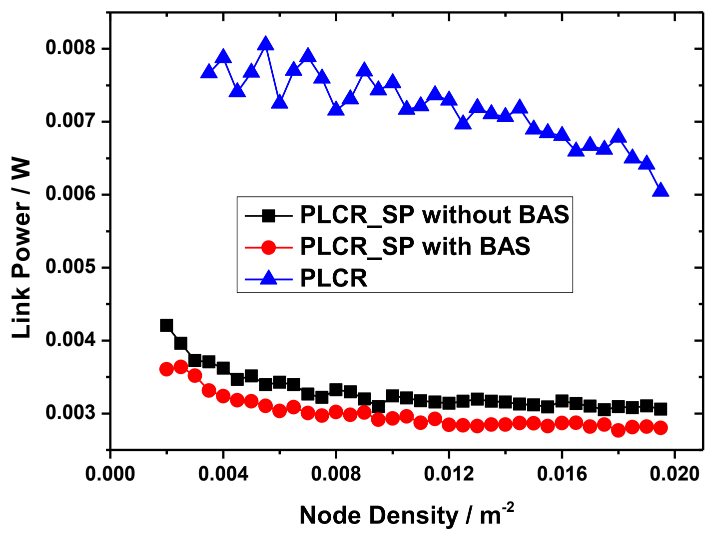

Figure 6 Link power vs Node density.

Figure 7 shows the impact of different path loss index on total link power of the three algorithms. With the increasing of path loss index, the total link power of three kinds of routing algorithms increase exponentially as the sending power is proportional to the d^k, where d is the transmission distance. The slope of increasing total link power of PLCR algorithm with path loss index is much sharper than that of both PLCR_SP algorithms with and without BAS. That indicates that PLCR_SP algorithm is more suitable in poor transmission environment whose path loss index is relatively high.

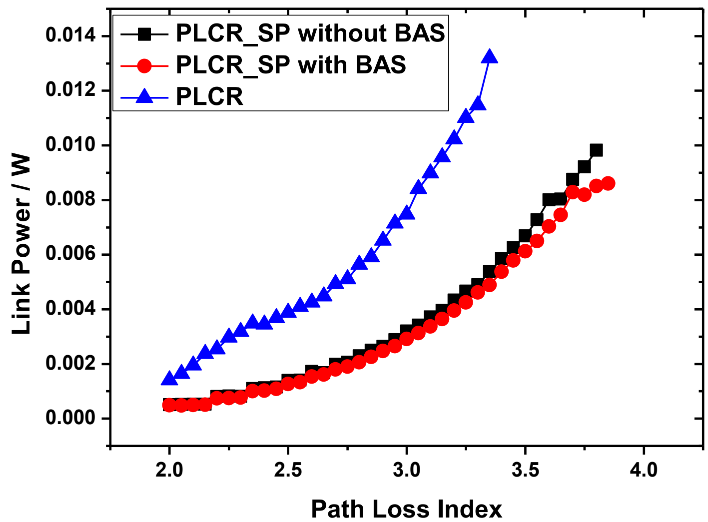

Figure 7 Link power vs Path loss index.

Figure 8 shows the impact of different bad node rate on total link power of the three algorithms. With the increasing of bad node rate, the total link power of three kinds of routing algorithms increase gradually for the increasing of the retransmission times caused by “bad nodes”.

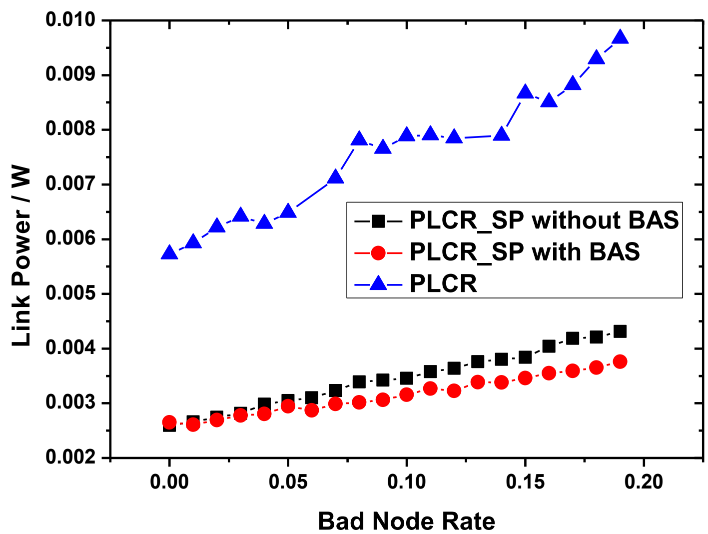

Figure 8 Link power vs Bad node rate.

In summary, though the node density and power upper limit value are relatively low, as well the path loss index and the bad node rate are relatively high, which means the transmission condition is relatively poor, PLCR_SP algorithm has a more outstanding performance in the saving power consumption than PLCR algorithm. In addition, the BAS can contribute to link power saving to a certain extent.

6.3. TRANSMISSION SUCCESS RATE

Figures9, 10, 11 and 12, respectively, show the comparison of the transmission success rate of PLCR_SP algorithm with and without BAS, and PLCR algorithm at different node density, power upper limit, path loss index and bad node rate.

It can be seen from Figures9, 10, 11 and 12 that in the vast majority of the range of the abscissas the transmission success rate of PLCR_SP algorithm with and without BAS, are both much higher and more stable than that of PLCR algorithm. That indicates that in the transmission condition of this simulation, the PLCR_SP algorithm is competent while PLCR algorithm is not. The total link power of PLCR_SP algorithm with BAS shows a very steady value approaching 1.0, a higher level than that without BAS.

Figure 9 shows the impact of different node density on transmission success rate of the three algorithms. There is an obviously inflection point both in PLCR_SP with and without BAS where node density is around $0.003/m^{-2}$. When the density is larger than this point, the transmission success rate of PLCR_SP algorithm shows a stable and level trend, while a sharp drop when the density is smaller than that point. As well the inflection point of PLCR appears around $0.008/m^{-2}$. The sharp drop of transmission success rate occurs when the average maximum transmission distance nodes can provide in this condition is shorter than the average distance between the nodes. So that the value of the inflection point can indirectly reflect the ability of an algorithm that the maximum transmission distance nodes can provide, which can be calculated from equation (7). This indicates that compared with PLCR algorithm, PLCR_SP algorithm can transmit farther in the same condition.

The inflection points like Figure 9 also appear in Figure 10, which is likewise caused by insufficient transmission distance according to equation(7) when sending power upper limit is very low. However, the difference is that for PLCR_SP algorithm without BAS there is a slope when power upper limit is larger than the inflection point. As this slope does not occur in PLCR_SP algorithm with BAS, it may be caused by the bad nodes' influence. In addition, there is no obvious inflection point for PLCR algorithm.

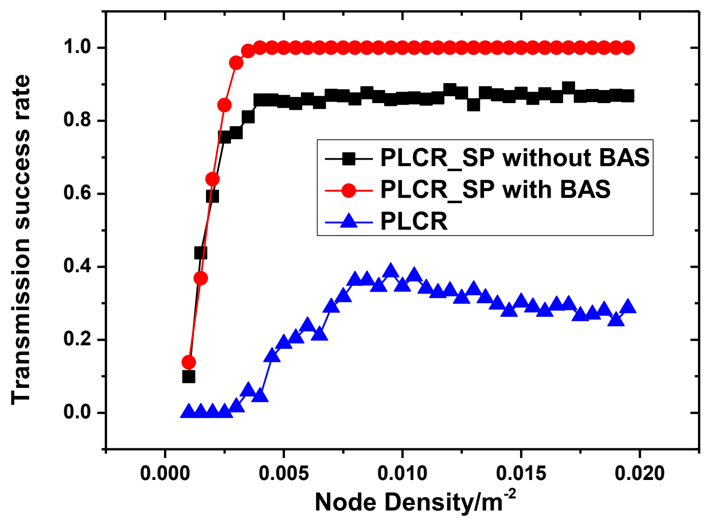

Figure 9 Transmission success rate VS Node density.

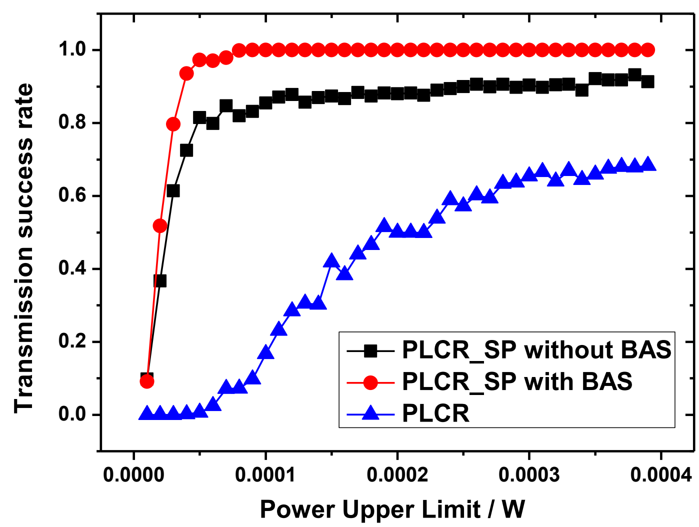

Figure 10 Transmission success rate vs Power upper limit.

Figure 11 shows the impact of different path loss index on transmission success rate of the three algorithms. Only PLCR_SP algorithm with BAS appears an obvious inflection point where k is around 3.5. The reason for this point can be also attributed to the insufficient transmission distance according to equation (7) when path loss index is high. The difference between PLCR_SP algorithm with and without BAS, that there is an obvious slope in PLCR_SP algorithm without BAS when k is smaller than 3.5, may indicate that when power upper limit is low (0.0001w) and path loss index is high, according to equation (8), the outage probability for each hop will increase and create some "bad nodes". Here we need to mention that when path loss index is near 2.0, the transmission success rates of PLCR_SP algorithm with and without BAS, are almost equal and approaching 1.0. This phenomenon can be explained as follow: when the value of path loss index is near 2.0, the transmission environment is close to the ideal environment and the hop number in a whole link will be few according to equation (8) and (10); as the destination node cannot be set up as a bad node, it will reduce the ratio of bad node in the entire link. This can also be used to explain the drop of transmission success rate of PLCR algorithm where k is from 2.0 to 2.3.

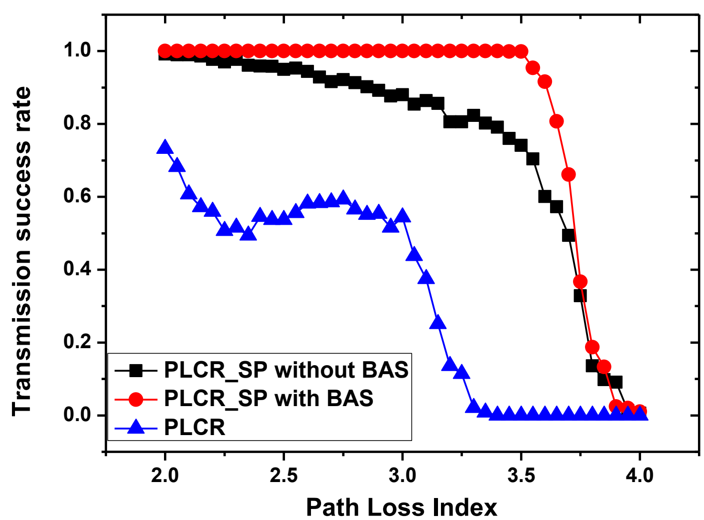

Figure 11 Transmission success rate vs Path loss index.

Figure 12 shows the impact of different bad node rate on transmission success rate of the three algorithms. Except for PLCR_SP algorithm with BAS, the transmission success rate of both PLCR_SP algorithm without BAS and PLCR algorithm have negative linear relationship with bad node rate.

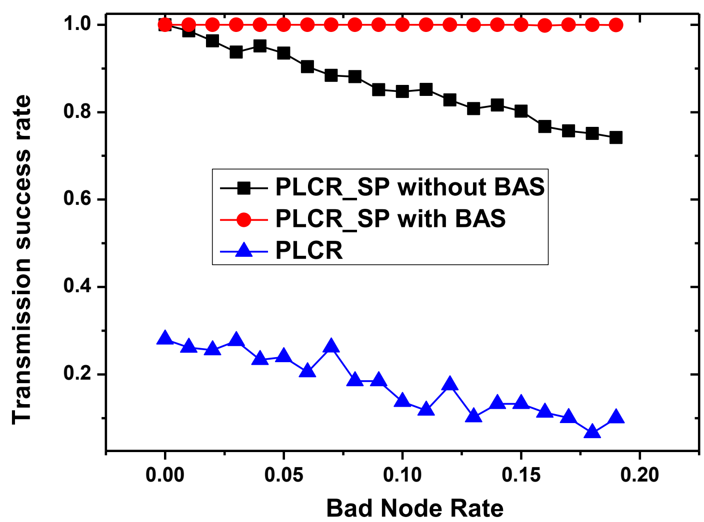

Figure 12 Transmission success rate vs Bad node rate.

In summary, when node density and sending power upper limit are relatively low, while path loss index and bad node rate are relatively high, PLCR_SP algorithm with BAS can has a very stable and reliable performance in transmission success rate until the appearance of inflection point.

6.4 RETRANSMISSION RATE

Figure 13shows the comparison of the retransmission rate of PLCR_SP algorithm with and without BAS, and PLCR algorithm at different bad node rate.

It can be seen from Figure 13 that with the increasing of bad note rate the retransmission rate of three algorithms increases. The slope of PLCR_SP algorithm with BAS are much lower than that of both PLCR_SP algorithm without BAS and PLCR algorithm while the latter two have no obvious difference between each other. This indicates that in the transmission condition of this simulation, BAS effectively avoids multiple retransmissions to bad nodes and thereby reduces the retransmission rate. However, PLCR_SP algorithm itself does not affect the retransmission rate.

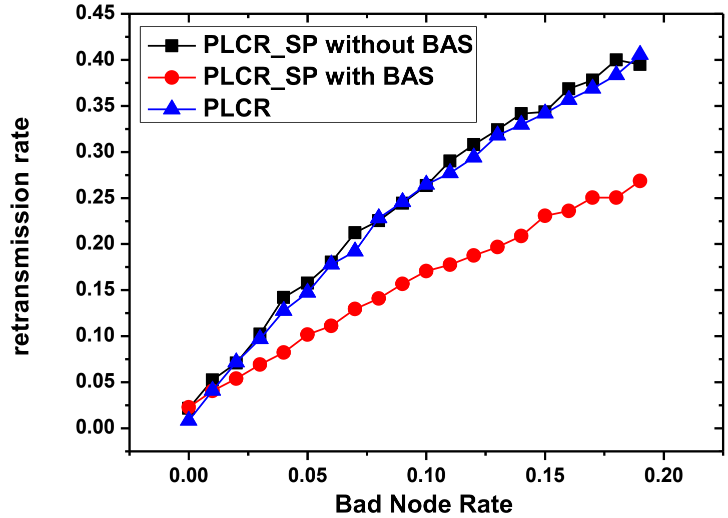

Figure 13 Retransmission rate vs Bad node density.

6.5 PATH NODES

Figure 14 randomly shows 10 path nodes result of PLCR_SP algorithm with and without BAS, and PLCR algorithm at different bad node rate in 1000 simulations in which the power upper limit is 0.0001w, bad note rate is 0.1 and the node density is 0.005. The source node and destination node are located at (250, 0) and (250, 500). The middle axis coincides with the line which represents k=3. The area on the left of the middle axis is the region with better transmission environment whose k is lower, while the other side is the region with worse transmission environment whose k is higher. The path nodes of PLCR_SP algorithm with BAS symmetrically distributed on both sides of the middle axis. On contrast, the path nodes of PLCR_SP algorithm without BAS and PLCR algorithm in left side of the middle axis are more than right. This indicates that PLCR_SP algorithm with BAS can work well wherever k is higher or lower with the help of BAS. The path nodes of PLCR algorithm is more concentrated near the source node than that near the destination node, while the path nodes of PLCR_SP algorithm with and without BAS both have symmetrically vertical distribution. This means PLCR_SP algorithm has more reliable performance with little failures.

This figure visually displays the reliable performance of PLCR_SP algorithm and the high adaptability BAS can provide.

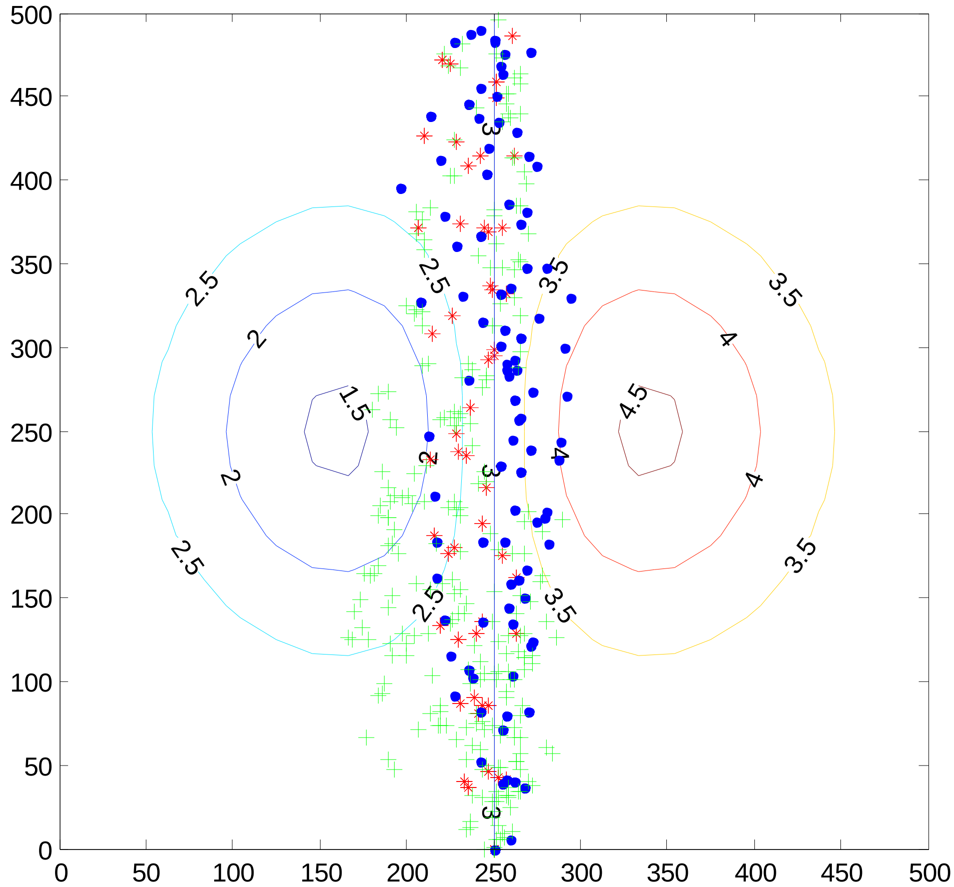

Figure 14 The pathways node maps.

7. CONCLUSIONS AND FUTURE WORK

In this paper we propose a location based cooperative routing algorithm for WSNs called Power-efficiency Location-based Cooperative Routing with Sensor Power-upper-limit (PLCR_SP), in order to take advantages of the low link power and high channel gain of the cooperative routing in WSNs and make it work well in the case where the transmission power is really low. Node location information analysis and selection policy based on the RTS / CTS handshaking mechanism is the core part of the algorithm. The main idea of the algorithm is that each node uses its transmit power upper limit as its transmit power in order to ensure enough transmission distance in case of low energy. In this case, the transmission distance and the outage probability will mutually influence each other, both of which can be calculated under the lowest link power, and then the sending node will use the calculated transmission distance as the basis for selecting the location of the next hop node. The algorithm adopts a single cooperative node strategy， and the cooperate link ensures to maintain a relatively low outage probability even under a long transmission distance. In addition, the algorithm further includes a bad node avoidance strategy. The cooperative node will not drop packets until the transmission of this hop success so that it can replace the next node to continue transmission when the next hop node cannot receive or decode packets.

Simulation results show the following conclusions. Firstly, when nodes' transmission power upper limit is extremely low as 10^{-5}-$4*10^{-4}$W, and path loss index and bad node rate are relatively high, 2-4 and 0-0.2 respectively, PLCR_SP could significantly reduce the overall power and retransmission rate and enhance the transmission success rate, compared with PLCR, the algorithm proposed in previous study. Secondly, PLCR_SP algorithm shows a very stable performance within a fairly large range of conditions, as the transmission success rate is approaching 1.0 until an obvious inflection point appears. Thirdly, the retransmission rate will be lower and transmission success rate will be higher with bad node avoidance strategy (BAS) than without. This shows that PLCR_SP algorithm with BAS can better adapt to the WSNs network with low node density, small transmission power and bad transmission environment.

Future work: we are expected to find a way to make this routing algorithm not only power-efficient but also energy-efficient [34], [35]. What is more, we should research the approximate calculation of the transmission distance. Last but not least, we want to study about the implementation when the routing algorithm adopts the multi-relay strategy. All above are aim to improve the performance of WSNs.

REFERENCE

1. Juanfei Shi; Kai Liu: Power-efficient location-based cooperative routing in wireless networks. *Systems and Informatics (ICSAI)* **2012**, 5, 1454 - 1458.
2. Liang, X. D.; Chen, M.; Xiao, Y.; Balasingham, I.; Leung, V. C. M., MRL-CC: a novel cooperative communication protocol for QoS provisioning in wireless sensor networks. *International Journal of Sensor Networks* **2010,** 8, (2), 98-108.
3. Al-Karaki, J. N.; Kamal, A. E., Routing techniques in wireless sensor networks: A survey. *Ieee Wireless Communications* **2004,** 11, (6), 6-28.
4. Coronel, P.; Doss, R.; Schott, W., Location-based cooperative relaying in wireless sensor networks. *2007 2nd International Conference on Communication Systems Software & Middleware, Vols 1 and 2* **2007**, 868-873.
5. An, B.; Lee, J. S.; Kim, N. S.; Kim, D. H., CARP: A cooperative-aided routing protocol in mobile ad-hoc wireless sensor networks. *10th International Conference on Advanced Communication*

Technology, Vols I-Iii **2008**, 737-741.
6. Huang, X. X.; Zhai, H. Q.; Fang, Y. G., Robust Cooperative Routing Protocol in Mobile Wireless Sensor Networks. *Ieee Transactions on Wireless Communications* **2008,** 7, (12), 5278-5285.
7. Chen, S. H.; Mitra, U.; Krishnamachari, B., Invited paper: Cooperative communication and routing over fading channels in wireless sensor networks. *2005 International Conference on Wireless Networks, Communications and Mobile Computing, Vols 1 and 2* **2005**, 1477-1482.
8. Hu, H. F.; Yang, Z., The study of power control based cooperative opportunistic routing in wireless sensor networks. *2007 International Symposium on Intelligent Signal Processing and Communication Systems, Vols 1 and 2* **2007**, 364-367.
9. Liu, L. C.; Ge, H., Space-time coding for wireless sensor networks with cooperative routing diversity. *Conference Record of the Thirty-Eighth Asilomar Conference on Signals, Systems & Computers, Vols 1 and 2* **2004**, 1271-1275.
10. Chen, Z. J.; Lin, C.; Wen, H.; Yin, H., An analytical model for evaluating IEEE 802.15.4 CSMA/CA protocol in low-rate wireless application. *21st International Conference on Advanced Networking and Applications Workshops/Symposia, Vol 2, Proceedings* **2007**, 899-904.
11. Babulal, K. S.; Tewari, R. R., Increasing connectivity using hybrid farthest intermediate cooperative cross layer design for wireless sensor networks. *National Academy Science Letters-India* **2011,** 34, (7-8), 265-273.
12. Dai, S. J.; Jing, X. R.; Li, L. M., Research and analysis on routing protocols for wireless sensor networks. *2005 International Conference on Communications, Circuits and Systems, Vols 1 and 2, Proceedings* **2005**, 407-411.
13. Dehghan, M.; Ghaderi, M.; Goeckel, D., Minimum-Energy Cooperative Routing in Wireless Networks with Channel Variations. *Ieee Transactions on Wireless Communications* **2011,** 10, (11), 3813-3823.
14. Ben Nacef, A.; Senouci, S. M.; Ghamri-Doudane, Y.; Beylot, A. L., A Combined Relay-Selection and Routing Protocol for Cooperative Wireless Sensor Networks. *2012 8th International Wireless Communications and Mobile Computing Conference (Iwcmc)* **2012**, 293-298.
15. Duy, T. T.; An, B.; Kong, H. Y., A Novel Cooperative-Aided Transmission in Multi-Hop Wireless Networks. *Ieice Transactions on Communications* **2010,** E93b, (3), 716-720.
16. Ben Nacef, A.; Senouci, S. M.; Ghamri-Doudane, Y.; Beylot, A. L., ECAR: an Energy/Channel Aware Routing Protocol For Cooperative Wireless Sensor Networks. *2011 Ieee 22nd International Symposium on Personal Indoor and Mobile Radio Communications (Pimrc)* **2011**, 964-969.
17. Fang, W. W.; Liu, F.; Yang, F. N.; Shu, L.; Nishio, S., Energy-Efficient Cooperative Communication for Data Transmission in Wireless Sensor Networks. *Ieee Transactions on Consumer Electronics* **2010,** 56, (4), 2185-2192.
18. Ben Nacef, A.; Senouci, S. M.; Ghamri-Doudane, Y.; Beylot, A. L., RBCR: a Relay-Based Cooperative Routing Protocol for Cooperative Wireless Sensor Networks. *2011 Ifip Wireless Days (Wd)* **2011**.
19. Ge, W. Y.; Zhang, J. S.; Xue, G. L., Cooperative geographic routing in wireless sensor networks. *Milcom 2006, Vols 1-7* **2006**, 1771-1777.
20. Ge, W. Y.; Zhang, J. S.; Xue, G. L., Joint clustering and optimal cooperative routing in wireless sensor networks. *2008 Ieee International Conference on Communications, Proceedings, Vols 1-13* **2008**, 2216-2220.
21. Hu, H. F.; Yang, Z., Cooperative Opportunistic Routing Protocol for Wireless Sensor Networks. *2007 International Conference on Wireless Communications, Networking and Mobile Computing, Vols 1-15* **2007**, 2551-2554.
22. Islam, M. R.; Han, Y. S., Cooperative MIMO Communication at Wireless Sensor Network: An Error Correcting Code Approach. *Sensors* **2011,** 11, (10), 9887-9903.
23. Li, B.; Wang, W. J.; Yin, Q. Y.; Zhang, D.; Yang, R.; Sun, L., Energy-efficient Cooperative Geographic Routing in Wireless Sensor Networks Utilizing Transmit Diversity and Multi-sensor Diversity. *2011 Ieee Vehicular Technology Conference (Vtc Fall)* **2011**.
24. Liang, P. Y.; Liu, X. C., CRAT: A Novel Routing Algorithm for Wireless Sensor Networks Based on Cooperative MIMO. *2010 5th International Icst Conference on Communications and Networking in China (Chinacom)* **2010**.
25. Liang, X. D.; Balasingham, I.; Leung, V. C. M., Cooperative Communications with Relay

Selection for QoS Provisioning in Wireless Sensor Networks. *Globecom 2009 - 2009 Ieee Global Telecommunications Conference, Vols 1-8* **2009**, 3229-3236.

26. Long, C. Z.; Chen, H.; Li, L. H., Energy-Efficiency Cooperative Communications with Node Selection for Wireless Sensor Networks. *Paciia: 2008 Pacific-Asia Workshop on Computational Intelligence and Industrial Application, Vols 1-3, Proceedings* **2008**, 1717-1721.
27. Patrikar, R. M.; Akojwar, S. G., Neural Network Based Classification Techniques For Wireless Sensor Network with Cooperative Routing. *Proceedings of the 12th Wseas International Conference on Communications* **2008**, 433-438.
28. Radi, M.; Dezfouli, B.; Abu Bakar, K.; Lee, M., Multipath Routing in Wireless Sensor Networks: Survey and Research Challenges. *Sensors* **2012,** 12, (1), 650-685.
29. Shastry, N.; Bhatia, J.; Adve, R. S., A theoretical analysis of cooperative diversity in wireless sensor networks. *GLOBECOM '05: IEEE Global Telecommunications Conference, Vols 1-6* **2005**, 3269-3273.
30. Sobeih, A.; Hou, J. C.; Kung, L. C.; Li, N.; Zhang, H. H.; Chen, W. P.; Tyan, H. Y.; Lim, H., J-Sim: A simulation and emulation environment for wireless sensor networks. *Ieee Wireless Communications* **2006,** 13, (4), 104-119.
31. Tolle, G.; Culler, D., Design of an application-cooperative management system for wireless sensor networks. *Proceedings of the Second European Workshop on Wireless Sensor Networks* **2005**, 121-132.
32. Yang, B. W.; Guo, J. H.; Yu, H. Y.; Zhang, D. L., Cooperative MISO-based energy efficient routing strategies for wireless sensor networks. *2007 Second International Conference in Communications and Networking in China, Vols 1 and 2* **2007**, 268-272.
33. Zamalloa, M. Z.; Seada, K.; Krishnamachari, B.; Helmy, A., Efficient geographic routing over lossy links in wireless sensor networks. *Acm Transactions on Sensor Networks* **2008,** 4, (3).
34. Zhou, Z.; Zhou, S. L.; Cui, J. H.; Cui, S. G., Energy-efficient cooperative communication based on power control and selective relay in wireless sensor networks. *2007 Ieee Military Communications Conference, Vols 1-8* **2007**, 1094-1100.
35. Zhou, Z.; Zhou, S. L.; Cui, J. H.; Cui, S. G., Energy-efficient cooperative communication based on power control and selective single-relay in wireless sensor networks. *Ieee Transactions on Wireless Communications* **2008,** 7, (8), 3066-3078.
36. Zhou, Z.; Zhou, S. L.; Cui, S. G.; Cui, J. H., Energy-Efficient Cooperative Communication in a Clustered Wireless Sensor Network. *Ieee Transactions on Vehicular Technology* **2008,** 57, (6), 3618-3628.
37. Petro, C.; Robin, D.; Wolfgang, S., Location-Based Cooperative Relaying in Wireless Sensor Networks. *IEEE Global Telecommunications Conference, 2007.* 646-651.