Energy-Balanced Routing Algorithm in Wireless Sensor Networks Using Cauchy Operator

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Abstract. Efficient and reliable routing is a critical issue in wireless sensor networks in which network availability and node lifetime involved in the course of routing design need to be deliberately considered. In this study, we propose an energy-aware routing scheme using Cauchy operator and considering the factors of node's residual energy adjacent to current transmit node along with the routing distance. Based on Cauchy inequation, we achieved the relationships between the single-hop distance and path energy consumption as well as the overall routing distance and energy usage of the whole networks. By fixing a relay selection parameter and identifying the transmission hops appropriately, we obtain the balancing energy-aware routing algorithm. Numerical results are provided to testify the lifetime and equilibrium of the network energy by compared with traditional approaches.

Keywords: Wireless sensor networks · Energy-aware · Router · Optimization

1 Introduction

Wireless sensor networks (WSNs) are event-driven network systems which have attracted sustained research interest because of their wide applications in environmental and habitat monitoring, medical diagnostics and healthcare etc. [1,2]. Due to usually employed in harsh and distant circumstances, it is envisioned that the wireless sensor nodes cannot be repowered and cared frequently, therefore the efficient usage of limited energy is clearly of great crucial to maintain the overall network's stability.

Many approaches such as multi-hop cooperative transmission, cluster management and sleep mechanism in WSNs have been deeply studied for lifetime elongation of the sensor networks [3–5]. How to design suitable strategies of energy allocation, working mode as well as node deployment for the relay transmission networks attracts lots of attention where various of technique tools, including topology, game theory and intelligent algorithms etc. [6] are applied.

X.-L. Huang (Ed.): MLICOM 2016, LNICST 183, pp. 237–246, 2017.
DOI: 10.1007/978-3-319-52730-7_24

Specifically, reference [3] reveals the shortcomings of currently evaluative standard and current cluster-based routing protocol by HEED, and proposes a clustering patch hierarchical routing protocol with the purposes of improving network coverage rate and effective network lifetime. The authors in [4] consider the problem of optimal deployment of numbers of sink nodes in a WSN for minimizing average hop distance between sensors and its nearest sink with maximizing degree of each sink node which can solve hot spot problem which is another critical issue of WSNs design. Reference [5] designs a mobile sensor node platform to achieve a highly accurate localization mechanism by using ultrasonic, dead reckoning, and radio frequency information which is processed through a particle filter algorithm. In [6], the authors propose a hub-spoke network topology that is adaptively formed according to the resources of its members. A protocol named resource oriented protocol which divides the network operation into two phases is developed to build the network topology.

The main challenges in a WSN include the energy, bandwidth constraint and complicated topology structure of the sensor nodes which triggers many innovations of software algorithms, hardware solutions and transmission protocols. One of the most important innovations of an energy efficient solution lies in the network layer of the WSNs, the routing protocol and route node finding to elongate nodes energy and network's lifetime. In this work, we mainly focus on the optimal route node searching for multi-hop relay transmission in sensor networks in light of the energy-balancing-aware of the whole system. In the course of searching next optimal relay node, a dynamic route rather than static route need to be figured out ceaselessly so as to avoid the paralysis of the hot transmit path with the results of the interrupt of overall networks. With the development of various applications of WSNs, new routing approaches are attracting plenty of attention in recent years [7–9]. In [7], the authors propose a routing algorithm which intends for WSNs that needs a period and event-driven approach and can adapt to the situation the sensor faces. Reference [8] develops a routing solution off-network control processing that achieves control scalability in large sensor networks by shifting certain amount of routing functions to an off-network server. A tiered routing approach, consisting of coarse grain server based global routing, and distributed fine grain local routing is designed for achieving scalability by avoiding network wide control message dissemination. In [9], the authors propose an energy-aware trust derivation scheme using game theoretic approach, which manages overhead while maintaining adequate security of WSNs. A risk strategy model is first presented to stimulate WSNs node's cooperation.

In this paper, we propose a dynamic routing algorithm for WSNs to elongate network lifetime by searching optimal relay node uninterruptedly and balancing energy consumption over whole networks. To extend the survival cycle of wireless sensor nodes and avoid network paralysis due to regional usage overheating, source sensor nodes need to select different transmission paths according to node's residual energy and holistic energy consumption in whole route. In every single cycle, the source node is supposed to start data transmission after sending detecting signal package to acknowledge the transmit route. Based on Cauchy

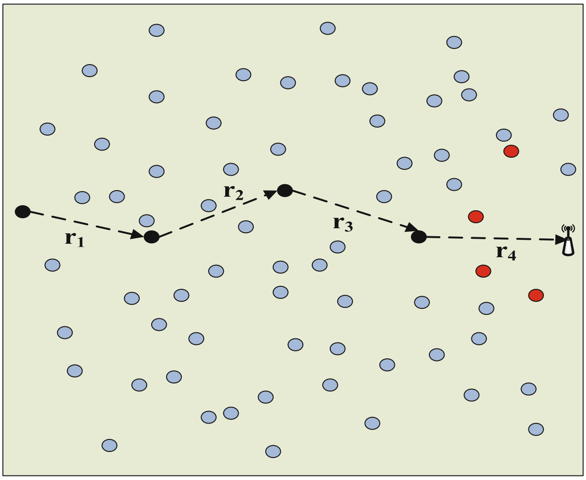

Fig. 1. Multi-hop relay transmission in WSNs

operator, we design a relay selection parameter to ascertain the next transmit node dynamically. Since the transmit tasks require multiple hops rather than single hop, we pursue to find the optimal routing by taking the expenditure of transmit energy on the whole router into account rather than only next hop. In order to evaluate the network performance and energy consumption effects, we perform several simulated network tests to testify the consumption of node's energy and the number of the death node. A uniform distribution mapping of residual network energy along with relative few death nodes are achieved. Also, comparison experiments are also performed to evaluate the performance of our proposed algorithm.

2 System Model

In this paper, we consider a model of WSNs where numbers of wireless sensor nodes and a fusion center locate in the networks as shown in Fig. 1. Because of wide distribution area and limited battery capacity within the sensor nodes, multi-hop relay transmission should be frequently applied. Relay communication was originally encountered in bent-pipe satellites where the primary function of the spacecraft is to relay the uplink carrier into a downlink [10]. In general, relay cooperative transmission can benefit sensor transmitter in terms of power saving, degressive outage probability and improved system capacity. We further assume the relay node works in regenerative mode, and suppose the distribution of the sensor nodes is relatively static and the channel conditions are changing not much over time.

The energy consumption of transmit sensor node mainly depends on the transmit distance, thus we can consider the following equation

$$E = \kappa d^n \tag{1}$$

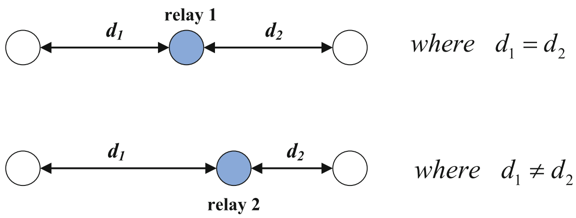

Fig. 2. Relay transmission models

where E is the energy consumption, κ is constant coefficient and d denotes the distance between the transmit couples in WSN. Furthermore, n is power coefficient locating at $[2, 4]$, and we can choose $n = 2$ in following deductions.

We consider two kinds of relay transmission models as shown in Fig. 2. Suppose a source sensor needs to select a relay station to finish its signal transmission as shown in Fig. 2. In the first case, the relay station locates at the middle position between the source and the destination nodes. According to (1), we can obtain the energy consumption as

$$E = \kappa(d_1^2 + d_2^2) \tag{2}$$

As there is $a^2 + b^2 \geq \frac{(a+b)^2}{2} = \frac{m^2}{2}$, and the equation holds only when $a = b = \frac{m}{2}$, thus we have

$$E_1 = 2\kappa d_1^2 < E_2 = \kappa(d_1^2 + d_2^2) \tag{3}$$

In WSNs, it always requires multiple hops to finish the signal transmission through source node to sensor fusion. Then, the total energy consumption over the multi-hop relay transmission can be expressed as

$$E = \sum_{j=1}^{n} \kappa d_i^2 \tag{4}$$

Then the optimization objective function can be given as

$$min \sum_{j=1}^{n} \kappa d_i^2 \tag{5}$$

Also, according to Cauchy inequation, there is

$$\sum_{i=1}^{n} a_i^2 \sum_{i=1}^{n} b_i^2 \geq \{\sum_{i=1}^{n} a_i b_i\}^2 \tag{6}$$

Let $b_i = 1$, we have

$$(a_1^2 + a_2^2 + \cdots + a_n^2) \geq \frac{1}{n}(a_1 + a_2 + \cdots + a_n)^2 = \frac{C^2}{n} \tag{7}$$

where $a_1 + a_2 + \cdots + a_n = C$, and the equation holds if and only if $a_1 = a_2 = \cdots = a_n = \frac{C}{n}$. It means the entire energy consumption can be minimal when every relay distance is equal in condition of fixed total route length. In real monitoring environment, the distribution of wireless sensor nodes is usually random, and the distance between source node and sensor fusion is inconstant. Whereas, we can control the distances of every hop to make every d_i similar or even equal. In condition of same SINR communication effects, shorter transmission distance brings evident energy benefits. Therefore, we can decrease the total energy consumption by suitably choose the senor node in every hop.

In this study, we want to investigate the optimal relay selection of every single hop in precondition of settled total router length. According to the analyses above, we can obtain that the energy consumption of whole sensor networks will be optimized and the network lifetime can be prolonged by carefully control the distance between adjacent relay hops when the router length is fixed. Furthermore, we need to balance the energy usage overall the networks by preferring the node with more residual energy. Hence, we consider the following equation as our proposed method of relay selection

$$\begin{aligned} &\gamma_i = S(i).E - \frac{A\{d(i-1,i) - d(i-2,i-1)\}}{\log_2(r+1)} \\ &\textit{where } r \geq 1, S(i).E \geq 0, i \geq 2 \end{aligned} \tag{8}$$

where $S(i).E$ denotes the residual energy of the next hop, γ_0 means the source node station, $d(i,j)$ is the distance between relay i and relay j, A is a correlation coefficient and r is the cycle number which also means the data transmit times. In this relay selection strategy, a sensor node will be chosen in priority of more usable energy. Besides, we can receive a rational energy efficiency when the transmit length of every hop approaches to the previous hop. When $i = 1$ which means the source node is looking for the first relay, the objective function returns to be $\gamma_i = S(i).E$. On the other hand, when the monitoring sensor networks have carried out many rounds of signal transmission, it can be concluded the available energy within the wireless sensor nodes will be very limited. Hence, we introduce a parameter denoted as the cycle number which means the emphasis of the relay selection will be put on current residual energy. We set the parameter on denominator to balance the impacts of residual energy and relay distance. With the increase of transmit times, the available energy $S(i).E$ becomes smaller and the distribution of node's energy overall the networks gets proportional. We add a parameter on the latter section to balance the effects between the two parts. Besides, we need to confirm every new hop is closer to the fusion center. Otherwise, the relay transmission gets meaningless. Also, when no available sensor node can meet the selection conditions, the parameter $d(i,j)$ which denotes the searching coverage will be increased. The thresholds of searching distance and residual energy are further settled to guarantee the rationality of the proposed algorithm. The diagram of this routing method is shown as Fig. 3.

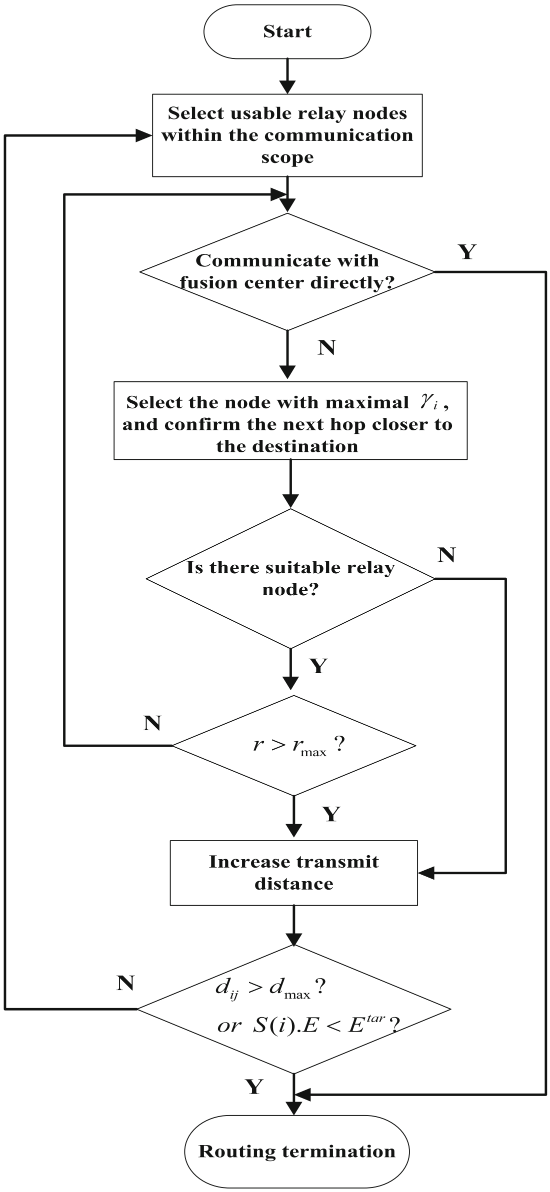

Fig. 3. Flowchart of our routing algorithm

3 Simulation Results and Performance Evaluation

In this section, we evaluate the performances of our proposed balancing energy-aware routing algorithm in Matlab simulation platform. As shown in Fig. 4, we randomly generate wireless sensor topologies with size $500 \times 500\,m^2$, and node's initial energy is randomly settled with maximum $1500\,J$. Initial transmission distance is 60 m, and the communication range can be suitably increased when there is no available node within the initial distance. We ignore the effects from other cells, and suppose the usable bands is enough.

In the set of simulations, 360 sensor nodes randomly locate in the networks as shown in Fig. 4. The QoS threshold of every relay hop is identical. Sensor nodes select next hop according to Eq. (8). The energy consumption in every single transmission is identified by (1) where we set $\kappa = 2$. Here, we suppose the maximal transmit-distance of sensor node to be 140 m [11]. If the current sensor node cannot find suitable hop with enough energy within the scope, the routing will be terminated. Also, the number of death nodes is upgrading with the increase of the transmit-cycle, and we set a minimal threshold of active sensor nodes which is 3% total node's quantity.

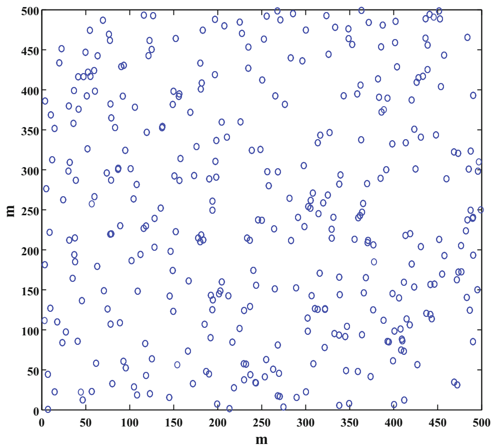

Fig. 4. User distribution in WSNs

As shown from Figs. 5, 6 and 7, we give the performance of node's residual energy. In Fig. 5, an initial energy distribution is presented. Due to random distribution of node's residual energy, we can obtain from the figure that the usable energy of every node is asymmetric, therefore the source node should carefully select the router to balance network energy according to our proposal. In this test, we fix the initial source node at the coordinate (0,250) and the fusion center at (500,250). In the following tests, we also evaluate the performance in variant source nodes. In Fig. 6, the energy distribution of all the sensor nodes at 400 transmission cycles is shown. In fact, the sensor node in this WSNs does not know the residual energy of its adjacent nodes. It needs to send detecting signal to acquire the energy information of the other nodes within the transmit-scope firstly. In our proposed method, more residual energy node will likely be chosen so that the energy distribution in this network becomes smooth over time. Furthermore, in Fig. 7, after 2000 transmission cycles, the energy figure gets flat except for several heaves in four corners where the sensor nodes are very distant to the fusion center which will lead to a selection discarding as a result. In the routing algorithm, we suppose the next hop must be closer than the prior one, so very isolated sensor nodes will not often be selected to assist the cooperative transmission.

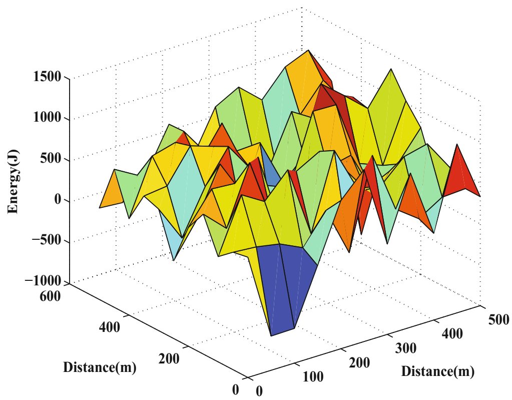

Fig. 5. Residual energy of sensor nodes in initial status

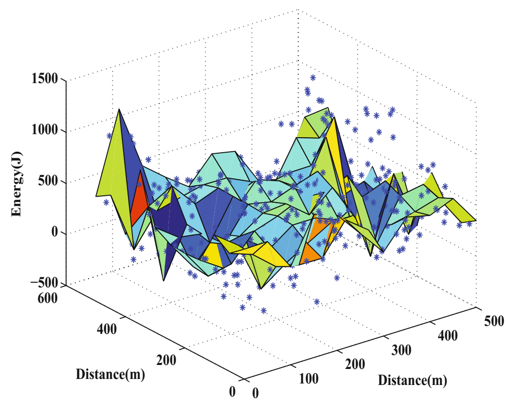

Fig. 6. Residual energy of sensor nodes with 400 transmission cycles

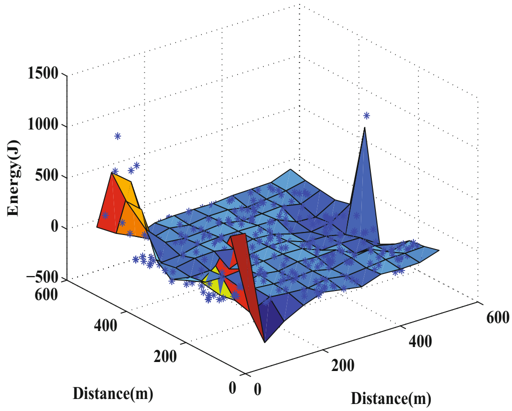

Fig. 7. Residual energy of sensor nodes with 2000 transmission cycles

4 Conclusion

In this paper, we develop a balancing energy-aware routing algorithm for WSNs. In pursuing the goal of energy consumption minimum, we take care of energy equilibrium over the networks. According to Cauchy operator, we achieve the energy equation by investigating the distances between every relay hop. In given total router length, minimal energy consumption can be attained in condition of equal hop length. Furthermore, a corresponding routing program is provided to testify our proposal. In the progress, we identify the routing nodes by considering the node's residual energy as well as the distance compared with prior hop. Numerical results show the algorithm's equilibrium is rational, and the energy efficiency is evaluated by a comparison tests.

Acknowledgment. This work was supported by the National Natural Science Foundation of China (No. 51404211) and Natural Science Foundation of Zhejiang Province (No. LY14F010009 and LQ14H180001) along with Foundation of Zhejiang Educational Committee (No. Y201431820), Zhejiang Open Foundation of the Most Important Subjects (No. 20150705) and the Fundamental Research Funds for the Central Universities under Grant No. DUT16RC(3)045.

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