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Energy-balanced Distance-based Routing Algorithm in Wireless Sensor Networks

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Abstract. In routing process, individual distance is regarded as the primary parameter in order to adjust the energy consumption. In this paper, we build a time and distance-based system model, and effectively design route setup and route maintenance phase. An Energy-balanced Distance-based Routing Algorithm (EDRA) is put forward to maximize network lifetime. Simulation results demonstrate that the EDRA effectively prolongs the network lifetime and reduces the energy consumption than other routing algorithms.

Introduction

A Wireless Sensor Network (WSN) is composed of a collection of wireless nodes that are designed to monitor, store and report phenomena, usually with minimal human interaction [1]. Since the sensor nodes are powered with limited battery and they can not be easily re-charged once deployed, the energy consuming operations must be kept at a minimum [2-3]. Hotspot problem is caused by the unbalanced energy consumption among the sensors.

In order to effectively alleviate the hotspot problem, we need to balance energy consumption among all sensors by considering factors like traffic pattern, transmission manner, Distance and hop number etc. Since the radio transceiver typically consumes more energy than any other hardware component onboard a sensor node, design of energy optimized routing algorithms is of great importance to prolong network lifetime.

Routing protocols can be divided into three classes based on the structure of the network organization [4]: flat, hierarchical; and location based. Among flat routing protocols, SPIN [5] can be viewed as the first data-centric routing protocol which utilizes the data negotiation method among sensor nodes to reduce data redundancy and save energy. In hierarchical routing protocols, Low-Energy Adaptive Clustering Hierarchy (LEACH) [6] is based on an aggregation technique that combines or aggregates the original data into a smaller size of data. Location-based routing protocols [7-8] can get location information through global positioning system (GPS) devices or certain estimation algorithms based on received signal strength (RSS).

Through analysis of energy consumption for data transmission, according to existing problems of energy optimized routing, and considering efficiency and balance of energy consumption of nodes, complexity of implementation, different network architectures and application requirements, we study on the routing algorithms and related issues for WSN. The main objective in this paper is to overcome the hotspot problem and prolong network lifetime and through an energy-balanced distance-based balancing routing algorithm.

System Model and Problem analysis

Network Model and Energy Model

Suppose a WSN is a hybrid network with a BS having additional processing power and n remote sensor nodes deployed in an $L_x \times L_y$ monitoring area. There are m points of interest in the monitoring area. The location of the sensor node is assumed to be known a priori. Thus, the network is represented by the Euclidean graph G, and $G = (V, E)$ [9]. V is a set of nodes in the network and $V = \{S, BS\}$, where S is a set of sensor nodes with a circular sensing range r_s and $S = \{s_1, s_2, \ldots, s_n\}$, BS is the base station, and n is the number of sensor nodes.

Each sensor node will consume the following E_{Tx} amount of energy to transmit a k-bits message over distance d:

$$E_{Tx}(k,d) = \begin{cases} k \cdot E_{elec} + k \cdot \varepsilon_{fs} \cdot d^2, & d < d_0 \\ k \cdot E_{elec} + k \cdot \varepsilon_{mp} \cdot d^4, & d \geq d_0 \end{cases} \quad (1)$$

On the receiver side, the consumed energy to receive one bit of data is as (2):

$$E_{Rx}(k) = k \cdot E_{elec} \quad (2)$$

and E_{Fx} amount of energy to forward this message:

$$E_{Fx}(k,d) = E_{Tx}(k,d) + E_{Rx}(k) = \begin{cases} 2k \cdot E_{elec} + k \cdot \varepsilon_{fs} \cdot d^2, & d < d_0 \\ 2k \cdot E_{elec} + k \cdot \varepsilon_{mp} \cdot d^4, & d \geq d_0 \end{cases} \quad (3)$$

The transmitting power and receiving power are defined as equation (4) respectively [10].

$$P_t = E_{elec} + \varepsilon_{fs} \cdot d^2, \; P_r = P_t \lambda^2 / ((4\pi)^2 d^2) \quad (4)$$

Where λ is the wavelength. When a node receives signal with transmission power P_t and received power P_r, the distance between transmit and receive node is $d = (\lambda / 4\pi)\sqrt{P_t / P_r}$.

Time and Distance-based System Model

Under time-based traffic model, each node will take turn to transmit its data to sink node. Therefore, the key difference between time-based and event/query-based traffic model is the packet length. If we use the same methodology to let $d_1 = d_2 = \ldots = d_n = d/n$, node n will become hotspot node and die quickly since it has more traffic burden to forward. On the other hand, node 1 will have much residual energy when node n dies, which is not desirable. Thus, the objective we have here is to let $E_1 = E_2 = E_3 \cdots = E_n$ in order to maximize network lifetime.

Since node i will transmit its own k-bits data for once and forward the traffic for $(i-1)$ times after all nodes take turn to transmit their data to sink node. The energy consumption for node i is:

$$E_i = k \cdot (E_{elec} + \varepsilon_{amp} \cdot d_i^{\alpha}) + k \cdot (i-1)(2E_{elec} + \varepsilon_{amp} \cdot d_i^{\alpha}) = k \cdot (2i-1)E_{elec} + k \cdot i \cdot \varepsilon_{amp} \cdot d_i^{\alpha} \quad (5)$$

Let $E_i = E_{i+1}$, we can finally get:

$$d_{i+1} = \sqrt[\alpha]{\frac{-2E_{elec} + i\varepsilon_{amp} d_i^{\alpha}}{\varepsilon_{amp}(i+1)}} = \sqrt[\alpha]{\frac{-2iE_{elec} + \varepsilon_{amp} d_1^{\alpha}}{\varepsilon_{amp}(i+1)}} \quad (6)$$

Since $d_n > 0$, namely $\frac{-2(n-1)E_{elec} + \varepsilon_{amp} d_1^{\alpha}}{\varepsilon_{amp} n} > 0$, it must satisfy:

$$n < \frac{\varepsilon_{amp} d_1^{\alpha}}{2E_{elec}} + 1 \quad \text{or} \quad d_1 > \sqrt[\alpha]{\frac{2(n-1)E_{elec}}{\varepsilon_{amp}}} \quad (7)$$

Through formula (7), we can get the corresponding lower bound distance d_1 when hop number $n = [2:9]$ Given the multi-hop number n, we provide the lower bound distance value d_1 as well as the minimal source to sink node distance $d = \sum d_i$.

Energy-balanced Distance-based Routing Algorithm

In EDRA, each sensor node has two tables. One is the routing table, and the other is the neighboring table. Thus, each node can make intelligent decision of the next hop based on EDRA and the algorithm is easy to implement for practical engineering applications. Through the source to sink node Distance and hardware parameters, we can get energy-balanced route with the optimal multi-hop number and prolong network lifetime.

Flow Chart of EDRA

The flow chart of EDRA is composed of two phases. One is the route setup phase, and the other is the route maintenance phase.

On the condition that the source node has data to be transmitted to the BS, it will first determine the transmission manner.A route request (RREQ) message is sent to that specific next hop neighbor with its own location information inside RREQ. Once the next hop node receives the RREQ message, it will send back an acknowledgement (ACK) message to confirm the reception of RREQ message. Afterwards, the next hop node will continue to find its own next hop neighbor in an iterative way until the RREQ message finally reaches BS. At last, a route reply (RREP) message is sent back by BS to the source node along the reverse route.

If the ACK message is not achieved within certain time, a link failure is detected. Then a local repair process will first be initiated. If the node can find an alternative next hop node, it will determine its next hop in a similar way like above. Or else, it will notify all the involved nodes about the failure of this link by sending a route error (RERR) message. This broken link will be deleted by all involved nodes from their routing table and neighboring table and they will avoid using this link later on. Finally, the source node will restart the route setup phase.

Route Setup Phase

Given that source node has data to send, it will try to set up a route from source to sink node as follows. First, it determines the transmission manner by comparing the source to sink node distance d and $d_i(n=2)=100$, as is explained above. It is worth mentioning that we might choose direct transmission when $d \geq 100+\Delta$ under real network environment. For example, when $d=120$, it is very difficult to find 2-hop route with $d_1=100$ and $d_2=20$ so that $E_1=E_2$ under random network topology. The value of Δ is dependant on network density and we set $\Delta \in [20,50]$ in this paper under different network topologies.

As a result, the final next hop node j is chosen after the following 3 steps. First, we choose a set of candidates with $d(i,j) \in (d_i, d_i+\Delta)$ based on the analysis in Eq. (6). Then, some of the candidates whose distance to BS is less than the current node i to BS are chosen based on greedy routing mechanism, namely $d_{j,BS} < d_{i,BS}$. Among them, we will choose half of them whose distance to BS is smaller than the other half. Finally, the one with the largest residual energy is chosen as the next hop.

In case source node gets RREP message with complete route information from sink node, the traffic can get started. After the traffic session is closed, each node on the route will update its routing table as well as neighboring table.

Route Maintenance Phase

Link failure will be detected and route maintenance phase will be initiated if an ACK message is not received for certain TTL (time-to-live) time. Link failure is usually caused by reasons like node dies out of power, interference etc.

On the condition that the source node detects a link failure, it will restart the route setup phase by choosing another next hop in a similar way above. If an intermediate node detects a link failure, it will first attempt a local link repair process. In other words, the intermediate node will first try to choose another proper neighbor in order to fix the route to BS. In this way, the end to end latency can get reduced and the energy consumption as well as overhead can be reduced. This local repair process will last for certain time until an ACK message is received or when TTL is expired.

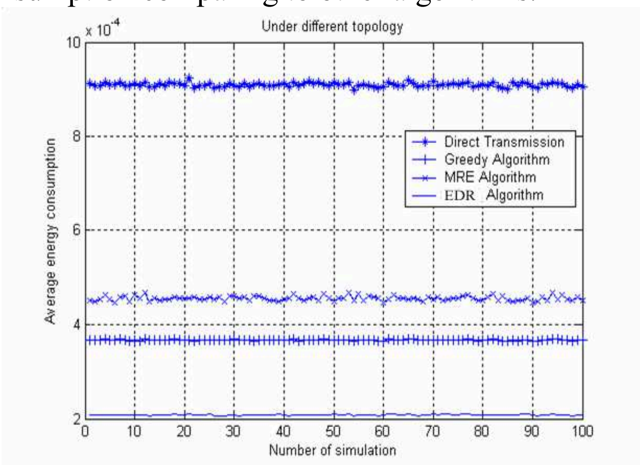
Provided that the local link repair process fails, a RERR message will be sent from intermediate node to source node in a reverse way based on the information stored in RREQ. Finally, this route will be deleted from source node and intermediate nodes and a new route setup phase will be initiated.

Performance Analysis and Results

There are 500 sensor nodes randomly deployed in a $400 \times 400\, m^2$ area WSN with BS placed in the middle of the area. The maximal transmission radius is 150 meters. The initial energy of each node is 5-10*J*. Each node takes turn to transmit a message compose 2500 bits to BS using either direct transmission or multi-hop transmission based on different routing algorithms.

In NS 2.34 in Linux (FEDORA 16 version), we compare our EDRA with the following three popular routing algorithms which are direct transmission, greedy and maximal residual energy (MRE) algorithms.

We can conclude from Figure 1 that direct transmission algorithm consumes the largest amount of energy since the average source to sink node distance is relatively long and multi-path model is used here. EDRA consumes the least energy due to it distance-based nature. The performance of greedy and MRE algorithm is in the middle under 100 simulations. From here we can see that EDRA can not only balance energy consumption for all sensor nodes but also reduce energy consumption comparing to other algorithms.



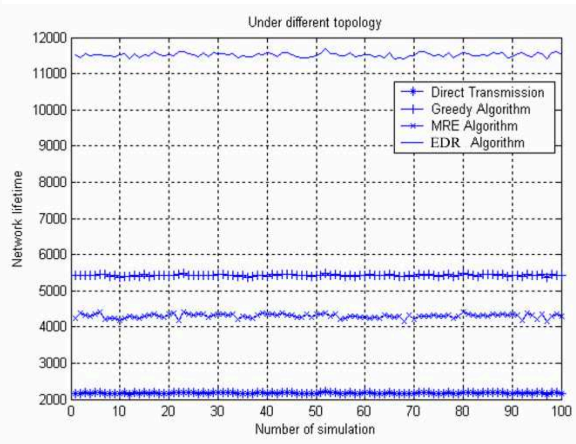


Fig. 1 Average energy consumption Fig. 2 Network lifetime

Figure 2 tells network lifetime under the same network environment. Here, network lifetime is defined as the time when the first node dies out of energy since this might cause network partition or isolated area quickly afterwards.

As shown in Figure 2, direct transmission has the shortest lifetime under large scale network or when the average source to sink node distance is large. Under that network context, multi-hop transmission is more preferred than direct transmission. For MRE algorithm, the node chooses its next hop based on the remaining energy which is irrelevant to the distance distribution. Therefore, the final multi-hop route might has too many short hop number which consumes more average energy, as is shown in previous Figure 1. For greedy routing algorithm, each node will prefer to choose its next hop with distance close to *R* in order to make greediest progress toward the sink node. Thus, more energy consumption is caused with relatively short network lifetime. Again we can see the EDRA has the longest network lifetime due to its energy efficient and balancing nature.

Results Discussion

Given the source to sink node distance and the hardware parameter values, we can determine the transmission manner, the optimal multi-hop number as well as the corresponding individual distances. The key difference between EDRA and other energy efficient routing algorithms is that we try to let each node consume the energy at similar rate rather than to minimize the total energy consumption during each routing process.

The selection criterion of the next hop node is the essential problem in the process of routing. In this paper, we treat the distance metric as the primary parameter and we also consider node residual energy as the secondary parameter. Thus, the energy consumption can get well balanced based on the distance and residual energy distribution. From this paper, we can see that EDRA is a distributed, localized, energy efficient and balancing algorithm which can be easily used in real applications.

The demerit of the EDRA is the requirement of source to sink node distance, which can be obtained through GPS devices, certain localization or positioning techniques with additional computing and communication overhead. Also, EDRA is not usable under sparse network environment or when there are obstacles between the neighboring nodes. In both cases, the next hop node based on our EDRA might not be found.

Conclusions

To efficiently decrease and balance the energy consumption in WSNs, we proposed an Energy-balanced Distance-based Algorithm (EDRA) based on theoretical analysis and numerical illustration under different energy and traffic models. Given the source to sink node distance, the optimal multi-hop number in addition to the related individual distance can be determined in order that all sensor nodes can consume their energy at similar rate. During routing process, we consider distance distribution as the first parameter and the residual energy as the secondary parameter. The final results indicate that EDRA can guarantee better energy efficiency and energy equilibrium performance compared with other popular multi-hop routing algorithms.

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References

[1] E. Lattanzi, E. Regini, A. Acquaviva, and A. Bogliolo, Energetic sustainability of routing algorithms for energy-harvesting wireless sensor networks, Comput. Commun., vol. 30, no. 14-15, pp. 2976-2986, 2007.

[2] XL. Wang, LY. Li, Research of an Adaptive Aggregation Routing Algorithm in Wireless Sensor Networks, Journal of Networks, vol. 7, pp. 1071-1077, Jul 2012.

[3] S. Mahfoudh and P. Minet, Survey of Energy Efficient Strategies in Wireless Ad Hoc and Sensor Networks, in Seventh Intl. Conf. on Networking, pp. 1-7, 2011.

[4] S. Sarangi and S. Kar, Mobility aware routing with partial route preservation in wireless sensor networks, Ubiquitous Computing and Communication Journal, vol. 6, no. 2, pp. 848-856, 2011.

[5] J. Kulik, W.R. Heinzelman, H. Balakrishnan, Negotiation-based Protocols for Disseminating Information in Wireless Sensor Networks, ACM/IEEE Int. Conf. on Mobile Computing and Networking (MobiCom'99), Seattle, Washington, USA, 1999; pp. 169-185.

[6] W. Heinzelman, A. Chandrakasan, H. Balakrishnan, Energy-efficient Communication Protocol for Wireless Microsensor Networks, Hawaii International Conference System Sciences, pp. 1-10, 2000.

[7] J. N. Al-Karaki, A. E. Kamal, Routing Techniques in Wireless Sensor Networks, IEEE Wireless Communications, vol. 11, pp. 6-28, 2004.

[8] C. Ma and Y. Yang, Battery-aware routing for streaming data transmissions in wireless sensor networks, Mob. Netw., vol. 11, no. 5, pp. 757-767, Appl. 2006.

[9] A. Bari, S. Wazed, and A. Jaekel, A genetic algorithm based approach for energy efficient routing in two-tiered sensor networks, Ad Hoc Networks, vol. 7, no. 4, pp. 665-676, 2011.

[10] R. Langar, N. Bouabdallah, and R. Boutaba, Mobility-aware clustering algorithms with interference constraints in wireless mesh networks, Computer Networks, vol. 53, no. 1, pp. 25-44, 2009.

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