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Routing algorithm for relay node selection in wireless sensor networks

Wireless Sensor Networks is a network system which is composed of one or more sinks and many sensor nodes in generally. The process of wireless communication exists path loss in the wireless channel, which can be affected by the distance between receiver and transmitter, the operating frequency or the other factors. It is especially vital for choosing the optimal relay nodes in the case of energy limitation. To emphasize the energy optimally, a method of relay nodes selection based on the energy model is proposed which is considering the effective data transmission and the energy consumption. Theoretical analysis and experiments show that the energy consumption of the next hop relay nodes is smaller.

Keywords: Wireless sensor networks, routing algorithm, energy consumption, relay nodes.

1.0 Introduction

Wireless Sensor Network is a network system which is composed of one or more sinks or base-stations and several sensor nodes in generally. In the sensor area, nodes may transmit data to the sink or base station directly which is called single-hop, or go through multiple relay nodes which is called multi-hops as shown in Fig.1. In the process of wireless communication, the signal strength in the wireless channel will gradually decay due to the increase of distance. In other word, there is the path loss in the wireless channel, which can be affected by the distance between receiver and transmitter, the operating frequency or the other factors [1].

Research on data routing strategies for wireless sensor networks has focused on energy-efficiency. Batteries are the most prevalent powering method for most wireless sensor nodes, because they are a cost effective, ubiquitous, commonly known, and well understood powering technology. However, they present several specific challenges which include finite useful life, replacement cost, and disposal concerns. So how to select the relay nodes is particularly important when the energy is limited. In the recent years, ambient energy harvesting as a power solution

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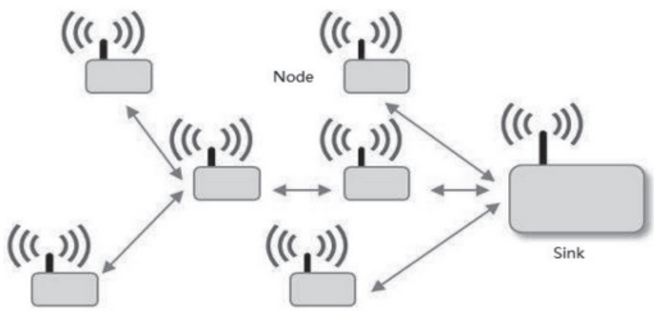

Fig.1: Multi-hops sensor network

has steadily gained momentum, especially with significant progress in the functionality of low power embedded electronics such as wireless sensor nodes. We define an energy harvesting node as any system that draws part or all of its energy from the environment such as solar energy, temperature variations, kinetic energy or vibrations. The energy-aware routing schemes proposed in recent years are not localized, not scalable. They rely on the dissemination of route discovery information and routing tables. Networks lifetime cannot be considered. They rely on beacons for dynamic networks changes [2-4]. To address these limitations, we need to investigate and propose energy-aware routing schemes that result in increased energy-efficiency, reliability, scalability, and network lifetime.

2. Related works

The type of data transmission in wireless sensor networks is roughly divided into three transmission models:

(1) Data-based method [5]. The sink sends a request (query) message, and then the request is distributed by nodes in the networks, each node will check whether the data itself is complied with the request, when it is, the node will send the data to the sink. In the process of diffusion, each packet will record the path which it has travelled. Because of the broadcast mode, it is easy to cause the network congestion and the transmission delay.

(2) Hierarchical method [6]. Nodes can be divided into several layers which there are one or several clusters, each cluster selects a Cluster-Header (CH) who is responsible for collecting their own data and then reunification to sink

which can avoid the large amounts of data and the unnecessary energy consumption in the network. The typical method is Low-energy Adaptive Clustering Hierarchy (LEACH) which has two stages: set up and steady-state (steady). During the setting stage, each node generates a random number (between 0 and 1) firstly, the node will become CH if the value of the node is less than the critical value in this round. When the CH is selected, it will broadcast to the non-CH nodes and determine who is the CH of this node according to the strength of the signal, and finally it will allocate the time when each node can transmit which is called TDMA scheduling strategy. During the steady-state, CH is responsible for collecting data of peripheral nodes and transferring data to sink. After a period of time, CH returns to the setting stage and goes round and round.

(3) Position-based method [7]. The position of the node is represented by coordinates, which can be used to calculate the distance to the neighbour for evaluating the energy consumption of passing the data. There is no need to maintain large topology information, just need the One-Hop neighbour information, select a neighbour who has a better energy consumption can reduce the excess energy consumption and delay the life cycle of the network. Energy-efficient beaconless geographic routing with energy supply (EBGERS) aims to minimize the total energy consumed while delivering each packet to the sink. In EBGRES energy-harvesting at the nodes offers more residual energy for the transmission of data packets. By sending a data packet first (DATA), EBGRES performs the neighbour selection using greedy forwarding only among those neighbors that successfully received the data packet that fall in the relay search region. EBGRES uses a three-way (DATA/ACK/SELECT) handshake and a timer-assignment contention mechanism, the discrete dynamic forwarding delay (DDFD), which was proposed for selecting and confirming the next forwarding node within the relay search region. DDFD divides the neighbour area into subareas according to the progress of the packet towards the destination and this enables the delay timer for receiving the ACK messages at the source.

The nodes that are selected for forwarding the data will also make forwarding decisions based on the available energy (from energy harvesting) and duty cycle updates to increase the network lifetime and workload. The protocol maintains a high minimum residual energy on the node and achieves a better load balance in the case of less standard deviation of residual energy between nodes.

In this paper, we present a relay node selection method based on energy model which is used the advantages of location and the characteristics of the distance of energy consumption model to evaluate the energy efficiency of all the neighbors for choosing a batter relay node.

3.0 Energy model-based relay node selection (EMBRNS)

3.1 Energy consumption model

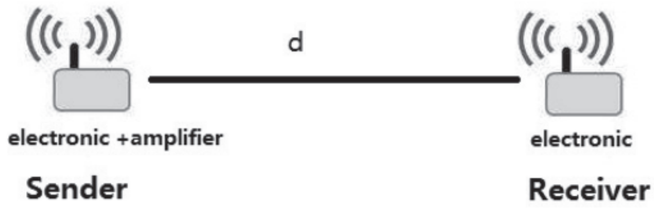

Fig.2: Data transmission model

As the Fig.2 shows, the left on the diagram is the sender and the right is the receiver, the sender through an electronic component, special amplifier and the antenna to transmit the data to the receiver with an electronic component which is used to receive data [8]. While transmitting the data, the energy consumption of sender is as follows:

$$E_s(n) = E_e \times n + E_a \times n \times d^k \quad \text{... (1)}$$

Where E_e and E_a are the energy consumption of components and amplifiers, n is the amount of data (bit), d is the linear distance between transmitter end and receiver end, and k is the path loss index. The receiver simply uses the component which receives the data, and the energy consumption is:

$$E_r(n) = E_e \times n \quad \text{... (2)}$$

The total energy consumption:

$$E_t(n) = 2 \times E_e \times n + E_a \times n \times d^k \quad \text{... (3)}$$

Assume a monitoring environment without obstacles, there is a source of p, many relay nodes and the sink. If all nodes at every optimal location, it can make the overall energy consumption to a minimum value if the distance is always d_0 in every transmission.

$$d_0 = \sqrt[k]{\frac{2E_e}{E_a(k-1)}} \quad \text{... (4)}$$

So that, according to the energy consumption model, the minimum energy consumption of 1-bit data per transmission can be calculated according to formula (3) and (4):

$$E_t(d_0, 1) = 2 \times E_e \times 1 + E_a \times 1 \times d_0{}^k = \frac{2E_e k}{k-1} \quad \text{... (5)}$$

If the linear distance between u and sink is D, then it needs D/d_0 times to transmit the distance of D, so that the overall energy consumption of transmitting 1-bit data can be calculated as:

$$E_t(D, 1) = \frac{2E_e k}{k-1} \times \frac{D}{d_0} - E_e \quad \text{... (6)}$$

Although it is the most energy saving for each transfer to the best location, there is no guarantee of a node in the optimal location, so we propose a method to select the relay node.

3.2 Optimal node selection

The greedy mode will set a search range when selecting the relay node. We try to not limit the range, in other word, all the neighbours within the communication range of p can be the relay node, selecting from these neighbours for the best location of the node as a relay node.

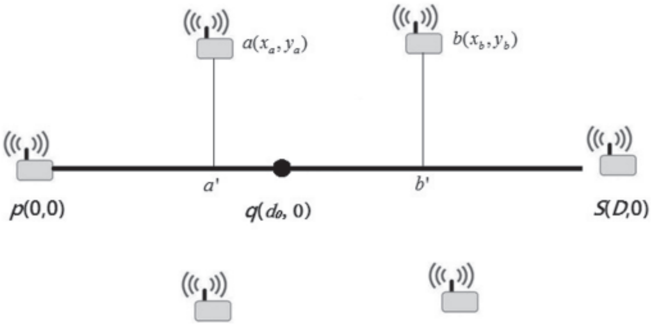

Fig.3: Transmission model diagram

There is an unobstructed flat space where we assume that each node is equipped with the same antenna, and the nodes in the monitoring range have been set up (for full coverage). There is a source of p and sink node s, drawing an arc with p as the center of the circle, with the best distance d_0 as radius and the arc is intersecting with ps at q which can be the dividing line where we can find a node a and b in its left and right. As it is shown in the Fig.3. p is the origin and the coordinates of a, b and q are respectively. a' and b' are the vertical mapping points of a and b in line $ps.a'$ or b' is closer q to the energy consumption is optimal. Suppose that on the right hand side you can find a point b who is closest, the increased energy consumption of relative optimal location q is:

$$E_+(b) = \frac{2E_e + E_a\,|pb|^k}{|pb|\cos\angle bps} \quad \text{... (7)}$$

Suppose that we can find the nearest point a on the right side, and the reduced energy consumption of relative optimal location of q is:

$$E\_(a) = \frac{2E_e + E_a\,|pa|^k}{|pa|\cos\angle aps} \quad \text{... (8)}$$

Transmission distance is positively correlated with energy consumption, the farther away the transmission is, the greater the energy consumption is, and however, if the energy consumption is small, the transmission distance will be close. Therefore, we stipulate that the point is a if $E_+(b)>E\_(a)$ and the other case is b.

Give an example to illustrate the method. If p is the origin of plane coordinates, the coordinate of s is (100, 0) and there are two points of a and b, whose coordinates are (21, 13) and (42, 3). Assuming that, E_e=50*nJ/bit*, E_a=100*pJ /bit/m*^{2} and k=2, so that the coordinate of d_0 is (31, 0). If we find the relay candidate a and b on both side respectively. The calculation results are $E\_(a)$=7.67*nJ* and $E_+(b)$=6.6*nJ* according to the formula (7) and (8). Therefore, node b will be a better relay node in this transmission, and it can be seen from the calculation that the energy required for path p to s through a is 902*nJ*, path p to s through b is 714.6*nJ*.

3.3 The optimization of the selection method of node

A node closest to q is selected as a relay node, and we have to consider whether there are multiple nodes whose distances to q are the same. As shown in Fig.4, assuming the node p, s and q their coordinates are $(-d_0, 0)$, (D, 0) and (0, 0).

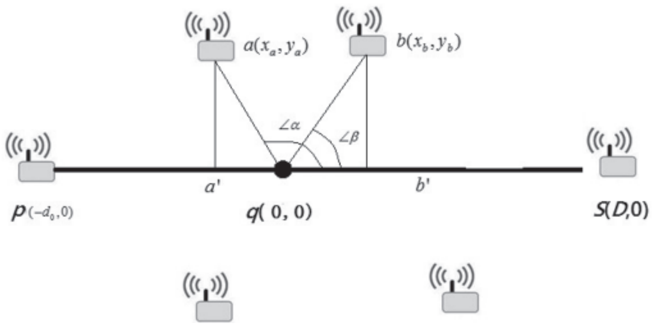

Fig.4. Transmission optimization diagram

$|aq|=|bq|=r$ means that a and b have the same distance to q. Which node should be selected as the relay node? The coordinates of a and b are and (r cos α, r sin α) and (r cos α, r sin β) and (r cos β, r sin β), and $r<d_0$, $\alpha>\beta$, $0<\alpha<90^o$, $0<\beta<180^o$ where the path loss index k=2. So the distance from p to a and b is:

$$|pa|^2 = ((r\cos\alpha - (-d_0))^2 + (r\sin\alpha)^2 = r^2 + d_0^{\,2} + 2rd_0\cos\alpha \quad \text{... (9)}$$

$$|pb|^2 = ((r\cos\beta - (-d_0))^2 + (r\sin\beta)^2 = r^2 + d_0^{\,2} + 2rd_0\cos\beta \quad \text{... (10)}$$

According to the formula (7), (8), (9) and (10), the energy consumption required for the data to be sent to and of per unit distance is as follows:

$$E(a) = \frac{2E_e + E_a\,|pa|^2}{|pa|\cos\angle aps} = \frac{2E_e + E_a(r^2 + d_0^{\,2} + 2rd_0\cos\alpha)}{|r\cos\alpha + d_0|} \quad \text{... (11)}$$

$$E(b) = \frac{2E_e + E_b\,|pb|^2}{|pb|\cos\angle bps} = \frac{2E_e + E_b(r^2 + d_0^{\,2} + 2rd_0\cos\beta)}{|r\cos\beta + d_0|} \quad \text{... (12)}$$

$$\begin{aligned} &E(b) - E(a) \\ &= \frac{2E_e + E_b(r^2 + d_0^{\,2} + 2rd_0\cos\beta)}{|r\cos\beta + d_0|} - \frac{2E_e + E_a(r^2 + d_0^{\,2} + 2rd_0\cos\alpha)}{|r\cos\alpha + d_0|} \\ &= \frac{(\cos\alpha - \cos\beta)r^3E_a}{|(rr\cos\beta + d_0)(r\cos\alpha + d_0)|} \end{aligned} \quad \text{... (13)}$$

We can get that $E(b)>E(a)$ if $\cos\alpha > \cos\beta$ for formula (13), therefore, if the distance between multiple nodes and q is the same, if the angle of a node with q and s is the smallest, then this node is the best relay node.

3.3 EMBRNS Algorithm

Algorithm 1 Energy Model-based Relay Node Selection (EMBRNS) Algorithm

Input:

S : Sink node in the network.

p : Sensor node which wants to send data

N : N = (L, E), All the sensor nodes in the network, *L* is set of location, *E* is set of energy.

Output:

R : The set of relay nodes in the best positions

While (*p*!=NULL)

$d_0 = min\ (Ee, Ea)$

n' = NULL

n' = *Arc* (*N*,*d*0)//Computing mapping point and selecting the closest node

If (*count(n')*>1)//Several points of the same distance.

r=min *Angle(n')*//Selecting the node with minimum angle

If(*count(n')*==1)//Only one points

r = n'

If (*n'*==NULL)

p = NULL

R = R∪u

4.0 Experiment

We set up a simulation experiment environment in NS2 [9] to detect the performance of each algorithm. We set a source *p* and sink *s* in a monitoring environment without obstacles, assume that nodes are randomly and uniformly distributed within the scope of monitoring, and no nodes in the same position, each node is loading the same type of antenna, the maximum transmission distance of antenna is 50 meters, each node has enough energy to work during simulation. We compared the simulation environment of 500m×500m and 1000m×1000m and the energy consumption under different

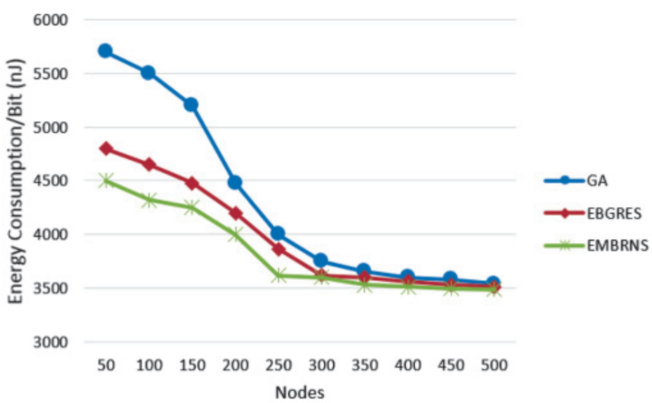

Fig.5: Energy consumption analysis under simulated environment of 500×500

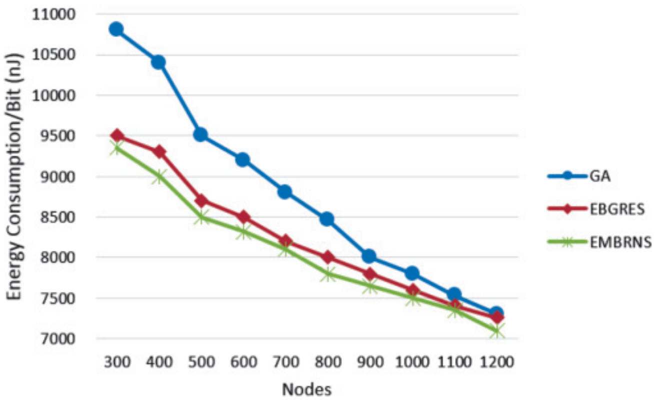

Fig.6: Energy consumption analysis under simulated environment of 1000×1000

nodes. The simulation results are shown in Figs.4 and 5. The X-axis is the number of nodes in the simulation experiment environment, and the Y-axis is the average energy consumption (nJ) required to transmit 1-bit data. We compared the greedy algorithm (GA), EBGRES and EMBRNS proposed in this paper.

From the simulation results, it can be seen that EBGRES and EMBRNS have a good performance when the node density is sparse, and EMBRNS performs best. Greedy algorithms often fail to find any nodes in the search area, resulting in long-distance transmission and excessive energy waste. With the number of nodes increases, the energy consumption of the three groups tends to be consistent, nevertheless, EMBRNS is still slightly superior.

5.0 Conclusion

Wireless sensor network is widely used in monitoring and control with its low cost and low power consumption, easy to implement and maintain. Energy-saving optimization is one of the key research contents of wireless sensor network. The energy consumption still needs to be considered in the selection of relay nodes in data transmission. In this article, our objective is to design a relay node selection method based on energy model which can complete the data transmission, as well as to minimize energy consumption and increase the network lifetime. The simulation results show that the method of this paper has smaller energy consumption, whether the node density is sparse or dense. In the future, we will continue to optimize the energy model and consider energy consumption and data fusion transmission from a global perspective to maximize the network life cycle.

6.0 Acknowledgements

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7.0 References

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