An Energy Aware Ladder Diffusion Routing Algorithm for WSNs

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***Abstract*—In Wireless Sensor Networks (WSNs), energy efficiency is one of the most important factors to improve the networks' performance, and well designed routing algorithm can obviously modify the WSNs' energy efficiency. In this paper, some typical existing routing algorithms are analyzed, and the advantages and defects of these algorithms are introduced. According to these analyses an energy aware ladder direction diffuse routing algorithm named EALD is proposed. In EALD, the nodes' residual energy is taken into account when message packet selects transmitting route. And to ensure nodes' store acute energy information, a special packet head and a special link which storing neighbor nodes are defined to update nodes' energy information when transmitting message. Through these designs, the route of transmitting can be dynamic adjusted to make the energy consumption between different nodes more reasonable. At last, EALD is compared with other typical routing algorithms in a series of experiments, and the experiments' result proves that EALD has obviously improved the WSNs' energy efficiency.**

***Index Terms*—WSNs, energy efficiency, ladder diffusion**

I. Introduction

Wireless Sensor Networks (WSNs) is a new kind of information access platform, and it can be deployed in special environment in which people could not work to obtain information. WSNs has broad application prospects such as in military, agriculture, healthcare, and environmental protection, and it has been one of the focus topic in computer research fields [1], [2]. There should be one or a few sink nodes and a number of sensor nodes in WSNs. Sink node's energy is supplied through cable and is unlimited; sensor node's energy is supplied through battery and is limited. If the energy of a sensor node is exhausted, wireless sensor network leaks will appear, and failure nodes will not relay data to the other nodes during transmission processing. Thus, other sensor nodes will be increasingly burdened with transmission processing. Given these issues, energy consumption in wireless sensor networks is an important research issue. So it is an important factor to improve the performance of WSNs that to raise the sensor node's energy efficiency. There are many methods about raising the sensor node's energy efficiency, and designing properly routing algorithm is one of the most efficient approaches among these ones.

This paper proposes an energy aware ladder diffusion (EALD) algorithm to map out the data relay routes in wireless sensor nodes. The algorithm focuses on balancing the data transmission load, increasing the lifetime of sensor nodes and their transmission efficiency. In this paper, the definition of energy efficiency would be introduced in section 2; some typical existing routing algorithms would be analyzed in section 3; then the detail design of EALD would be proposed in section 4; simulation and experiment would be stated in section 5; at last, the feature of EALD would be concluded in section 6.

II. The Concept of Energy Efficiency

To make the target of routing algorithm definite, this section introduces two definitions to explain the conception of energy efficiency as following:

Definition 1 Networks lifetime: The networks lifetime means duration beginning when WSNs is activated until when WSNs is failure because one or part of sensor nodes died for energy exhausting.

Definition 2 Energy efficiency: It means the ratio of network lifetime to the sensor node's energy. And if the sensor node's energy is stable, the energy efficiency would be as good as the length of network lifetime.

In WSNs application, the sensor node's energy would be used to monitor, compute and transform the information. Among these operations, energy consumption in transforming is more than other operations, and there are many factors affecting energy consumption in transforming such as node hardware parameters, the length of information and the distance of transforming. In this paper, the energy consumption is computed by classical mode mentioned in ref [3] as eq.1.

Manuscript received July 9, 2013; revised September 11, 2013.

doi: 10.12720/lnit.2.1.1-6

$$E_{TX}(L,D)=\begin{cases} LE_{Elec}+L\varepsilon_{fs}d^2, d<d_0 \\ LE_{Elec}+L\varepsilon_{mp}d^4, d>d_0 \end{cases}. \quad (1)$$

It can be learned from eq.1 that distance is the key factor affecting energy consumption if all nodes are same and data formation is stable. So adding the number of hop and decreasing the distance of every hop would conserve the energy. But it can't ensure to prolong the network lifetime just through conserving energy. For example, if some nodes are located at the optimal energy path, these nodes would always forward the message, and their energy would be exhausted much faster than others. So WSNs would be failed for these nodes' death, and this phenomenon is called "Hot Spot". And in multi-hop WSNs, the sensor nodes near the sink node would always forward the message from the nodes far away from the sink node, so these nodes' energy would be consumed much more than the faraway ones. This phenomenon is called "Energy Hole". Based on these analyses, the target of designing energy efficient routing algorithm is to add the number of hops, choose reasonable routing nodes, and balance the nodes' energy consumption.

III. Existing Typical Routing Algorithms

The routing protocols designed for WSN can be classified based on path selection, as proactive [4], reactive [5] and hybrid [6]. Based on the network architecture, they can be further classified as flat (data-centric, flooding) [7], hierarchical, such as LEECH [3], TEEN [8], APTEEN [9], and UCR [10], and geographical information based, such as GAF [11], GEAR [12] and HGMR [13]. In this section, three typical algorithms based on diffusion would be introduced including of DD [7], LEO [14] and LD [15].

A. The Directed Diffusion (DD)

C. Intanagonwiwat *et al*. [7] introduced the directed diffusion (DD) protocol in 2003. DD aims to reduce the data relay in order to better manage power consumption. Basically, DD is a query-driven transmission protocol. The collected data are transmitted only if they fit the query from the sink node, thereby reducing the power consumption due to data transmission. First, the sink node provides interested queries in the form of attribute-value pairs to the other sensor nodes by broadcasting the interested query packets to the entire network. Subsequently, the sensor nodes only send the collected data back to the sink node in case they fit the interested queries.

In DD, all sensor nodes are bound into a route when broadcasting the interested queries, even if the route is such that it will never be used. In addition, several circle routes, which are built simultaneously when broadcasting the queries, result in wasted power consumption and storage. In the real world, the number of the sensor nodes in a system is in the hundreds or even thousands. The waste of power consumption and storage becomes worse with larger-sized systems, and the "Hot Spot" and "Energy Pole" problems also become more serious.

B. Simple Least-Time Energy-Efficient Routing Protocol with One-Level Data Aggregation (LEO)

LEO is proactive, but the entire route from each node to the BS is not required to be known by all the nodes in the network. Each node has the information about its neighbors only, thereby reducing the memory requirement of each node. Two kinds of information of the neighbors is stored in the neighbor table of each node: first, the absolute time required for a packet to reach the BS from that node, and second, the residual node energy. This protocol is generic and has not been designed to optimally work in any specific application. And this protocol saves the energy overhead involved for diffusion in diffusion-based routing protocols, creation of cluster heads in hierarchical routing protocols, and communication overheads in the geographical information based routing protocols. In sum, the key features of this protocol are its simplicity, less computational complexity, very less routing overheads and the need for the nodes to broadcast only once to create the neighbor table.

But in LEO, there are two flaws in its design. Firstly, the model of WSNs applied in LEO is designed to idealistic to be used in application. In this WSNs, it will consume the same energy when the message is transformed between each pair of nodes, which means the distances between all sensor nodes are equal, and it is inconsistent with the WSNs' application environment. Secondly, the concurrency of LEO is not well dealt with, and the nodes' energy station in the neighbor table is not accurate. So LEO cannot resolve the "Hot Spot" and "Energy Pole" problems.

C. The Ladder Diffusion Algorithm (LD)

In LD, first, the sink node broadcasts the ladder creating packet with the grade value of one, and grade value of one means that the sensor node receiving this ladder creating packet transmits data to the sink node requires only one hop. Then sensor nodes increase the grade value of the ladder-creating packet to two and broadcast the modified ladder-creating packet. A grade value of two means that the sensor node receiving this ladder-creating packet sends data to the sink node requires two hops count. And repeat this step until all sensor nodes are activated. The ladder diffusion algorithm has two advantages: firstly, avoiding redundant relays: The LD algorithm can assure that the direction of data transfer always occurs from a high grade value to a low grade value, which means each relay is forwarded to the sink node since each sensor node records the grade value of relay nodes in the ladder table; secondly creating back-up routes: There are two ways as the sensor nodes moved or they are out of function. One involves sending the RERR packet of the route error to the sensor nodes that wish to transmit data. The sensor nodes will resend the discovering route packet again.

But LD algorithm has a main flaw that it doesn't consider the sensor nodes' residual energy when the route is chosen. So the LD algorithm cannot dynamical adjust route according to WSNs energy station and it is easy to involve in the “Hot Spot” and “Energy Pole” problems.

IV. The Design of EALD

In this paper, an energy aware ladder diffusion algorithm is proposed based on LD to resolve the “Hot Spot” and “Energy Pole” problems. This algorithm takes the sensor nodes’ residual energy account into choosing routes, so it can dynamically adjust the route according to the energy station of WSNs, and the robust of routing is much improved. EALD includes two steps as following: step1, activation phase, in this phase, all sensor nodes would be activated by sink node through a special activating packet; step2, transmitting phase, in this step, WSNs would sensing information and transmitting message packet steadily. In both phases, nodes’ residual energy should be always updated to ensure its information be accurate. To complete these functions, a special packet head is defined as Table I and a link of neighbor nodes (LNN) stored in every node is defined as Table II.

TABLE I. The Definition of Packet Head

ID	ID of the node which sends this packet
Pkt-typ	Packet type (LAD/ CON/ DATA)
Gra	Grade value
Ene	The node’s residual energy
Axis	The axis of node ID

TABLE II. The Main Structure of LNN

ID	ID of current node in LNN
Gra	current node Grade value
L-Next	The next node in LNN
Ene	The node’s residual energy
Axis	The node’s axis

A. Activating WSNs

In this step, sink node would broadcast the ladder creating packet to activate all sensor nodes in WSNs and the detail operations as following:

First, the sink node would broadcasts the ladder creating packet with the grade value one to its one hop neighbor nodes, and these nodes would set their grade as one and update packet head with its information and increase the packet grade value to two. The Fig. 1 shows the procedure.

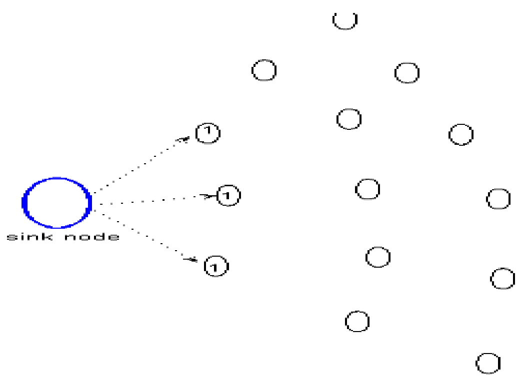

Figure 1. First step to activating WSNs.

Then these nodes would broadcast the new packet to its one hop neighbor nodes. When a node receives a ladder packet, it would extract the grade value from this packet and compare the value with itself. If the packet value is larger than itself, the packet would be abandoned; otherwise, the node’s information would be updated by the packet as: make its grade as packet, add the packet source node to LNN, and update the packet with its information. And then the new packet would be sent to next hop nodes, which is shown in Fig. 2 and Fig. 3.

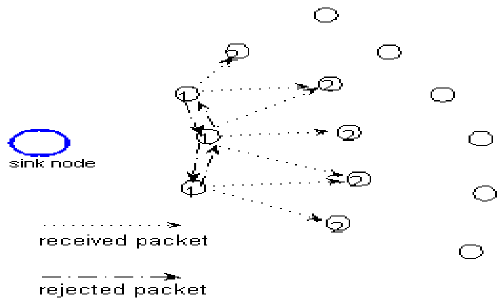

Figure 2. The second step of activating WSNs.

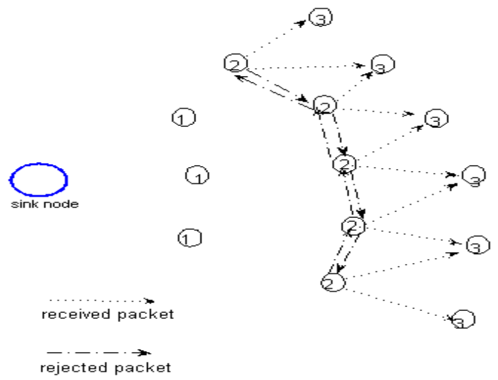

Figure 3. The last step of activating WSNs.

Repeat last operation until all nodes of WSNs have been activated.

B. Transmitting Message

In this phase, there would be two steps: first, the sensor node finds the information and sends the message packet to sink node; second, when sink node has received the packet, it would send a confirm packet to source node. And the detail operations are shown as follow in Fig. 4 and Fig. 5.

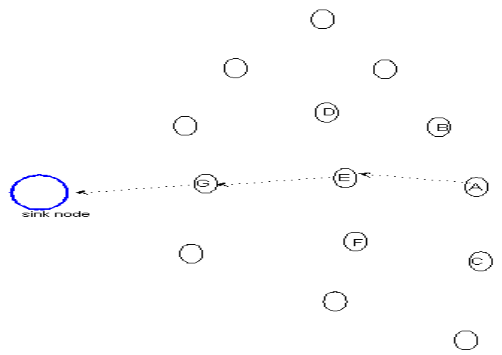

Figure 4. Send sensing message to sink node.

In Fig. 4, when a node whose ID is A finds some information to be sent to sink node, it would browse its LNN and find the node which has the most residual energy assuming node E as the next hop transit to relay message. When node E receives the message packet, it would also browse its LNN to find the next hop transit assuming node G. And G would send the packet to sink node directly.

While message is being transmitted, the node's residual energy information would be updated in time. First, the distance between itself to next hop node would be calculated as eq2.

$$Dae = \sqrt{(X_a - Xe)^2 + (Y_a - Ye)^2} \tag{2}$$

In eq2, Xa and Ya respectively represent X axis Y axis of node *a*, and *Xe* and *Ye* respectively represent X axis Y axis of node E. And then the energy consumption of transmitting from node *a* to node *b* is as eq3.

$$E_{ae} = E_{TX}(L, D_{ae}) \tag{3}$$

And then the latest node residual energy is calculated as eq4.

$$E_a = E_a - E_{ae}. \tag{4}$$

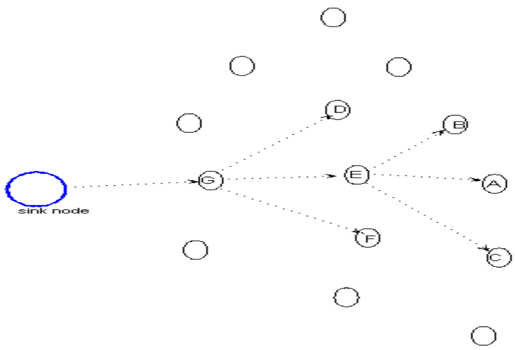

Figure 5. Send confirm message to source node.

In Fig. 5, when sink node receives the sensing message packet, it would send a confirm packet to source node by the reverse route. First, sink node would send the packet to node G. To make all neighbor nodes of G have latest residual energy information, node G would broadcast the confirm packet to the nodes which have larger grade value in its LNN. And before broadcasting, the energy consumption of broadcasting message would be calculated as eq5.

$$E_{br} = \sum_{i=d}^{f} E_{gi}. \tag{5}$$

And the residual energy information of node G would be updated as eq6.

$$E_g = E_g - E_{br}. \tag{6}$$

Then the confirm packet content would be updated by the new and be sent to node D, E and F. Although node D, E and F all receive the confirm packet from node G, only E would broadcast the packet to the nodes which have larger grade value in its LNN as the operation done by G, because node D and F did not transmit message to sink node. And node D and F would just update their LNN content about the residual energy information of node G.

Repeat these operations until the confirm packet has been sent to the source node A. And node A would broadcast its latest residual energy information to the nodes which have larger grade value in its LNN to make them store the right value in their LNN.

V. THE SIMULATION AND EXPERIMENT

To prove the efficiency of EALD, a simulation platform is designed by matlab, and through this platform, several existing routing algorithms including DD, LEO and LD are simulated to compare with EALD. The energy efficient standard of an algorithm can be reflected the lifetime length of WSNs. In these experiments, all sensor nodes are randomly deployed in the sensing area. And part of parameters of sensor node is shown as the Table III.

TABLE III. THE MAIN PARAMETERS OF EXPERIMENT

Threshold distance(d_0)(m)	10
E_{Elec} (nJ/bit)	50
ε_{fs} (pJ/bit/m2)	10
ε_{mp} (pJ/bit/m4)	0.0013
Sensing area (m2)	1000*1000

A. The Result of Simulation

According to the definition1, the standard to judge if WSNs lifetime are as there is one or part of nodes dead, the WSNs' lifetime should be over. This paper adopts the strictly one that if there is one node dead, the WSNs' lifetime should be over. To overall compare different algorithms, there are three kinds of comparison of these algorithms: the lifetime's change with the number of sensor nodes' increase is shown in Fig. 6; the lifetime's change with the move of sink node's location is shown in Fig. 7; and the lifetime's change with the variety of sensor nodes' initial energy is shown in Fig. 8.

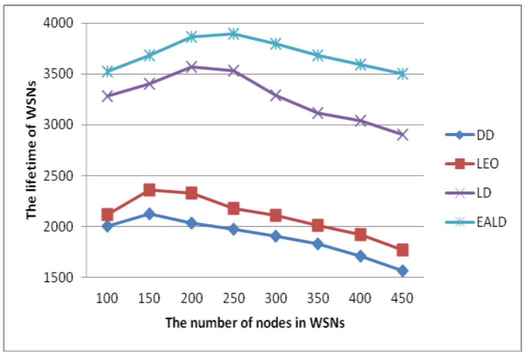

Figure 6. The variety of WSNs' lifetime changing with the number of nodes.

At the condition that all sensor nodes have same initial energy (0.5J), and the sink node is located in the central spot (500,500), the simulation results are shown in fig. 6. It can be concluded that the lifetime of DD is the shortest one; LEO is a little better than DD; and LD is much better than DD and LEO; EALD has the longest lifetime of all. And from Fig. 1, it can be observed that EALD is influenced by the number of nodes lest, and LD is influenced some bigger than EALD, and DD and LEO are influenced biggest.

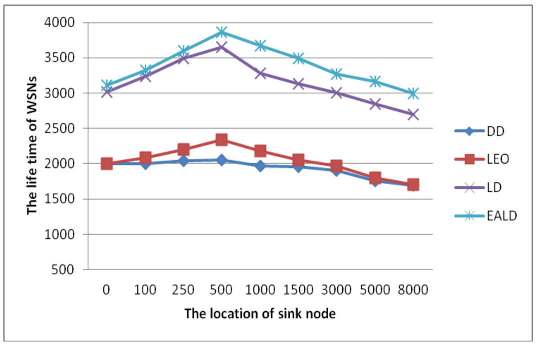

Figure 7. The variety of WSNs' lifetime changing with the location of sink node.

At the condition that all sensor nodes have same initial energy (0.5J) and the number of sensor nodes is always 75, the simulation results are shown in Fig. 7. According the figure, it can be concluded that the curve of DD is the smoothest algorithm; the curves of LD and EALD are sharper than DD; the curve of LEO is the in the middle of all. This means that the efficiency of DD is influenced lest by SN location; the efficiency of LEO and LD are influenced most by SN location, but LD and EALD are still more efficient than others.

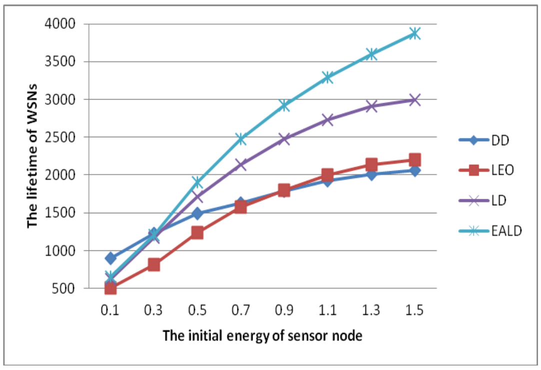

Figure 8. The variety of WSNs' lifetime changing with the initial energy of nodes.

At the condition that the number of sensor nodes is always 200 and the sink node is located in the outside spot (500, 3000), it can be concluded that every algorithm has different efficiency at different level of initial node energy. When the energy is at lower level (≤0.3J), the lifetime of DD is the longest; The lifetime of LEO is the shortest; LD and EALD have a little disparity to LEACH. And with the initial node energy increase, lifetime of DD has been exceeded by others, and the lifetime of LD and EALD are prolonged more obviously than others. When the initial node energy is bigger than 1J, just EALD can maintain a good growth rate of lifetime with the increase of node energy.

B. The Analysis of Experiment Results

Through these experiments, it can be concluded that EALD has the best energy efficiency to prolong the WSNs' lifetime of all four algorithms in most of conditions except that the sensor nodes' number is very small or the nodes' initial energy is very little. Comparing with DD and LEO, EALD adapts the ladder diffusion method to transmit message, which much reduces the additional overhead and conserve the node's energy; and comparing with LD, an energy aware strategy is adapted to dynamically adjusted the routes of transmitting according to the nodes' residual energy which makes the energy consumption in different nodes is more balancing. So EALD has the most energy efficiency in these algorithms.

VI. Conclusion

To improve the performance of WSN, modifying the sensor nodes' energy efficiency is one of the most important methods. "Hot Spot" and "Energy Pole" are two main problems to be resolved to improve energy efficiency, and many routing algorithms are proposed to attain this goal. In this paper, after analyzing the mainly existing algorithms, a new energy aware routing algorithm named EALD is proposed. There are three innovations about this algorithm as: first, a special packet head is defined to update nodes' information with transmitting message and special data structure named LNN is stored in every nodes to memorize its neighbor nodes information; second, new ladder diffusion method is designed to activate the nodes in WSNs; third, an energy aware routes choosing method is designed to improve the energy efficiency of WSNs. Finally the advance of EDLA in energy efficiency is proved by a series of experiments.

Acknowledgment

This research is supported by Natural Science Foundation of China under the contract number 60573065; and is supported by Natural Science Foundation of Shandong under the contract number 2010ZRQL02 and ZR2012FL12; and is partially supported by Natural Science Foundation of China under the contract number 60903176.

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