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New Energy Efficient Routing Algorithm for Wireless Sensor Network

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***Abstract*—Energy efficiency is the most challenging topic in Wireless Sensor Networks (WSN). Because of the increasing demands of various applications, and the constraints of energy, memory and computational power of the WSN nodes, many studies have focused on these areas in recent years. Researchers have proposed a variety of protocols such as LEACH, PEGASIS, HEED, TEEN, etc.**

In this paper, we will discuss how energy efficiency is affected by scaling, i.e. different network sizes, and by different routing algorithms. With the increasing applications of large scale WSNs, such as smart grid and environmental monitoring. We will propose a new routing algorithm to optimize the energy efficiency by reducing the number and total transmissions distance in order to save energy. Simulations suggest that the proposed algorithm will be more energy efficient in medium to large scale wireless sensor networks.

Keywords—Wireless Sensor Network; Energy Efficient; Clustering; Routing Algorithm

I. INTRODUCTION

A wireless sensor network (WSN) is composed of different types of sensors which are used to send and receive data through the wireless network. Since sensors may be deployed randomly, WSNs do not have a fixed infrastructure and there is no well-defined centralized organizing procedure.

WSNs are also different from traditional wired data communication networks because the sensors are densely deployed, and nodes may be easily damaged in some hazardous environments. The sensor topology may change from time to time, nodes may fail or be moved, and thus the links between nodes are subject to change. Therefore, maintaining a stable wireless sensor networks is a challenging task and it requires a mature monitoring and control strategy.

Wireless sensor network applications are very board ranging from smart grid, military, health care, tracking, civil, industrial sectors, environmental monitoring and control. In most applications, a wireless sensor network may consist of hundreds or even thousands of sensor nodes [1, 2].

Because of their increasing usage, and constraints of limited energy source, memory and computational power of WSN nodes, there are many studies in these related areas in recent years. Energy efficiency is the most challenging topic in wireless sensor network. This is because sensors are powered by battery and are required to run remotely for a long period of time without human physical interaction. Therefore, it is difficult to replace or recharge batteries especially when they are widely deployed in remote locations.

Every node uses battery power for its sensors, communication with other nodes and microprocessor computations. These nodes have limited energy power, low storage size, and narrow bandwidth for communication.

In the past, there are always studies focusing on energy efficiency of wireless sensor network [3, 4, 5]. Many researchers are working hard on saving the energy consumptions on wireless sensor network in order to maximize the lifetime of the network.

In this paper, we will propose a new routing algorithm for wireless sensor networks with energy efficiency as the primary consideration. The new proposed algorithm will be compared with existing algorithms with respect to network quality and robustness of the wireless sensor network. Different network sizes will be considered.

It is expected that the design of the routing algorithm and protocol techniques will highlight crucial decision points in managing the complicated wireless sensor network environment by balancing the affecting factors to improve the robustness of a network. Therefore, many large scale WSNs would require efficient algorithm to solve the unreliability problems of the wireless sensor networks in an effective way. Hence, energy efficiency is a major concern.

II. BACKGROUND OF WSNS

A. Hierarchical Routing Algorithms

Hierarchical routing algorithms in WSNs have been studied from a variety of angles [6, 7, 8]. A common method is clustering, i.e. dividing sensor nodes into groups [8]. This is a commonly used data communication technique to reduce the energy consumption by sending data from sensors to a base station. In hierarchical clustering, the whole sensor network is divided into different clusters or multiple layers. Transmission within a cluster is coordinated by each cluster head which is also responsible of routing between clusters or base stations.

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Data travels from one level to another enabling it to travel longer distances. This can make the data communication happen faster and more energy efficient. Thus, clustering provides data aggregation advantages among cluster heads at different levels in order to improve the performance of the whole wireless sensor network.

Single Hop Transmission - Cluster head will send data to the base station directly without passing through other cluster heads. It is the simplest transmission method without the need to consider other information. However, it may not be suitable for large scale network because there is a transmission distance limitation with sensors, and they are not allowed to transmit data outside a certain range. Even if the data can be transmitted, it may lead a heavy burden on the cluster head because the energy consumption is directly proportional to the distance, and it is worse for long distance transmissions.

Multiple Hop Transmission: Cluster heads will send data to the next cluster head(s) until the base station is reached. This method can divide a single long distance into multiple shorter distances for transmissions. This can share the loadings among cluster heads, and it is more suitable for large scale networks. However, a suitable routing method is needed because energy will be wasted for unnecessary transmissions.

B. Existing Common Hierarchical Clustering Algorithms

LEACH - Every node has an equal chance to act as a cluster head. However, due to single-hop routing, the cluster heads will consume a lot of energy when they are located far away from the base station and it is not suitable for large scale applications. Besides, LEACH may not guarantee a fair and uniform cluster head distribution because cluster heads are elected randomly.

PEGASIS - This algorithm minimizes the number of data transactions by using the data aggregation method through a chain. However, energy is required to collect the location of sensors in order to find the next hop. Also, a time delay may occur due to data passing through many nodes.

TEEN - It reduces the number of transmissions based on degrees of interest and degree of changes in order to save energy. This algorithm can control the trade-off between energy efficiency and data accuracy, and therefore it is suitable for large scale networks. However, the network will slow down if the threshold values of interest and change are not received. Therefore, if the data requirements are too high, a delay will occur especially when periodic data is required.

HEED - It can balance the energy loading among different sensor nodes by utilizing and tracking residual energy. However some energy will be required to communicate the information about the amount of residual energy and the nodes' locations [9].

C. Criteria of a Robust Wireless Sensor Network

There are several criteria to determine a robust wireless sensor network as stated in [6, 7], the degree of importance of the criteria may be varied due to different applications:

Efficient power usage - Reduce the energy consumptions of every sensor nodes and extend the lifetime of the whole network.

Scalability - Since the applications of wireless sensor networks range across different disciplines, the number of sensor nodes deployed in a wireless sensor network can vary from tens, hundreds, or even thousands. Thus, when designing routing algorithms, they should be adaptable across different network sizes.

Reliability - This is also a critical factor for evaluating the success of a wireless sensor network. Basically, reliability is also related to the power consumption because if the sensor nodes die very quickly, then the sensor node cannot transmit data. In addition, if the dead node is a cluster head, the whole cluster's performance will be affected. Reliability suffers, because the successful delivery ratio will decline. Also, reliability is affected by the congestion control mechanism of the routing algorithm.

Self-organization - After the sensor nodes are deployed in the network, they should be able to re-organize themselves in case of node failure or changes within the network.

Adaptability - In sensor networks, sensor nodes can join or leave a cluster in different iterations, which will change the node density and network topology of the newly formed cluster. Thus, network routing algorithms used for sensor networks should be flexible enough to cater for the frequent changes in cluster membership.

III. OUR PROSPOSED ROUTING ALGORITHM

In this paper, we will propose an Energy-efficient Clustering algorithm to optimize the energy efficiency of the whole network. As the wireless sensor networks are applied to large scale wireless sensor networks rapidly nowadays, the design of our algorithm will put more emphasis on it and minimize the energy consumption of long distance transmission.

We will try to determine if our routing algorithm is suitable for small, medium and large scale networks by comparing it with other algorithms i.e.: single hop and multiple hop with shortest distance to next hop transmission algorithms.

A. Assumptions of our WSN Model

- There is a base station (BS) in the WSN, and its storage, communication and computation resources are unlimited.
- The sensors nodes are randomly distributed.
- The energy of every sensor node is initialized to the same constant value
- The sensors are randomly distributed and static.
- The sensor nodes are grouped into clusters, and there is one cluster head (CH) in each cluster. Cluster members can transmit messages to their cluster head or directly to the BS. CH can then sends data directly to the BS, or

though multi-hops by sending data to next CHs, and finally to the BS.

B. Cluster Formation Algorithm

Cluster formation is based on the remaining energy and node density, distances between nodes and distances to the base station. The remaining energy will be used in the selection of the cluster head. The cluster head's role will rotate if its energy falls below a threshold.

The following is the flowchart for our proposed cluster formation algorithm:

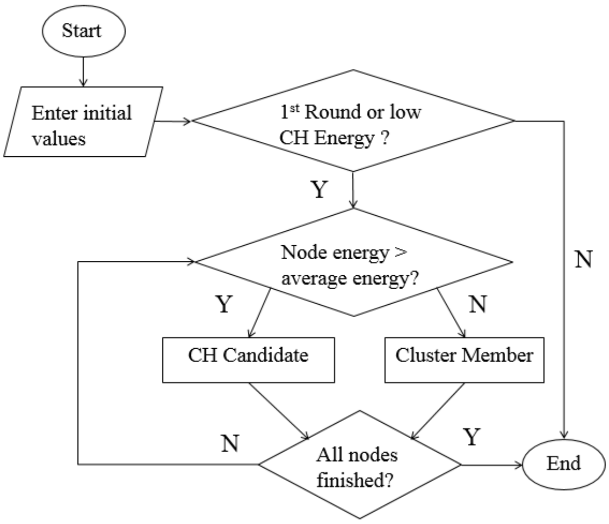

Fig. 1 Selection of Cluster Head Candidates

First, the expected minimum required energy of a cluster head and cluster members and the total number of sensor nodes are entered into the system.

While it is the first round of Cluster Head selection or the cluster head's remaining energy less than the required value. The base station will calculate the average energy, E-average, of the current network.

If the energy of the node is greater than E-average, then that particular node has the chance to be selected as a cluster head and will be put into the Cluster Head candidate list. Otherwise, it will be considered as a normal node.

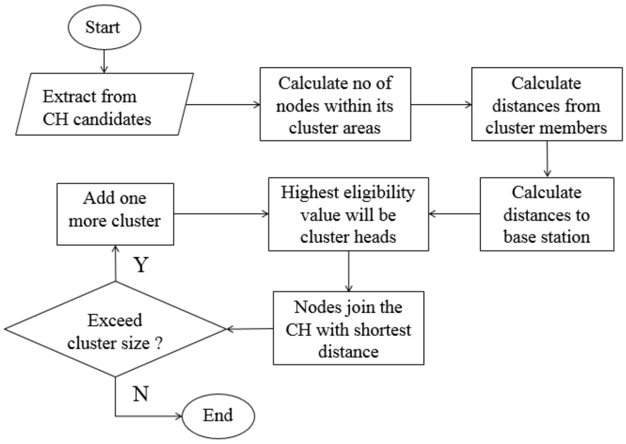

Fig. 2 Joining cluster

Next, the system extracts the sensor nodes from the cluster head candidate list, and calculates the number of nodes within the optimal cluster area. It will then update the cluster heads candidate list.

Furthermore, it measures the centrality by calculating the cumulative distances from the candidate members and the cluster head, it also measure the proximity to the data sink by calculating the cumulative distance from the cluster head to the base station. The candidate with highest eligibility value will be the cluster heads.

To join a cluster, every sensor node calculates its distance between all cluster heads and the base station. If the distance to the Base Station is the shortest, then the sensor node does NOT join any cluster. Otherwise, the sensor node will join the cluster with the shortest distance, and the system will update the membership of the clusters.

The joining cluster process will continue until all sensor nodes are considered. If the number of sensors within a cluster exceeds the maximum member size, then assign one more cluster head for the group based on the candidate list.

C. Multi-Hop Energy Efficient Distance Routing Algorithm

To save energy, we divide the network into multiple clusters where the cluster head node collects and aggregates information from its neighbors and delivers the summary through minimum number of hops to the base station to avoid redundant transmissions and save communication costs.

However, if a sensor node is close to the base station, it can send data to the base station directly and thus also save energy. Below is the diagram for our proposed routing algorithm:

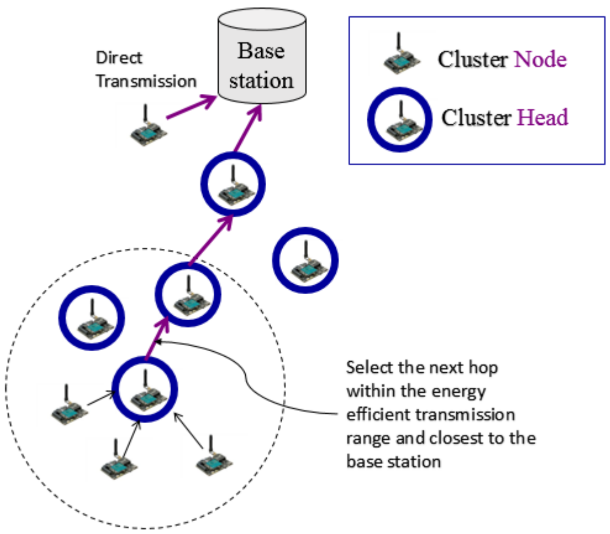

Fig. 3 Multiple Hop Transmission with Energy Efficient Distance

Cluster heads will wait for a fixed period of time or for a certain message size to accumulate before starting a transmission. If the distance to the base station is shorter than other cluster heads, data will be sent to base station directly. Otherwise, it will extract the cluster heads information from the database. It selects the next targeted cluster heads within its energy efficient transmission range and also closest to the base station.

It then estimates the energy used for data transmission of both cluster heads. If the remaining energy is enough for both cluster heads, it will send the data, and update the remaining energy of the cluster heads

The energy consumed for a sensor to transmit k-bits data over d meters is based on the First Order Radio Model:

$$Etrans(k,d) = E_{elec} * k + E_{fs} * k * d^2, \; d<=d_0 \quad (1)$$
$$Etrans(k,d) = E_{elec} * k + E_{amp} * k * d^4, \; d>d_0 \quad (2)$$

$$d_0 = \sqrt{\frac{E_{fs}}{E_{amp}}} \quad (3)$$

E_{fs}: required energy for amplification of transmitted signals to transmit a one bit in open space
E_{amp}: required energy for amplification of transmitted signals to transmit a one bit in multi path models
E_{elec}: the energy spent in transmitting and receiving data for a sensor's electronics

The energy is consumed for a sensor to receive k-bits data

$$Ereceive(k) = E_{elec} * k \quad (4)$$

D. Simulation and Analysis

The initial settings of the parameters are described in Table 1, and the environments of the WSN are mentioned in Figure 1.

TABLE 1: INITIAL SETTINGS FOR SIMULATIONS

Network size	100 x 100 m (small) 300 x 300 m (medium) 400 x 400 m (large)
Number of nodes	100 nos.
Initial Energy of nodes	0.5J
Eamp	0.0013pJ/bit/m
Efs	10pJ/bit/m
Eelec	50nJ/bit

In our simulations, we have analyzed the three routing algorithms in three different scales of grid sizes (100 x 100 m, 300 x 300 m, and 400 x400 m).

- Single hop
- Multiple hops with shortest distance to next hop
- Multiple hops with energy efficient distance

Case 1: Small Scale Network

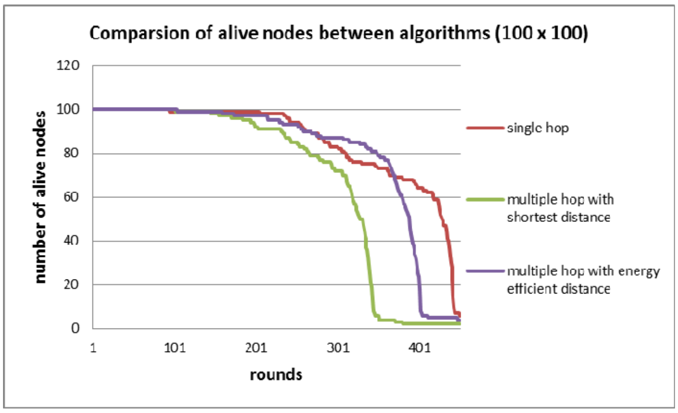

Fig. 4 Comparison of alive nodes for small scale network

We have found that single hop transmission is better in a small scale network (100 x 100 m). This is because the distance between the base station and nodes is short, and direct transmission to the base station is already good enough to save energy. On the contrary, if multiple hop transmission is used in a small scale network, energy will be wasted because of more transmissions than necessary between the cluster heads.

This wasted energy gains prominence when performing routing based on 'shortest distance to the next hop' because short distance to the next hop does not always result in the shortest overall transmission distance. Thus, energy may be wasted for unnecessary transmissions.

Case 2: Medium Scale Network

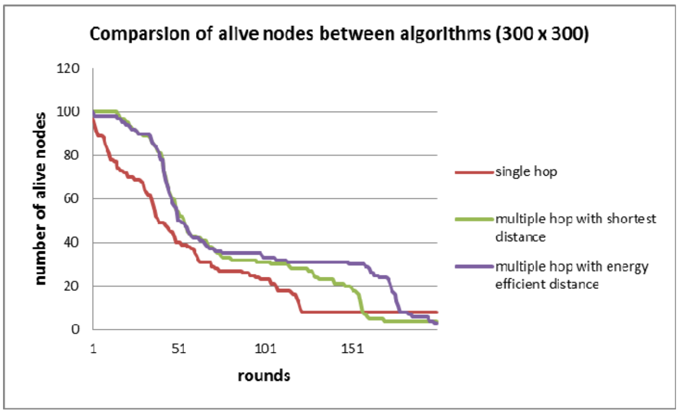

Fig. 5 Comparison of alive nodes for medium scale network

For medium scale networks (300 x 300 m), single hop transmission is the worst case because the distance between the base station and nodes are longer, and more energy is consumed. Therefore, the nodes are depleted more quickly early in the simulation compared to multiple hop transmissions.

On the other hand, for multiple hops transmission, the transmission with energy efficient distance is better than shortest distance to the next hop. They performed similarly in the early stage, but the nodes in transmission with shortest distance expired quickly afterwards. This is because a higher number of transmissions will result when routing transmissions based on the 'shortest distance to the next hop' criteria i.e. energy will be wasted for unnecessary transmissions.

Case 3: Medium Scale Network

When it comes to large scale networks (400 x 400 m), it is very similar to the medium scale network. Single hop transmission is not suitable especially for large scale network because of long distance transmission by individual node.

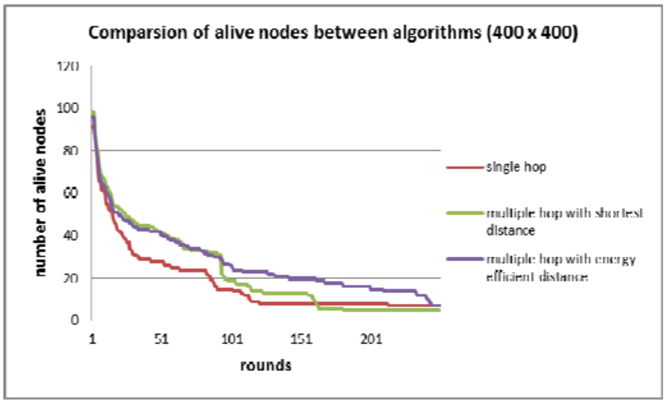

Fig. 6 Comparison of alive nodes for large scale network

Moreover, transmissions with energy efficient distance is better than shortest next hop distance because it can reduce the number of transmissions between cluster heads and with the consideration of energy used based on the energy efficient distance.

IV. DISSCUSSION AND CONCLUSION

Based on our findings, we can conclude that single hop is good for small scale networks because direct transmissions by individual nodes can be done without unnecessary transmissions.

However, for medium and large scale networks, multiple hop transmission is more suitable because a single long distance transmission can be broken down into pieces and the energy consumption can be shared among all cluster heads.

We also found that routing with 'energy efficient distance' path is better than the 'shortest distance to the next hop' algorithm. This is because some energy will be wasted for unnecessary transmissions when using the shortest next hop distance method. In the 'shortest distance to the next hop' system, the distance the next cluster head is minimized but this may still result in a longer overall path and require more energy than the alternative 'energy efficient distance' path.

We have propose an energy efficient transmission distance algorithm in which the cluster head will find the next hop which is closest to the base station and also within the energy efficient transmission range. It is proposed this will reduce the energy consumptions and the number of transmissions as well. From initial simulations, the proposed routing algorithm performs better in medium and large scale wireless sensor networks.

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