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Lifetime Enhancement in Wireless Sensor Networks Using Modified Relative Direction-Based Sensor Routing Algorithm

Ho-Lung Hung, Chien-Erh Weng

***Abstract*—Extending lifetime of wireless sensor networks (WSNs) is one of the most critical issues in WSNs. Lifetime limitations are caused by limited energy resources. However, in WSNs due to the cost and environment constraint, the battery power of sensor node is not always rechargeable. This will cause network partition, isolated nodes and much shortened network lifetime. Thus, how to balance energy consumption for sensor nodes is an important research issue. In this paper, a major concern here is how to conserve battery consumption. An energy-efficient sensor routing algorithm, namely modified relative direction-based sensor routing (MRDSR) algorithm is proposed to solve the routing loop problem. Moreover, a network partition-free and energy-efficient routing (PFEER) algorithm is proposed to solve the network partition problem. Through extensive numerical simulations, we demonstrate that PFEER solves the network partition problem and offers a longer system lifetime for the conventional wireless sensor networks. This also prevents network coverage from reducing rapidly.**

***Index Terms*—wireless sensor networks, Lifetime, Relative direction-based sensor routing, Energy-efficient routing**

I. Introduction

A wireless sensor networks (WSNs) is a collection of sensor nodes that usually derive their energy from attached batteries [1-3]. WSN lifetime is the key characteristics for the evaluation of sensor networks. The applications of WSNs are broad, such as weather monitoring, battlefield surveillance, inventory and manufacturing processes, etc. [1]–[5]. In general, due to the sensory environments being harsh in most cases, the sensors in a WSN are not able to be recharged or replaced when their batteries drain out of power. The battery drained out nodes may cause several problems such as, incurring coverage hole and communication hole problems. Thus, several WSN studies have engaged in designing efficient methods to conserve the battery power of sensor nodes, for example, designing duty cycle scheduling for sensor nodes to let some of them periodically enter the sleep state to conserve energy power, but not harming the operating of the sensing job of the WSN [6]; designing energy-efficient routing algorithms to balance the consumption of the battery energy of each sensor node [7]–[13].

WSN are typically composed by a large amount of sensor nodes deployed to accomplish some monitoring and communications tasks. Sensors are constrained devices with low computing capabilities that are basically composed by three components: a sensing subsystem, a processing subsystem and a wireless communication subsystem [1]. These components are coupled to guarantee that each device is able to collect information from the environment, to decide how to manage that information and how and where to transmit that information to be processed. Additionally, the power supply is obtained from a battery provided with a limited amount of energy. Hence, lifetime, defined as the total time during which the WSN is able to provide target coverage and to send sensing information to the base station, is extended by activating these subsets at different moments. Therefore, such an approach can be successfully extended to consider WSN in which sensors can adopt different roles at different energy consumption rates

Energy efficiency is a key research concern and challenging issue during the design of routing algorithms for WSNs [4-5]. The autonomous sensor nodes are usually powered with very limited energy supply. Besides, the number of sensor nodes is usually large, and it is impractical to recharge or replace the battery power of sensor nodes. Moreover, long distance communication between sensor nodes and base station (or sink nodes) may also increase overall energy consumption. A well-known problem is that the sensors close to sink node will bear more traffic burden to forward to the sink nodes and they will deplete their energy much faster than those sensor nodes far away from sink nodes, leading to network disconnection and much shortened network lifetime. Those sensor nodes become bottleneck nodes and they are called hot spots, and this phenomenon is referred to as the energy holes problem. In the meantime, a large quantity of energy may not be used efficiently for the transmission of the rest of the data among many other residual sensors, which is not very desirable. These sensor nodes, with limited computing, communicating and sensing capabilities, as well as limited energy, can make the best use by gathering data from other sensor nodes and transmit the data to the base station (BS) by using excellent network topologies and optimizing routing algorithms [1], [6] monitor a wide region of interest, we require deploying a large number of sensor nodes to support surveillance functionality. However, keeping all sensor nodes active to monitor the sensor field is unnecessary and the battery attached to the sensor nodes will rapidly run out. This will shorten the lifetime of the sensor nodes.

In general, we use conventional sensor routing algorithm to transfer data to the BS. In this algorithm, when each sensor node detects an event, it broadcasts the event to all sensor nodes within a one-hop range. All the sensor nodes within one-hop range then repeatedly broadcast the message to the next nodes. These processes are recursively performed until the event reaches the BS. This conventional algorithm can lead to an excessive drain of limited battery power and increases collisions in wireless transmission. Therefore, an energy-efficient sensor routing algorithm, namely relative direction-based sensor routing (RDSR) algorithm was

Chien-Erh Weng, Department of Electronic Communication Engineering, National Kaohsiung Marine University, Kaohsiung, Taiwan, ROC, (e-mail: ceweng@mail.nkmu.edu.tw).

Ho-Lung Hung, Department of Electrical Engineering, Chienkuo Technology University, Taiwan, ROC, (e-mail: hlh@cc.ctu.edu.tw).

proposed [13]. This algorithm divides the sensor field into sectors and places a manager node in each sector. However, RDSR has routing loop problem. When a routing loop problem occurs, unnecessary energy consumption will increase. The manager node receives the collected data from the sensor nodes in its corresponding sector and then directly transfers the data to the BS through the shortest path of the 2-dimensional (*x*, *y*) coordinate.

In this paper, we focus our attention on the energy consumption associated with communications; in particular, we consider energy-efficient sensor routing algorithm for wireless sensor networks. However, a routing loop problem exist in RDSR as shown in paper could cause when the sensor nodes that select the next node satisfy the second step but do not satisfy the first step. Therefore, a modified relative direction-based sensor routing (MRDSR) algorithm is proposed to solve the routing loop problem. In MRDSR solved the routing loop problem, since sensor nodes do not have sufficient battery powers, some sensor nodes become inactive when working for a long time. This result will reduce network connectivity and cause the network partition problem. In order to solve the network partition problem, a network partition-free and energy-efficient routing (PFEER) algorithm is proposed. PFEER not only has the advantages of MRDSR but also solves the network partition problem.

The remainder of this paper is organized as follows. In Section II, a general description of LEUD algorithm is presented. In Section III, a detail description of our proposed routing algorithm is explained in detail. Analytical performance deviations of proposed algorithms and extensive simulation results are presented in section IV. Finally, the conclusions are given in Section V.

II. Overview of Lifetime-Extended under Uniform Distribution (LEUD) Algorithm

Energy is an extremely critical resource for battery-powered wireless sensor networks (WSN) [14-22], thus making energy-efficient protocol design a key challenging problem. The work in [16], instead, considered the problem of maximizing the network lifetime under joint network and target coverage as a maximum tree cover and proposed an efficient heuristic algorithm for scheduling active nodes. However, these works defined lifetime in terms of coverage, which is an application-specific characterization. In contrast, we take a network-oriented approach that is independent of a specific application, but general enough to be applied in different scenarios. Several works have exploited multipath routing for energy efficient communication in WSNs. An energy-efficient node disjoint multipath routing algorithm was proposed in [17] to establish multiple collision-free paths between a source and a sink through joint power control and flooding. A routing loop problem exist in RDSR as shown in Figure 1 could cause when the sensor nodes that select the next node satisfy the second step but do not satisfy the first step From a sensor deployment perspective, an energy conservation strategy can be considered in the "deployment phase" or the "post-deployment phase" [9]. We developed an algorithm, called the LEUD algorithm, to be used in the post-deployment phase to reduce energy consumption. The idea is to divide a region of interest (*ROI)* into several small regions. The total number of small regions in the *ROI* is defined as *Z*. If there is more than one sensor node located in a small region, we only permit one sensor node to be in the active mode and the others to be in the sleep mode in the small region at any time to prolong system lifetime [10-12]. The LEUD algorithm contains the following steps:

(1) *Divide the ROI into small regions*: To ensure that sensor nodes located within a one-hop distance of one another can communicate with each other, the maximum one-hop distance must be less than the sensors nodes' communication range (*cR)*. Adopting this constraint, the side length (*x*) of each small region in the *ROI* and the total number of small regions in the *ROI* can be calculated by Eqs. (1), (2), (3) and (4). Obviously, the value of *Z* depends on *cR*, as shown in Figure 2. For a fixed number of sensor nodes (*N)* in the *ROI*, the average number of sensor nodes in each small region increases as the value of *Z* decreases. As a result, the system lifetime increases since more sensor nodes within each region can be inactive at any one time.

$$\sqrt{x^2+(2x)^2} \le cR \quad , \tag{1}$$

$$x \le \frac{cR}{\sqrt{5}} \quad , \tag{2}$$

$$\frac{\sqrt{5*ROI}}{cR} \le \frac{\sqrt{ROI}}{x} \quad , \tag{3}$$

$$Z \ge \left(\left\lceil \left(\frac{\sqrt{5*ROI}}{cR} \right) \right\rceil \right)^2 \quad , \tag{4}$$

in order to prolong the system lifetime the lower bound of *Z* is chosen as

$$Z = \left(\left\lceil \frac{\sqrt{5*ROI}}{cR} \right\rceil \right)^2 \tag{5}$$

(2) *Categorize the sensor nodes into their own specific small regions*: Each small region in the *ROI* is distinguished by a unique two-dimensional coordinate (x, y). Each sensor node within a particular region is assigned the two-dimensional coordinates of that region as its unique identifier (*ID*). In other words, all of the sensor nodes within the same region share the same *ID*.

(3) *Select one sensor node in each small region to be active*: If the number of sensor nodes deployed in the *ROI* is fairly large, it is probable that each small region in the *ROI* will contain more than one sensor node. As described above, energy consumption in the network can be reduced by maintaining just one sensor node in each region in an active mode, while allowing the remaining sensor nodes to sleep. In the present study, each sensor node maintains an energy table detailing its own energy information and also that of all its neighboring sensor nodes with the same *ID*. If a sensor node establishes that its energy resources are higher than those of any of the other sensor nodes in the same region of the *ROI*, it nominates itself as the "major sensor node" and sets itself to the active mode; otherwise it sets itself to the sleep mode.

(4) *Determine the WSNs system lifetime*: Once all of the sensor nodes in the *ROI* have been to set to their respective modes, the major sensor nodes in each small region assume responsibility for sensing targets or events and begin to

consume an increased amount of energy. The energy consumed by a sensor node in each unit of time is defined as the continuous power (*CP*). When the remaining energy resources of a major sensor node fall below *CP*, the sensor node broadcasts a packet to its neighboring sensor nodes with the same *ID* informing them of the need to choose a new major sensor node. The time at which the deployed sensor nodes first begin to monitor the *ROI* is defined as the system initialization point, while the time at which more than *m*% of the small regions are inactive (i.e. the energies of all of the sensor nodes within these regions are less than *CP*) is defined as the system termination point. The duration between the initialization point and termination point is defined as the system lifetime (*SL*).

III. Description of MRDSR and PFEER

Energy-efficient communication in WSNs has received significant attention in recent years [20-22]. The following summarizes the research literature that is more closely related to our proposed solution. We first present general approaches related to lifetime maximization and load balancing, then focus on schemes specifically targeted to data collection trees. In order to solve the routing loop problem in RDSR algorithm, a modified relative direction-based sensor routing (MRDSR) algorithm is proposed. MRDSR algorithm is described as follows:

1. If there is a manager node within a 1-hop distance, the node is selected as the next node to deliver the event.

2. Otherwise, a neighbor node with the smallest sector ID is selected as the next node because it is closest to the BS. If more than one sensor node has the same smallest sector ID, the sensor node with the much power is preferred to balance power utilization. If more than one sensor node has the same power, one of them is randomly selected as the mediator.

In MRDSR algorithm since sensor nodes do not have sufficient battery power, some sensor nodes become inactive when working for a long time. This result will reduce network connectivity and cause the network partition problem as shown in Figure 3. In order to solve the network partition problem, a network partition-free and energy-efficient routing (PFEER) algorithm is proposed. PFEER reduces unnecessary energy consumption when sensor nodes directionally transmit sensed data to BS and solves the network partition problem resulting from early dead sensor nodes. PFEER algorithm is described as follows:

1. Categorize the major nodes into their own sectors: This is the same as the MRDSR algorithm.

2. Search for a mediator to transmit data: This is the same as the MRDSR algorithm.

3. Solve the network partition problem: If the sector ID of the neighbor nodes of a major node are equal to the major node, the neighbor node with the smallest distance to the BS is selected as the mediator. Otherwise, the major node is called the stuck node and executes the network partition reconstruction algorithm (NPRA). NPRA is described as follow:

1. Initialization: The stuck node sends a re-construction packet (RCP) to a mediator to search for the sensor node which is closest to the BS. The mediator selection has some constraints, as shown in Figure 4. The sensor node which has a 2-dimensional (x, y) coordinate, such as (2,4), (4,4), (2,3), (3,3), or (4,3) can be selected as a mediator for the stuck node. But the node with coordinate (2,3) exceeds the stuck node's communication range (cR), so it cannot be selected as the mediator. The node with the coordinate (3, 3) is dead, so it also cannot become the mediator. Therefore, the stuck node can only randomly select a sensor node with the coordinate (2,4), (4,4), or (4,3) as a mediator. If the mediator is located to the right of the stuck node, it will use the right hand rule to search for the next mediator. Otherwise, it will use the left hand rule to search for the next mediator [14].

2. Use the right/left hand rule to select the next mediator: The sensor node is selected as a mediator stores its location in the RCP table and determines if a search for the next mediator is needed. If it can communicate with the BS, it will return the RCP to the stuck node. Otherwise, it will send the RCP to the next mediator according to the right/left hand rule. In Figure 5, node searches for a range based on the vector and selects the node as the next mediator. The mediator has some constraints that are different from the initialization step shown in figure 6. The node with the coordinate, such as (1,5), (2,5), (3,5), (1,4), (3,4), (1,3), (2,3), or (3,3) can be selected as a mediator for the stuck node. Some sensor nodes cannot be selected as the mediator, such as the sensor node with the coordinate (1,3), because it exceeds the current mediator's cR. In Figure 6, the current mediator selects the node with the coordinate (2,3) as the next mediator. Because , the coordinate (2,3) is earlier searched than the coordinate (1,4). If the current mediator cannot find any node as the next mediator according to the right/left hand rule, it will return the RCP to the stuck node and tell the stuck node to re-send a RCP by recording the error information in the RCP.

3. Determine the moving direction and distance: If the RCP is returned to the stuck node without passing through the former path, the stuck node will determine the moving distance according to the nodes' locations recorded in the RCP. Because the stuck node is location-aware and knows the location of the BS, it can use a linear equation between the coordinate of the BS and the stuck node. We then calculate the value of the linear equation for each node's location recorded in the RCP. The two neighbor nodes which have different value signs are named as attached nodes. The stuck node moves along the direction of the BS and does not stop until it can communicate with the attached nodes as shown in Figure 7. If the RCP is returned to the stuck node according to the former path and does not record the error information, the stuck node will select the last node's location from the RCP as the goal node. Then the stuck node moves along the direction of the goal node and does not stop until it can communicate with the goal node as shown in Figure 8. When the number of times that the RCP has been resent for the stuck node has exceeded one and the RCP received by the stuck node still records the error information, the stuck node will find the location of the node that is nearest to the BS from the RCP. If the node's sector ID is smaller than the sector ID of the stuck node, the stuck node moves along the direction of the node and does not stop until it can communicate with the node as shown in Figure 9. Otherwise, the stuck node is regarded as an inactive node.

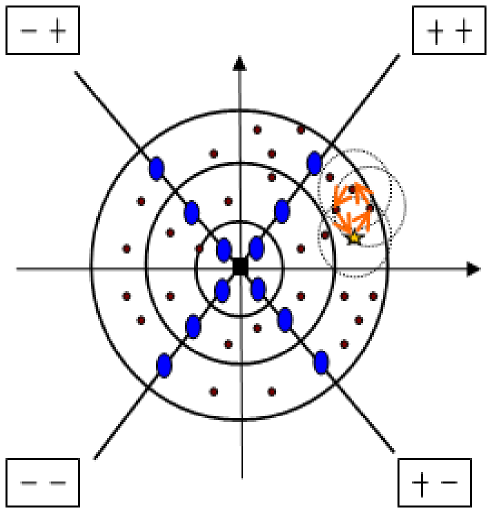

Figure 1. Routing loop problem in RDSR.

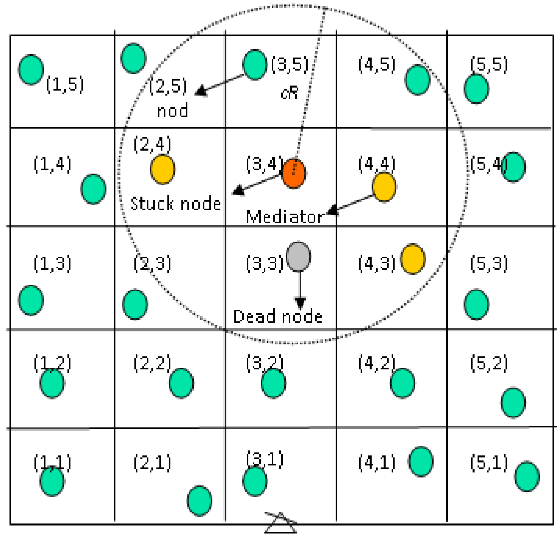

Figure 4. Possible mediators for the stuck node.

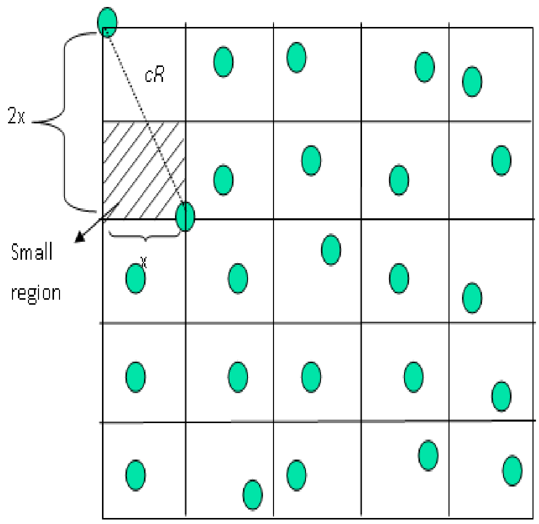

Figure 2.The total number of small regions (*Z*).

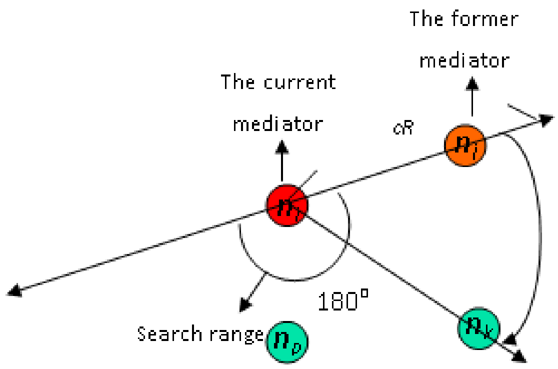

Figure 5. The left hand rule.

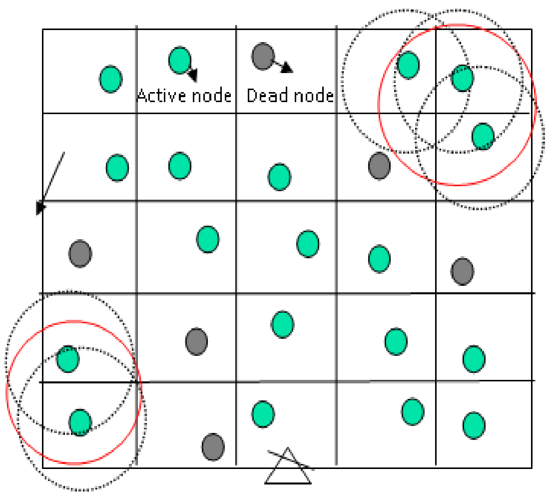

Figure 3. Network partitioning.

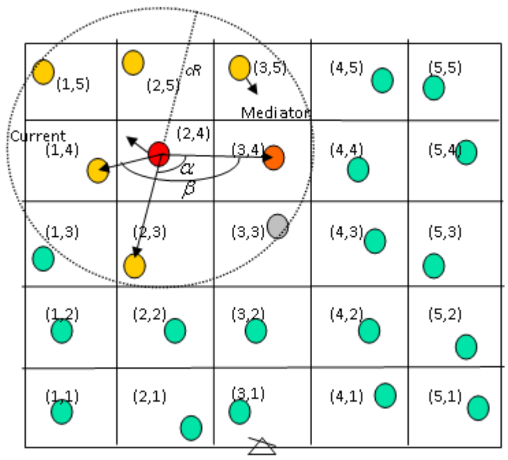

Figure 6. Possible mediators for the current mediator.

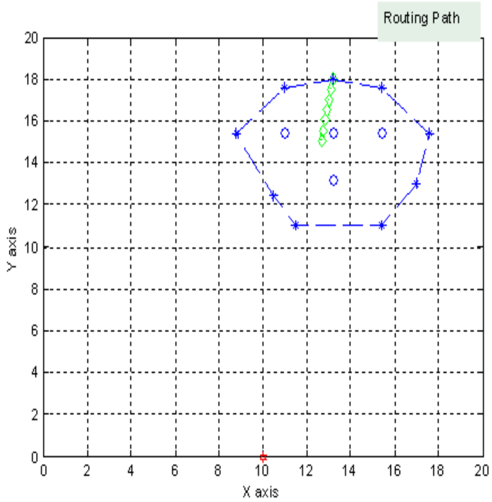

Figure 7. The moving direction and distance for the stuck node (the green points are stuck nodes, the red point is the BS, and the circles are the dead nodes).

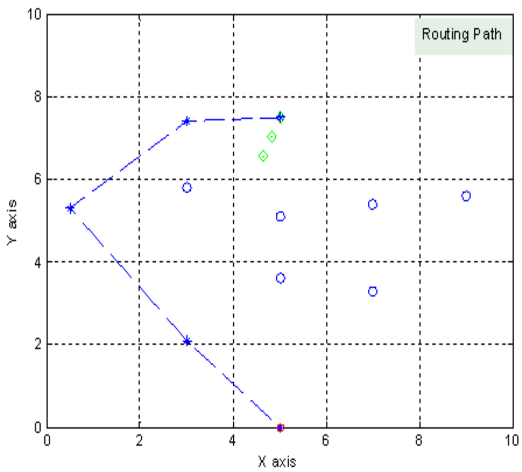

Figure 8. The moving direction and distance for the stuck node (RCP received without error.

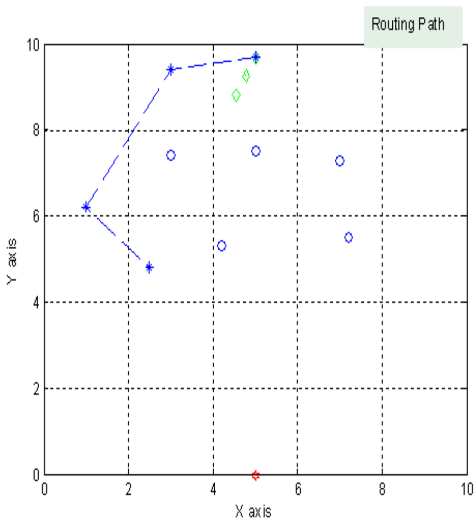

Figure 9. The moving direction and distance for the stuck node (RCP received with error information).

IV. Simulation Results

We use a Matlab simulator to evaluate the performance of our proposed routing algorithm here. The parameters of our simulation are as follows: The parameters of simulation are as follows: the initial node energy is 20 (J), the, cR = 5 (m), ROI = 20*20 (m2).

To verify that MRDSR can solve the routing loop problem, we evaluate the system lifetime performance of RDSR and MRDSR. In our simulations, we add a field in a packet to count the total number of hops that a sensor node uses to transmit data to the BS. If the total number of hops exceeds the threshold (Chop), a routing loop problem may occur on the network. Therefore, the packet will be given up. The value of the threshold Chop depends on the network size. In addition, if a sensor node cannot find any sensor nodes within its cR to relay data to the BS, it is regarded as an inactive node.

Figure 10 shows the system lifetime performance of RDSR and MRDSR. From figure 10, we can see that the performance of MRDSR is better than that of RDSR. But when the parameter u (u is the percentage of inactive sensor nodes in the ROI) less than 40, the system lifetime performance of RDSR outperforms that of MRDSR. This is because the number of inactive sensor nodes has exceeded 30% of all active nodes at the beginning of MRDSR. However, with an increase in the value of the parameter u, the effect of the routing loop on RDSR becomes obvious. However, the energy consumption for training the data predictor (computation) is non-negligible, and therefore they have investigated which conditions render using data predictors in CHs energy efficient. They showed that energy efficiency is a function of both the correlation of sensors' collected data and the desired error bound.

Figure 11 shows the coverage size performance for MRDSR and PFEER. The coverage size is defined as the number of active small regions. From figure 11, we see that the curve of the PFEER is smoother than that for MRDSR. This is because PFEER solves the network partition problem to prevent the number of inactive nodes from accumulating rapidly.

The system lifetime performance for MRDSR and PFEER is shown in figure 12. From figure 12, we see that PFEER has a longer system lifetime than MRDSR. The difference in the system lifetime performance between MRDSR and PFEER becomes obvious with the parameter m (m is the percentage of inactive small regions in the ROI). This is because the probability of network partition problem increases, and causes a significant effect on MRDSR. From the above discussion, to decrease the energy consumption of the RDSR, the energy consumption per unit of data transmission must be decreased, and/or the volume of data flowing through the network must be limited.

Finally, the relationship between the system lifetime and the number of sensor nodes is shown in figure 13. From figure 13, we see that the system lifetime performance of PFEER is better than that of MRDSR because PFEER has an advantage in improving network partition problem. For MRDSR and PFEER, the larger the number of sensor nodes get the better system lifetime. This is because more and more sensor nodes are selected as major nodes when there is an increase in the number of sensor nodes. The probability of each sensor node being selected as a major node is lower. Thus, the sensor nodes can conserve energy and prolong system lifetime.

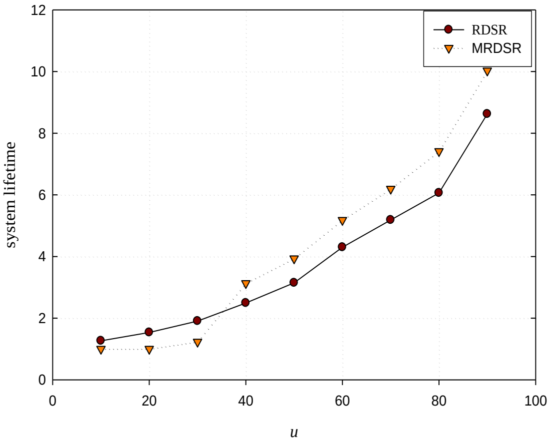

Figure 10. System lifetime versus *u*.

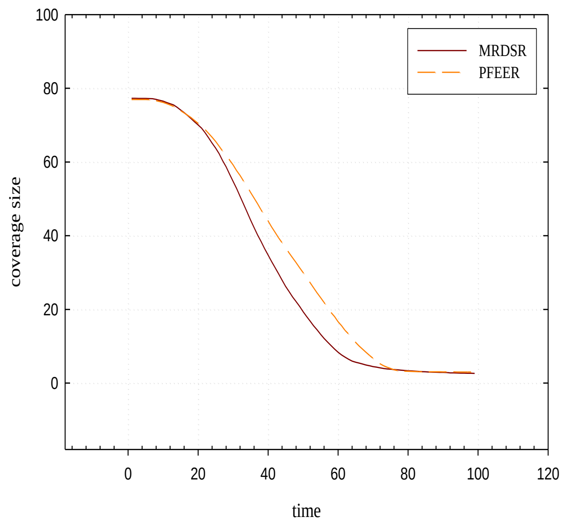

Figure 11. Coverage size versus time.

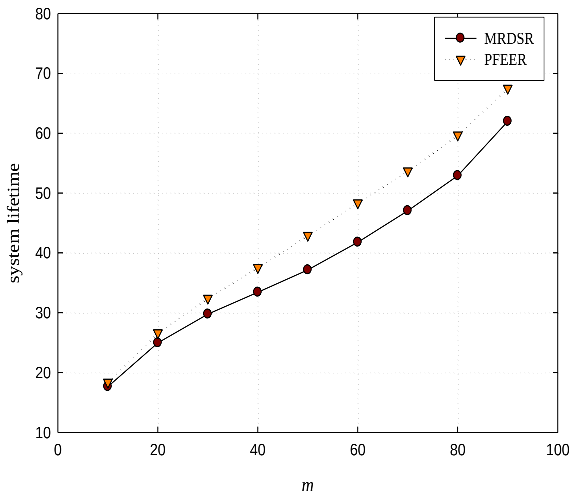

Figure 12. System lifetime versus *m*.

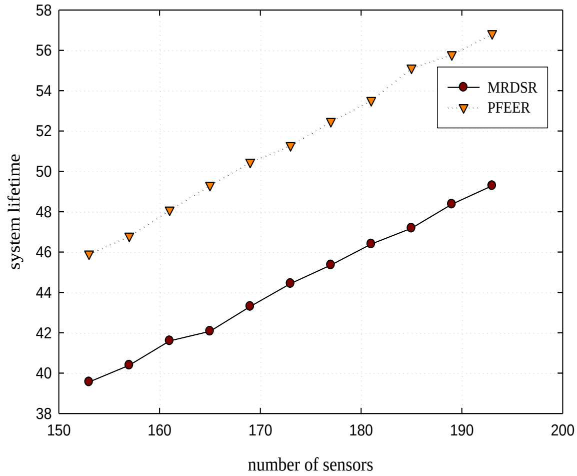

Figure 13. System lifetime versus the number of sensors.

V. CONCLUSIONS

In this paper, we have addressed the crucial problem of energy efficient routing for wireless sensor networks. The limited energy capacity along with the difficulty of changing batteries of deployed sensors makes energy-efficient technologies essential for the longevity of wireless sensor networks. Then, we further proposed an energy efficient routing algorithm for WSNs to improve network performance in terms of energy consumption and network lifetime. After the deployment of the sensor nodes is completed, the sensor nodes are designed to have active and sleeping modes to improve energy consumption and extend system lifetime by LEUD algorithm. When the aggregation of data is transmitted to a remote BS by RDSR algorithm, it has to select an optimal path to reduce the energy consumption. We modified the RDSR algorithm named as MRDSR algorithm to solve the routing loop problem. Moreover, when the partition problem happens on WSNs due to energy exhaustion of sensor nodes, in order to extend the system lifetime we must solve the network partition problem. Therefore, a novel routing algorithm named as PFEER was proposed. PFEER not only has the characteristic of MRDSR but also avoids the accumulation of inactive nodes in the ROI due to network partition problem and enhances network connectivity and coverage. From the simulation results, we observed that PFEER has a longer system lifetime than MRDSR and reduces coverage slowly. Through extensive numerical simulations, we demonstrated that the proposed algorithm can support a much longer network lifetime compared to the scheme optimized for the conventional wireless sensor networks.

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Ho-Lung Hung received the M.S. degree in electrical engineering from University of Detroit Mercy, Michigan, USA, in 1994 and the Ph. D. degree in electrical engineering from National Chung Cheng University, Chia-Yi, Taiwan, in 2007. From1995 to 2006, he was a lecturer with the Department of Electrical Engineering, Chienkuo Technology University, Taiwan. Since 2007, he was an associate professor with the Department of Electrical Engineering, Chienkuo Technology University, Taiwan. His major research interests include wireless communications, artificial neural networks, evolutionary optimization, and Wireless sensor networks, intelligent information processing and intelligent systems. He serves as an Associate Editor of the TELECOMMUNICATION SYSTEMS.

Chien-Erh Weng received the M.S. degree in Electrical Engineering from the National Yunlin University of Science & Technology, Yunlin, Taiwan, and the Ph.D. degree in electrical engineering from the National Chung Cheng University, Chiayi, R.O.C., in 2000 and 2007, respectively. Since Sep. 2010, he joined the Department of Electronic Communication Engineering at National Kaohsiung Marine University, Kaohsiung, Taiwan, R.O.C., as an Assistant Professor. His research interest is in the fields of performance study of UWB communication systems, wireless sensor networks and cooperative radio networks.