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Sink Relocation for Lifetime Elongation in Wireless Sensor Network

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Abstract— **With the emergence of diverse sensing application, there is a demand for increasing the lifetime of wireless sensor network. These include environmental monitoring, intrusion detection, battlefield surveillance, and so on. In a wireless sensor network (WSN), how to conserve the limited power resources of sensors to extend the network lifetime of the WSN as long as possible while performing the sensing and sensed data reporting tasks, is the most critical issue in the network design. The nodes neighbouring the sink suffer more rapid energy depletion due to high transit traffic. This problem can be mitigated by relocating the sink occasionally. To meet this challenge, Energy Aware Sink Relocation (EASR) method, a moving strategy technique for mobile sinks in wireless sensor networks has been proposed. In the proposed work the EASR method, incorporates the technique of energy aware transmission range which adjusts to tune the transmission range of each sensor node according to its residual energy.Some numerical analyse are given to show that the EASR method can extend the network lifetime of the WSN significantly.**

Keywords— Mobile sink, sink relocation, residual energy,wireless sensor networks.

I. INTRODUCTION

A Wireless Sensor Network of small sized sensor devices, which are equipped with limited battery power and are capable of wireless communications. When a WSN is deployed in a sensing field, these sensor nodes will be responsible for sensing abnormal events or for collecting the sensed data for environment. WSNs usually contain two types of nodes: sensor nodes and sink nodes.

A sensor node is a small device that has limited power, sensing and computation capabilities, while a sink node has more resources in terms of power, computation, and mobility. A cluster head manages the sensors in its cluster, gathers information from them, and forwards data to and from the sink. The sink node will then inform the supervisor through the internet. As shown in Fig 1, sensor node e detects an abnormal event and then it will send a warning message to the sink to notify the supervisor via a predetermined routing path, say Pea=e—d—c—b—a. The routing path may be static or dynamic, depending on the given routing algorithm.

Sensors are usually battery powered, for example, the Berkeley mote is powered by two batteries. In general, sensors are left unattended after the initial deployment and it is difficult to recharge them. It will take a limited time before they deplete their energy and become nonfunctional. A sensor network is usually expected to be functional for several months or one year without recharging. Optimizing energy consumption to prolong network lifetime is an important issue in WSNs. The applications of WSNs are broad, such as weather monitoring, battlefield surveillance, inventory and manufacturing processes, etc. 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.

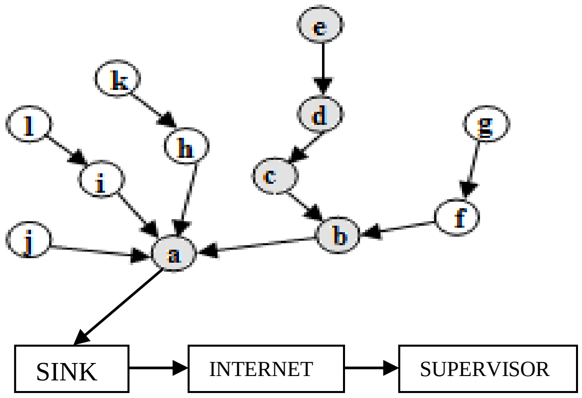

Fig. 1 An operating scheme of WSN

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, designing energy-efficient routing algorithms to balance the consumption of the battery energy of each sensor node, or using some data aggregation methods to aggregate similar sensory data into a single datum to reduce the number of transmitted messages to extend the network lifetime of the WSN.

A compromise approach is to use a mobile sink to relocate its position instead of relocating the sensor nodes. As shown in the Fig 1, the sensor node *a* near the sink will quickly drain out its battery power after relaying several rounds of sensed data with reported tasks being performed by other sensor nodes, and consequently the WSN will die. We call node *a* as hot spot. In the case of the sink being capable of moving, before the hot spot node *a* drains out all of its battery energy, the sink can move to another position to relieve the situation of heavy energy consumption of node *a*. As shown in the Fig

2, the sink relocates its position from the nearby node *a* to node *b*.

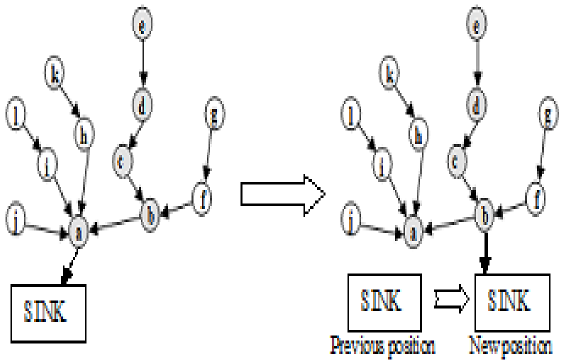

Fig. 2 Sink Relocation of WSN

In such a way, the role of the hot spot will be interchanged from one node to another node and consequently the network lifetime will be extended. The sink can be static or mobile, and can be placed at different locations in the WSN. In the case of a static sink, nodes located in the vicinity of the sink deplete their energy much earlier compared to the nodes located farther away from the sink due to higher data relaying load. In order to address this issue, sink mobilization has been introduced, where the sink moves along a certain path through the network.

II. MOBILITY MODEL OF WSN

For extending the lifetime of the nodes close to the sink is the utilization of a mobile sink. This is similar to using several static sinks however, using several static sinks requires additional global communication for collecting all data at a single final point. In order to overcome the shortcomings observed for a static sink, the use of a mobile sink has been proposed. A mobile sink can follow different types of mobility patterns in the sensor field, such as random mobility, predictable and fixed path mobility, or controlled mobility, which has consequences with respect to energy efficiency and data collection strategies. The following are some of the proposed solutions for each type of mobility.

A. Random Mobility

The sink follows a random path in the sensor field and it relate to the data collection strategy as shown in the Fig 3. The sink uses a pull strategy for collecting data from the sensor nodes. In a pull strategy, a node forwards its data only when the sink initiates a request for it, whereas in a push strategy a node proactively sends its data towards the sink. The random sink mobility can be used to reduce Emax and Ebar compared to the case of a static sink.

Single hop data collection leads to the strongest reduction of energy consumption, because no data relaying load on the sensor nodes exists. However, it can also result in incomplete data collection from the WSN, because with a random mobility pattern there is no guarantee that the sink will reach all nodes in the sensor field or it might take too much time to do so. If the time required for complete coverage of the field has to be even lower, then the sink can be programmed to collect data from all nodes which are within a maximum number of hops larger than one. This results in increased relaying load on the sensor nodes, and hence increases Emax and Ebar compared to the case of single hop data collection .

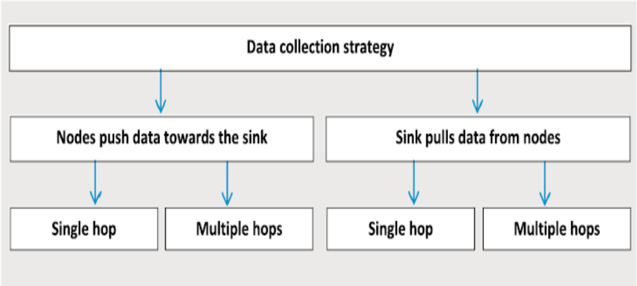

Fig. 3 Data Collection with Random Sink Mobility

If the data collection is not triggered by the sink, but follows a push strategy, another major overhead in the case of random sink mobility occurs because of the difficulty of tracking the current position of the sink and adapting the routing paths to the sink in the case of multihop communications shown in the Fig 3, which leads to increased energy dissipation. In order to address this issue, is to use the overhearing feature of the wireless networks to track the position of the randomly moving sink. In this method the mobile sink periodically transmit a beacon message containing its position.

Whenever a neighboring node of the sink hears this message, it updates the sink location in subsequently transmitted packets accordingly. Every node that over-hears the packet from neighboring nodes of the sink will also update the location coordinates of the sink thus eventually all nodes will have updated the location coordinates of the sink for geographic routing. A mobile sink based data collection scheme for delay tolerant networks by formulating an optimization problem that maximizes the lifetime of the WSN given delay and flow conservation constraints. The formulated model enables the node to identify the best time to route data to the sink so that all constraints regarding energy and delay can be met.

B. Fixed Mobility

In this class of schemes the sink is programmed to follow a fixed path in a round robin fashion. This fixed path is predetermined and is not influenced by the behavior of the WSN at runtime. Coverage of the sensor field has to be guaranteed by an appropriate strategy for determining the routing paths for the data packets. An important distinction is whether the sink can predict its future positions or not can be seen the Fig 4 and a reactive data forwarding mechanism done using a pull strategy based on request messages broadcasted by the sink

Sink mobility is planned such that the complete sensor field can be traversed in minimum possible time. As a result, energy dissipation (Emax and Ebar) can be very low. In case the sink is able to predict its future positions it can communicate this information to a node located in the vicinity of its future position. This node is responsible for collecting the sensor data in its vicinity so that when the sink actually arrives at this position, it should not have to wait for the data.

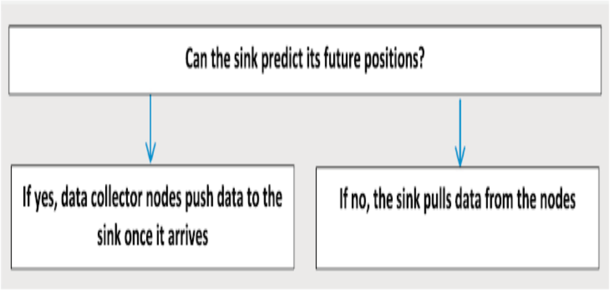

Fig. 4 Data Collection with Fixed Sink Mobility

If nodes in a WSN are programmed to report data towards the sink within a certain fixed time interval, then minimum Emax can only be achieved if the mobility trajectory of the sink is set close to the periphery of the sensor field. A practical routing protocol that not only balances the energy dissipation of the nodes but also tries to reduce loss of data.

In the case of varying data rates across sensors, energy dissipation can be balanced by partitioning the nodes in groups (clusters) such that each group has approximately the same total data rate. The cluster head was denoted as ‘‘sub sinks’’, which are deployed in the sensor field. Each sensor node is then associated with one of the sub sinks. The association criterion is based on how much time the sink spends with each sub sink. If a sub sink has the mobile sink in its vicinity for a longer time, then more sensor nodes are associated with it and vice versa, which improves the throughput of the sensor field.

C. *Controlled Mobility*

Sink mobility is controlled or guided based on a parameter of interest, such as residual energy of the nodes, or on a predefined objective function, or on predefined observable events. An energy unconscious mobility of the sink results in uneven energy dissipation from the nodes. To address this particular problem, a mobile sink based approach, where the sink tries to stay away from the nodes with less residual energy and tries to be in the vicinity of those nodes that have high residual energy. This helps balancing the energy dissipation from the nodes, and hence reduces Emax.

The idea of using controlled mobility in WSNs as shown in Fig 5 for reducing Emax was to determine sink movements, which define a mixed integer linear programming (MILP) model for maximizing sojourn times at the sites the sink can visit subject to constraints in terms of energy dissipation and other parameters. An off-line solution of this analytical model provides those sink routes that minimize Emax. A greedy maximum residual energy (GMRE) heuristic moves the sink only to those sites where the residual energy of the node is maximum. The communication required for retrieving the residual energies of the nodes adds extra overhead.

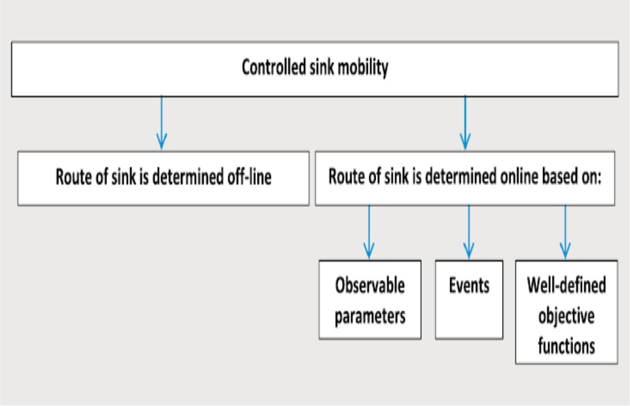

Fig. 5 Data Collection with Controlled Sink Mobility

Various metrics were used for defining the objective function, such as residual energy of the nodes, network congestion and average distance between nodes and the sink. The sink is mobilized to a new location whenever degradation in the objective function is observed. To improve the lifetime of a WSN can also be obtained using multiple mobile sinks. By using a heuristic algorithm we can compute the mobility trajectory as well as the sojourn time for each mobile sink such that network lifetime is maximized.

In event driven networks, adaptive mobility strategies can be used where the sink adapts its location based on current events in the field .In this scheme mainly focus on the generic model situation of a WSN with circular shape and a mobile sink which moves along a fixed concentric circle around the center. In addition to the influence of radius of this circular sink trajectory, the duty cycling of the sensor nodes on the energy consumption of the WSN can also be investigated.

III. ENERGY AWARE SINK RELOCATION METHOD

Sensor nodes are battery powered devices, charging batteries for sensor nodes is often difficult. Operations, such as sensing, communication, and computation, consume the energy of sensor nodes, and data transmission is the major source of energy consumption. Thus, it is a serious challenge to design an energy efficient routing scheme for reporting sensory data to achieve a high delivery ratio and prolong the network lifetime.

The EASR method [1], which incorporate the technique of energy aware transmission range adjusting to tune the transmission range of each sensor node according to its residual battery energy. In the case of the residual battery energy getting low after performing rounds of message relaying and environment sensing tasks, then its transmission range will be tuned to be small for energy saving. The relocating decision made by the sink will take the MCP routing protocol [9], as the underlying message routing in order to gain the merit of prolonging network lifetime.

IV. SYSTEM MODEL

Energy aware sink relocation method is a proposed sink relocating scheme to guide the sink when and where to move.

This method will briefly describes about the energy model of a WSN, the energy efficient routing scheme that will be incorporated into the EASR scheme, and the sink relocation mechanism. Besides the sink relocation scheme, the entire operation of the WSNs for environment monitoring also needs to incorporate the routing method for reporting the sensed data from the source to the sink, as well as the energy consumption model. At the end of this section, some related research works for sink relocation will also be addressed.

A. Energy Consumption Model

In this model which focus on the problem of maximizing the lifetime of a wireless sensor network where the sensor nodes communicate with the sink by delivering the sensed data across multiple hops with different transmission energy requirements. That is, there is flexibility of transmitter power adjustment and the energy consumption rate per unit information transmission is not the same for all neighbours of a sensor, but depends on the choice of the next hop node.

The lifetime of the network is defined as the time until a sensor node drains out of battery energy for the first time. In multiple sinks are used not only to increase the manageability of the network, but also to reduce the energy dissipation at each node. A linear programming formulation is given for the problem of determining the sink sojourn times at different points in the network that induce the maximum network lifetime.

The initial amount of energy and the rate at which data packets are generated are the same for all sensors. The wireless channel is considered bidirectional and symmetric. There is no power control since the transmission range is the same for all sensor nodes (equal to the size of a cell of the grid), and the sensor locations and the possible sink locations are the same.

In the energy consumption model, $E_{Tx}(k, d)$ and $E_{Rx}(k)$ denote the total energy required in a sensor node to transmit and receive a *k*-bits length message to and from a neighboring sensor node at distance *d* away, respectively. The energy consumed for message transmitting ($E_{Tx}(k, d)$) can be partitioned into two.

$$E_{Tx}(k, d) = E_{elec} \times k + E_{amp} \times k \times d^n \qquad (1)$$

$$E_{Rx}(k) = E_{elec} \times k \qquad (2)$$

The first part is the energy consumed in the transmitted electronic component and is equal to $E_{elec} \times k$, where E_{elec} denotes the energy consumed for driving the transmitter or receiver circuitry. The second part is the energy consumed in the amplifier component and is equal to $E_{amp} \times k \times d^n$, where E_{amp} denotes the energy required for the transmitter amplifier. The receiving process performed in a sensor node only includes the first part of the energy consumption.

B. Energy Aware Transmission Range Adjusting

Energy constraint is the most conspicuous characteristic in wireless sensor networks (WSN). Node deployment, dynamic topology control, and data transmission in WSN all consume a large amount of energy. Therefore, proper adjustment of transmission power (TP) contributes much energy saving. It is a feasible way to set the node in a sleep state in order to reduce energy consumption. Another way is to adjust a proper transmission power (TP) in working state, which tries to guarantee expected performance with minimum energy cost. Therefore TP control (TPC) has a great potential to save energy. In a larger transmission range set for a sensor node will increase the number of neighbours and consequently enhance the quality of the energy aware routing; however, it also bring the drawback of longer distance message relaying, which will consume more battery energy of a sensor node. For a shorter range of communication, it does not help too much for routing, it can conserve the usage of the residual battery energy. In the proposed method, the transmission range adjusting will depend on the residual battery energy of a sensor node. The sensor nodes are classified into three types by the ’healthy’ state of their battery and adjust their transmission range accordingly.

Let B be the battery energy value when the battery energy is full in the beginning and r (u) denotes the current residual battery energy of a sensor node u. In the case of $0 \geq r(u) < B/3$ (and $B/3 \geq r(u) < B/2$), then sensor node u belongs to type I (and II) sensor node and we set its transmission range to $\gamma/4$ (and $\gamma/2$), respectively, where γ denotes the initial transmission range of a sensor node. For the case of $B/2 \geq r(u) \geq B$, the sensor node *u* is very healthy for its battery energy (type III node) and we set its transmission range to γ.

Intuitively, a ’healthy’ sensor node can adapt a larger transmission range to shorten the routing path, while a sensor node with only a little residual battery energy can tune the transmission range to be small to conserve its residual energy. Thus an adaptable transmission range adjusting mechanism can enlarge the lifetime of a sensor node and the network lifetime. Energy conservation is advantageous to prolong the network lifetime and consequently the network lifetime.

V. NETWORK MODEL

Routing protocol designs of message reporting in a WSN can generally be classified into two categories: static routing and dynamic routing. For the static routing type, when as the message reporting paths are determined, each sensor node will report its sensed data along the predetermined path to the sink at any time. A dynamic routing protocol might alter the routing paths in each transmission round according to the current state of the sensor nodes residual battery energy. Due to the fact that the dynamic routing protocols can balance the load on each sensor node, it performs better for network lifetime prolonging than the static routing protocols.

The network model of this method uses a dynamic routing protocol, called Maximum Capacity Path (MCP) [9], as the underlying routing protocol of the proposed sink relocation method. The MCP is proposed and has also been demonstrated to perform well in prolonging network lifetime in a WSN.

A. Maxmimum Capacity Path Scheme

A sensor node in the layered network may have multiple shortest paths to reply the sensing data to sink. The MCP mainly consists of three procedure steps. They are layering graph G into a layered network N, determining the maximum capacity path for each sensor node in which routing performed and residual energy updated. The MCP will iteratively perform the above three steps for each round of message reporting.

For example, consider a layered network as shown in the Fig 6. The number beside each node represents its available energy. When sensor node at level 3 has a data packet to send, it has three routing paths: e—c—a—s, e—c—b—s and e—d—b—s. Node selects a neighbour node with maximum available energy as its forwarder, node d. The node e selects path to forward the data is e—d—b—s. However, the available energy of node b is very low and then node will run out of its energy rapidly. A WSN and its current residual battery energy state of sensor node can be modeled by a capacity graph G = (V, E), where set V denotes the collection of sensor nodes and *E* denotes all of the possible direct communication between sensor nodes.

Let $r : V \rightarrow R^+$ be the residual battery energy function to represent each sensor's residual battery energy. As shown in the Fig 6, node *s* stands for the sink with infinity energy due to the fact that it can plug in to a power line or is equipped with an extremely large capacity battery compared to that of the sensor nodes. The value that is associated with node a is equal to 50, which stands for the current residual battery energy of sensor node *a*.

The level number is represented as L_v with respect to each sensor node $v \ni V$ denotes the shortest path length from v to the sink s. In Fig 6, the shortest path length from nodes g and h to node s are both 4, $L_g = L_h = 4$. The layered network N can be obtained from graph G by deleting the edges $(u, v) \ni E$ hence $L_u = L_v$. Since $L_a = L_b = 1$ and $L_g = L_h = 4$, then edges (a, b) and (g, h) will be deleted from G. Then the layered network N obtained from G is a directed graph, such that for all of the remaining edges $(u, v) \ni E$ after the deleting operation, the directed edge (u, v) from node u to node v , if $L_u = L_v + 1$. The $P_{us} = u, u_1, u_2, \ldots, u_l$, s be a path from node u to the sink s in N. The capacity $c(P_{us})$ of path P_{us} be the minimum value of residual battery energy in path P_{us},hence $c(P_{us}) = \min\{r(u), r(u_1), r(u_2), \ldots, r(u_l)\}$. Let P_{us}^* be the maximum capacity path with the maximum capacity value among every path from node u to s. The resulting graph of the union of each maximum capacity path P_{us}^*, will be the routing paths for message reporting.

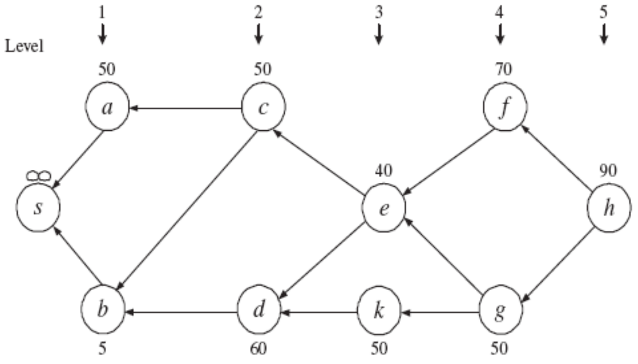

Fig. 6 Path Selection in Layered Network

The above operations are the second procedure steps of the MCP. Now, as a sensor node u detects an abnormal event or has sensed data to report to the sink node s, then the message will be relayed along the maximum capacity path P_{us}^* to s. For example, the maximum capacity path P_{gs}^* = g—e—c—a—s. After the message relaying from node g to s along path P_{gs}^* , the residual battery energy of each sensor node in the path is updated accordingly.

B. *Sink Relocation Mechanism*

The sink relocation mechanism consists of two parts. The first is to determine whether to trigger the sink relocation by determining whether a relocation condition is met or not. The second part is to determine which direction the sink is heading in and the relocation distance as well. For the relocation condition, the sink will periodically collect the residual battery energy of each sensor node in the WSN. After the collecting process is completed, the sink will use the MCP routing protocol to compute the maximum capacity path P_{us}^* with respect to each sensor neighbour u of sink s. For each maximum capacity path P_{us}^* , denotes the maximum capacity value with respect to P_{us}^* as $c(P_{us}^*)$. The collection of the sensor neighbours of s be N.

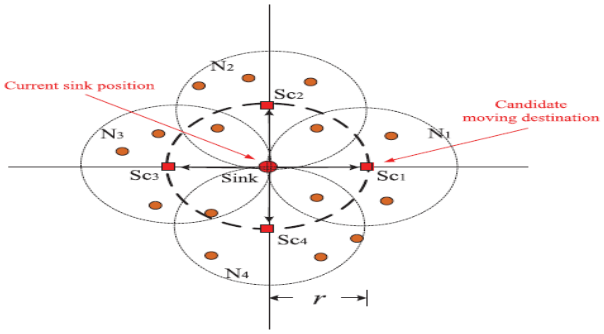

Fig. 7 Four Candidate Moving Destination for sink relocation

Then the relocation condition will be met when one of the following conditions occurrs when one of the capacity values $c(P_{us}^*)$ with respect to the sensor neighbor u in N drops below B/2 or the average residual battery energy of the neighbor set drops below B/2. When either the condition occurs, which means the residual energy of the nearby sensor nodes of the sink become small or the residual energy bottleneck of some routing paths falls below a given threshold (*B/*2). Then the sink relocation mechanism will be performed to relocate the sink to a new position, which can enlarge the network lifetime.

In the case of the sink having to relocate, it will firstly determine the positions of the moving destination. The moving destination has 4 candidate positions, S_{C1} , S_{C2} , S_{C3} , and S_{C4} , which are located in the right, up, left, and down direction γ distance away from the current position of the sink as shown in the Fig 7. Let the neighbour subset N_i with respect to each moving destination candidate S_{Ci} $(1 \geq i \geq 4)$ be the collection of sensor nodes that is located within the circle centered at node S_{Ci} with radius γ , respectively. Let a weight value w_i that is associated with each neighbour subset N_i , $1 \geq i \geq 4$ be

$$w_i = \min\{ c(P_{us}^*) | u \in N_i \} \tag{3}$$

where $c(P_{us}^*)$ denotes the maximum capacity value of P_{us}^*. Then, the relocating position S_{Ci*} will be chosen from S_{C1}, S_{C2}, S_{C3}, and S_{C4}, such that the weight value w_{i*} with respect to S_{Ci*} is the maximum value among w_i ($1 \geq i \geq 4$). Now the sink s will relocate itself to position S_{ci*}. Intuitively, the weight value w_i of a candidate position represents the residual energy lower bound among the bottleneck value of the routing paths to the sink when the sink relocate itself to the candidate position S_{Ci}. Thus the EASR method will drive the sink to the candidate position with the greatest w_i value among the four candidate positions by adopting 'healthy' routing paths to transmit the message to enhance the network lifetime. After the sink relocates to the new position, the above processes of the residual battery energy collecting and the relocating condition checking will be iteratively performed. In the case of the relocation condition once again being met, then the relocation process will also be invoked again.

VI. CONCLUSION AND FUTURE WORK

The depleting speeds of battery energy of sensor nodes will significantly affect the network lifetime of a WSN. Most of the proposed works have aimed to design energy aware routings to conserve the usage of the battery energy to prolong network lifetimes. A relocatable sink is another approach for prolonging network lifetime by avoiding staying at a certain location for too long which may harm the lifetime of nearby sensor nodes. This approach can not only relieve the burden of the hot-spot, but can also integrate the energy-aware routing to enhance the performance of the prolonging network lifetime. The proposed energy aware sink relocation method (EASR), which adopts the energy aware routing MCP as the underlying routing method for message relaying.

In this work the implementation was mainly focused on energy aware sink relocation method for achieving higher network lifetime .The future work will be focused on using a predetermined hexagon trajectory mechanism to obtain the multiple sink relocation. The analysis of energy efficiency will be compared using adaptive routing mechanism.

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