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An Improved Stable Election based Routing Protocol with Mobile Sink for Wireless Sensor Networks

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***Abstract*—Due to the nonuniform distribution of wireless sensor nodes, unbalanced energy consumption has become a major research problem for wireless sensor networks (WSNs). Traditional clustered networks with fixed sink nodes always suffer from high energy burden during multihop transmission. Recent researches show promising advantages by introducing mobile sink(s) to networks with benefits of low latency, low energy consumption, and long lifetime, etc. In this paper, we propose a mobile sink based improved stable election protocol with nonuniform node distribution for WSNs, which selects cluster heads primary based on the fraction of advanced nodes with additional energy, and secondary on the residual energy. Besides, cluster heads select routing path to mobile sink based on comparison between its distance to the trajectory and distance to the nearest cluster head. Simulation results demonstrate that our algorithm has better performance than traditional routing algorithms such as LEACH and SEP.**

Keywords-wireless sensor networks; mobile sink; clustering; multi-hop; lifetime

I. Introduction

Wireless sensor networks (WSNs) are designed to sense and transmit information from interest areas to end-users. Its potential applications mainly include military tracking and surveillance, natural disaster relief, hazardous environment exploration, and health monitoring [1-3]. As sensor nodes have very limited energy and they are often infeasible to get recharged, it is very important to design energy efficient routing protocols and algorithms to optimize and balance energy consumption and finally prolong the network lifetime for WSNs [4].

In recent years, researchers have done numbers of study on clustering protocols. Clustering has characteristics such as scalable, energy-efficient, low latency, which make it a very popular technique for WSNs. Its essential operation is to select a set of cluster heads from the set of nodes in the network, and then cluster the remaining nodes with these heads [5]. The data gathered are transmitted through cluster heads to remote base station or the sink node. However, the sink nodes are always fixed, which could lead the nodes which near the sink die much faster, causing network partition and isolated sensors.

Usually, static sink node is unable to operate as efficiently as mobile sink [6]. Employing mobile sink can provide energy-efficient data collection with well-designed networking protocols for WSNs [7]. In such mobile sink scenarios, sink nodes are attached to vehicles, animals or people that move around region of interest. Although single hop data collection is feasible in networks deployed in small regions, multi-hop transmission manner is more commonly used in large sensor areas [8]. Intuitively, mobile sink can achieve the advantages with mitigating hot spot problem, balancing energy among sensor nodes, prolonging network lifetime, reducing transmission latency, and improving network performance by periodically accessing some isolated nodes into the network.

In this paper, we propose a Mobile sink based improved Stable Election (MSE) algorithm with nonuniform node distribution. We define mobile sink's trajectory as the centre line of the sensing field. Sink node can move back and forth along the fixed trajectory which is predictable. Sensor network can be divided into several clusters based on stable election protocol (SEP) [9]. Each cluster head collects data and sends it to the mobile sink. The inter-cluster routing algorithm is also proposed between cluster heads using multi-hop or single-hop scheme.

II. Related Work

Low Energy Adaptive Clustering Hierarchy (LEACH) is a representative clustering algorithm which uses randomized rotation of local cluster heads to evenly distribute the energy load among the sensors in the sensor network. As the author claimed that LEACH reduces communication energy by as

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much as 8x compared with direct transmission and minimum-transmission-energy routing [10]. To cope with the disadvantages of LEACH, LEACH-C was proposed in [11]. It uses central control algorithm to form clusters, which distributes cluster heads more evenly throughout the network. To make sure the energy load is evenly distributed among all nodes, base station computes the average node energy. Nodes with energy below the average cannot be cluster heads for current round.

The main idea in Power Efficient GAthering in Sensor Information System (PEGASIS) is to make energy load distribution more evenly among sensors for WSNs. Each node will receive from and transmit to close neighbors and take turns being the leader for transmission to base station [12]. It assumes that all nodes have global knowledge of the network; the base station is fixed at a far distance from the sensor nodes; the sensor nodes are homogeneous and energy constrained with uniform energy. PEGASIS builds a chain to ensure that all nodes have close neighbors. It starts with the further node from the base station by using greedy algorithm. When a node dies, chain is reconstructed in the same way to bypass dead node.

Recently, several applications that motivate mobility in WSNs appeared. In [13], a mobility-based clustering (MBC) protocol for WSNs with mobile nodes is proposed. The author consider residual energy of a sensor node, together with the current speed of each sensor node. A threshold value is multiplied by the factors representing the residual energy and the current speed of a node. MBC used a heuristic mechanism that each sensor node wakes itself up one timeslot before its scheduled timeslot according to the TDMA schedule and goes back to sleep mode after its timeslot.

A network infrastructure based on the use of controllably mobile elements was discussed in [14], with the essential of reducing the communication energy consumption at the energy constrained nodes and, thus, increasing useful network lifetime. The controllably mobile infrastructure reduces the communication energy consumption at the energy constrained nodes and, thus, increases useful network lifetime. In particular, the infrastructure focuses on network protocols and motion control strategies.

Backbone-based Virtual Infrastructure (BVI) approach has been proposed to avoid the routing structure construction [15]. BVI approach supports sink mobility without global position information. However, BVI network is always considered as a single hop network, which makes the tree organized by too many cluster heads. Thus, in [16], a novel BVI-based communication protocol to support sink mobility without global position information. The author used multi-hop clusters and rendezvous cluster head to reduce the number of cluster heads.

In [17], the authors propose a novel localized Integrated Location Service and Routing (ILSR) scheme for data communications from sensors to a mobile sink in wireless sensor networks. In ILSR, sink updates location to neighboring sensors after or before a link breaks and whenever a link creation is observed. ILSR is the first localized protocol that considering both unpredictable and controllable sink mobility. In [18], to address the issue that a mobile sink with constant speed has limited communication time to collect data from sensor nodes deployed randomly, a Maximum Amount Shortest Path (MASP) collection scheme has been proposed. The MASP scheme can increase network throughput and conserves energy by optimizing the assignment of sensor nodes. In [19], a simulation-based analysis of the energy efficiency of WSNs with static and mobile sinks was proposed. It focused on mobility path of the sink and duty cycling value of the nodes. It has also been observed that adopting a mobile sink and reducing the duty cycle of the nodes does not necessarily reduce the energy dissipation of the WSN.

III. SYSTEM MODEL

A. Basic Assumptions

We make the following basic assumptions:

- All sensor nodes are fixed after deployment;
- Each sensor node has a unique ID;
- Sensor nodes are synchronized;
- Links are symmetric;
- Sensor nodes are location-aware and can adjust their transmission power based on relative distance.

As can be seen from the assumptions above, sensor network is not assumed to be homogenous. In other words, the network can be heterogeneous with various types of sensors and sink nodes (static or mobile). Some advanced sensor nodes and special sink nodes with more powerful energy supply are available.

B. Network Model

In traditional nonuniform distributed WSNs, a static sink locates at the center of the network. In this paper, we consider a WSNs consisting of N sensors randomly dispersed in a rectangular network. The network is clustered into a group of clusters. Sensors are selected as cluster head based on $T(n)$, which will be discussed later. The sensors will transmit their sensed data to the sink through cluster head via a single-hop or multi-hop transmission.

The network model can be described as an undirected connectivity graph $G(S,E)$, where S is a set of all sensor nodes and E is the set of wireless link between node i and node j. To indicate a sensor node's condition, a function with position, residual energy, initial energy, and communication rage has been taken into consideration in (1), where $(x(i,n),y(i.n))$ is the position, $e(i,n)$is the residual energy, $E(i,n)$is the initial energy, and R_i is the transmission range.

$$\Psi_i(n) = f((x(i,n), y(i,n)), e(i,n), E(i,n), R_i) \qquad (1)$$

In terms of energy consumption and network lifetime, to achieve better network performance, a mobile sink based strategy is proposed in Fig. 1 where the gray thick line is the predetermined movement path for mobile sink across the sensor network. Mobile sink node will move back and forth along the path in order to gather data packets from cluster heads.

C. Energy Model

We use one pupular energy consumptio model which is called the first order radio energy model [10]. In order to transmit an l-bit length message through a distance d, the energy consumption by the radio is given by:

$$E_{Tx}(l,d) = E_{Tx-elec}(l) + E_{Tx-amp}(l,d) = \begin{cases} lE_{elec} + l\varepsilon_{fs} d^2, d < d_o \\ lE_{elec} + l\varepsilon_{mp} d^4, d \geq d_o \end{cases}$$

where $E_{Tx\text{-}elec}$ represents the transmitter electronics, $E_{Tx\text{-}amp}$ represents the receiver electronics, E_{elec} is the energy consumed to transmit or receive one bit data, ε_{fs} and ε_{mp} illustrate the amplifier model, and l is the length for data waiting to be transmitted.

The total energy consumption in sensor network is thus calculated in (2), where E_{DA} represents the energy for data aggregation and N is the number of nodes distributed uniformly in the network.

$$E_{tot} = L \cdot \begin{pmatrix} 2NE_{elec} + NE_{DA} \\ +\varepsilon_{mp} k \cdot d_{toBS}^4 + N\varepsilon_{fs} \dfrac{M^2}{2 \cdot \pi \cdot k} \end{pmatrix} \tag{2}$$

The optimal number of clusters can be found by setting the derivative of E_{tot} with respect to k as zero, which is shown by the following k_{opt}:

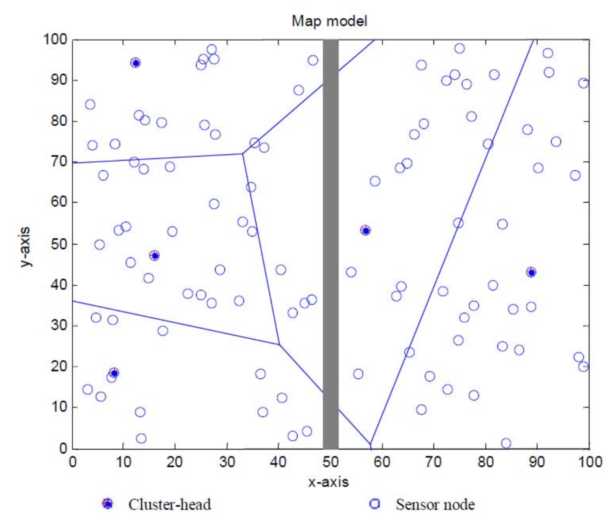

Figure 1. A nonuniform distributed WSN with a mobile sink trajectory on the centre line

$$k_{opt} = \sqrt{\frac{N}{2\pi}} \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \frac{M}{d_{toBS}^2}$$

$$P_{opt} = \frac{k_{opt}}{N}$$

IV. OUR PROPOSED MSE ALGORITHM

In this paper, we propose a mobile sink based improved stable election algorithm with nonuniform node distribution. We define mobile sink's trajectory as the centre line of the sensing field. Sink moves back and forth along the fixed trajectory which is predictable. Network is divided into several clusters based on improved stable election protocol, which selects cluster heads based primary on the fraction of advanced nodes with additional energy, and secondary on the residual energy. Each cluster head collects data and sends it to the mobile sink. The inter-cluster routing algorithm is also proposed between cluster heads using multi-hop or single-hop scheme.

A. Route Set-up Phase

1) Cluster Heads Selection

In our proposed algorithm, we consider network to be heterogeneous, where there are m percentage advanced nodes which have the additional energy factor (α) between itself and normal nodes. In [8], to deal with this kind of heterogeneous sensor network, SEP has been proposed, and discussed in detail. With these advanced and normal nodes, this kind of heterogeneous has no effect on the density of the network. Hence, the previous set of P_{opt} has no need to change. We assume initial energy to be E_0. The energy of advanced node in our proposed wireless sensor network is $E_0 \cdot (1+\alpha)$.

Hence, the total energy increase by $1+\alpha \cdot m$ times. Virtually there are $n \cdot (1+\alpha \cdot m)$ nodes with energy equal to the initial energy of a normal node. Based on equations of probabilities for advanced and normal nodes, which discussed detailed in [8], we improved the selection method with residual energy of certain sensor nodes. The weighed probability for normal nodes is:

$$P_{nrm} = \frac{P_{opt}}{1+\alpha \cdot m} \cdot \frac{E_{residual}}{E_0} \tag{3}$$

where P_{opt} is the optimal percentage of cluster head, α is the factor of additional energy, m is the percentage of advanced nodes, $E_{residual}$ is the energy left in sensor nodes after certain rounds, and E_0 is the initial energy of any nodes. Similarly, weighed probability for advanced nodes is:

$$P_{adv} = \frac{P_{opt}}{1+\alpha \cdot m} \times (1+\alpha) \cdot \frac{E_{residual}}{E_0} . \tag{4}$$

The SEP replaces P_{opt} by the weighted probabilities discussed above. It defines $T(s_{nrm})$ as a threshold for normal nodes and $T(s_{adv})$ as a threshold for advanced nodes. Every round, sensor node generates a random number between 0 and 1. If the random number is smaller than the current $T(n)$, it will be selected as a cluster head. For normal nodes:

$$T(s_{nrm}) = \begin{cases} \dfrac{P_{nrm}}{1 - P_{nrm}[r \bmod (1/P_{nrm})]} & if \ \ n \in G' \\ 0 & otherwise \end{cases}$$

where r is the current round, G' is the set of nodes which have not become cluster heads within the last $1/P_{nrm}$ rounds, and $T(s_{nrm})$ is the threshold applied to a population of normal nodes. Similarly, for advanced nodes, we define:

$$T(s_{adv}) = \begin{cases} \dfrac{P_{adv}}{1 - P_{adv}[r \bmod (1/P_{adv})]} & if \ \ n \in G'' \\ 0 & otherwise \end{cases}$$

where r is the current round, G'' is the set of nodes that have not become cluster heads within the last $1/P_{adv}$ rounds, and $T(s_{adv})$ is the threshold applied to a population of normal nodes [8].

2) *Cluster Formation*

In this section, we construct a routing tree based on cluster heads set which have been elected above. Final routing strategy for our MSE algorithm is illustrated in Fig. 2.

During broadcasting phase, each cluster head broadcasts an advertisement message (ADV_Msg) and its ID, location and type to sensors within its range using based on carrier-sense multiple access mechanism. Each normal cluster head will record the ID and location of an advanced cluster head with strongest received signal strength (RSS).

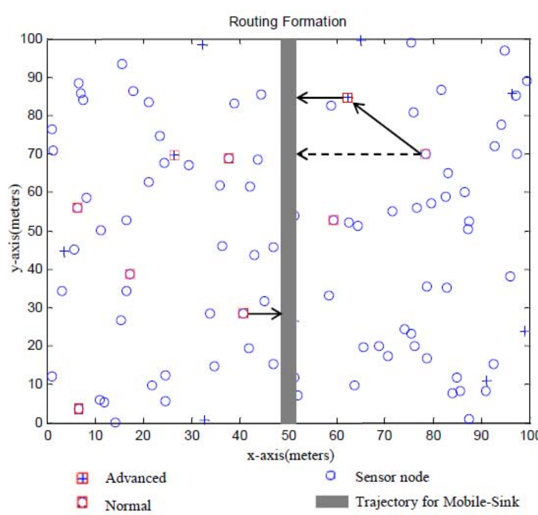

Figure 2. Routing strategy for our MSE algorithm

During decision phase, each non-cluster head node determines its cluster for this round by choosing the appropriate cluster head that has the strongest RSS of the ADV_Msg. After such node has decided which cluster it belongs to, it sends join message (J_Msg), which contains its ID and the chosen cluster head's ID, back to the chosen cluster head as well using the CSMA mechanism. After the cluster head receives all the J_Msg, it sets up a TDMA schedule and transmits this schedule to the sensor nodes in its cluster. By using TDMA schedule, collisions during messages transmission can be avoided effectively, and sensor nodes can be turned off if not on duty. This can effectively reduce the energy consumption for sensor nodes and prolong the lifetime of network.

If the vertical distance from a normal cluster head to the mobile sink trajectory is longer than the distance between itself to its nearest advanced cluster head, it will calculate the vertical distance from the advanced cluster head to the trajectory. Finally, if the distance between the advanced cluster head and the mobile sink trajectory is smaller, the normal cluster head will transmit its packet to the advanced cluster head. The packet will be fused and forwarded along with the data gathered in the cluster.

B. *Route Steady Phase*

Data sensing, fusion and transmission are the major activities which occur during the route steady phase.

In our proposed MSE algorithm, data of the interested region are sensed by the non-cluster-nodes in the network, and are transmitted to the respective cluster heads. To minimize the energy consumption in the network, the huge number of data gathered in the cluster head ought to be fused into a single data message before transmitting to the mobile sink. After all the data in the cluster are gathered, cluster head sleeps to further reduce energy consumption.

C. *Route Maintenance Phase*

As illustrated in Fig.3, there is a chance that the advanced

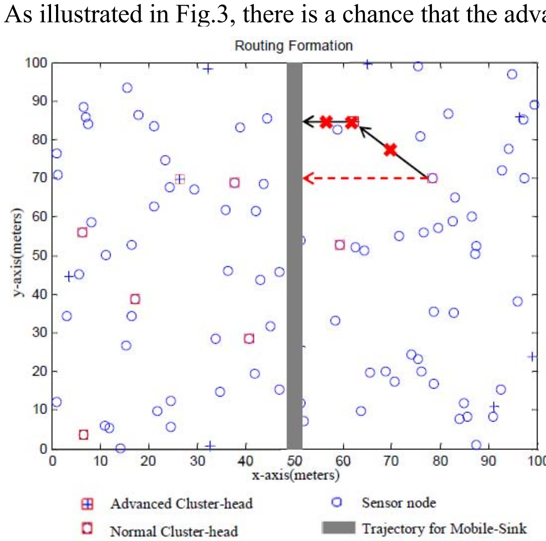

Figure 3. Maintenance of routing path

cluster head dies in a certain round or somehow there is a block between sensor nodes under real implementation, which will cause unexpected failures. Once the advanced cluster head died or blocked, its corresponding normal cluster head will have no next-hop, leading a certain area to be unreachable, and finally making the data inaccurate. However, reclustering a whole network only to solve one failure may result in significant resource waste.

To solve this phenomenon, calculating the residue energy of any advanced cluster head is recommended. Once the residue energy is not sufficient for the next data transmission and forwarding, it will send a stop message (STOP_Msg) to its corresponding normal cluster head and delete itself form the sensor network. In the meantime, TDMA schedule is ought to be updated. After the normal cluster head receiving the STOP_Msg, it will compare its distance to the adjacent advanced cluster head and trajectory. From this step on, the procedure is exactly the same as set-up phase. Once the original advanced cluster head died, the corresponding normal cluster head carried out the procedure above immediately, and forwards its data direct to the mobile sink. As illustrated in Fig.3, the original connected advanced cluster head lost its ability to forwarding data, and soon the normal cluster head find its new routing path to trajectory.

V. PERFORMANCE EVALUATION

A. Simulation Environment

We use MATLAB simulator to evaluate the performance of our proposed MSE algorithm. Relevant simulation parameters are listed in Table I, where 100 sensor nodes are distributed randomly in a rectangle region of 200x200 m^2. There are 20% of advanced nodes which are equipped with 400% more energy than normal nodes (which means m=0.2 and α =4). Obviously, the network with high density of advanced nodes will have a relatively long lifetime.

TABLE I. SIMULATION PARAMETERS

No.	Simulation Parameters		
	Parameters	***Representation***	***Unit***
1	N	Number of sensor nodes	100
2	E_0	Initial energy of sensor nodes	0.2*J*
3	E_{DA}	Data aggregation consumption	*5nJ/bit/signal*
4	E_{elec}	Energy dissipation to run the radio device	50 *nJ/bit*
5	ε_{fs}	Free space model of transmitter amplifier	10 $pJ/bit/m^2$
6	ε_{mp}	Multi-path model of transmitter amplifier	0.0013 $pJ/bit/m^4$
7	*l*	Packet length	4000 *bits*
8	d_0	Distance threshold	*m*

B. Performance Evaluation

Fig. 4 shows that the energy consumption rate of LEACH is much faster than our MSE. Consequently, the energy in LEACH network get drained away much earlier than MSE at about 400 rounds. From the figure we can point that MSE energy consumption curve is almost liner before 500 rounds, while the liner part for energy consumption curve of LEACH is before round 150.

Fig. 5 shows the number of packets received by sink. As illustrated, The result shows that MSE has higher number of data received than that of LEACH and SEP. In the first 200 rounds, the three proposed algorithms have nearly the same packet deliver numbers. However, after 500 rounds, the sensors in network with protocol of LEACH drain out totally and transmit no packet, while SEP and MSE continue delivering and forwarding.

Table II shows the round when the first node dies in three protocols respectively. The longer time for first node to die, the more balance the network will be. In a network which requires a more stable working time, our proposed MSE method will be more suitable.

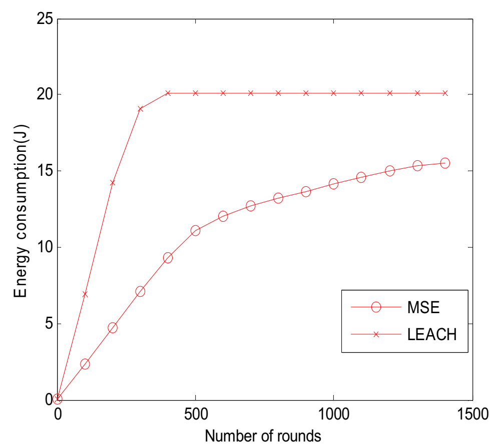

Figure 4. Energy consumption comparison

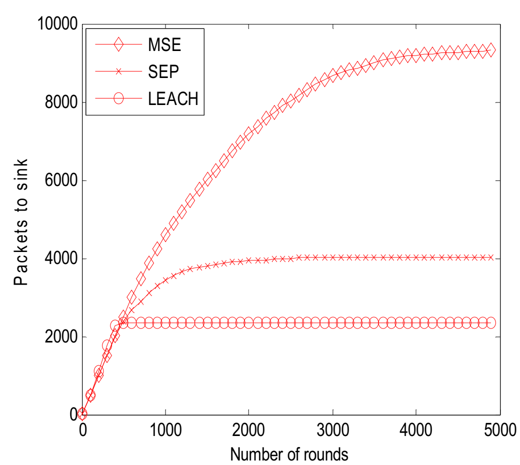

Figure 5. Number of packets received by sink node

TABLE II. ROUND WHEN FIRST NODE DIES

No.	First death round under different algorithms	
	Algorithm	*First death round*
1	LEACH	100
2	SEP	211
3	MSE	525

VI. CONCLUSION

In this paper, we propose a SEP based MSE algorithm for energy efficient routing for WSNs. Our proposed MSE algorithm forms hierarchical routing protocols by dividing the network into clusters and selecting cluster head based on fraction of advanced nodes with additional energy and ratio between residual and initial energy. MSE protocol showed promising performance in energy balancing and network lifetime prolonging. However, the trajectory in our proposed network is static, with the node dies or topology changes, the pre-located fixed trajectory may be unsuitable all the time.

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