Applied Mathematics & Information Sciences
An International Journal

http://dx.doi.org/10.12785/amis/090336

Shuffled Frog Leaping Algorithm based Unequal Clustering Strategy for Wireless Sensor Networks

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Received: 6 Aug. 2014, Revised: 7 Nov. 2014, Accepted: 8 Nov. 2014
Published online: 1 May 2015

Abstract: In energy-limited WSNs, coverage and connectivity are two of the most fundamental QoS issues, which have a great impact on the performance of WSNs for minimizing the node energy consumption and maximizing the network coverage lifetime. Due to the node distribution, the energy consumption among nodes is more imbalanced in cluster-based WSNs. Based on this problem, this paper proposes Sink Mobility based Energy Balancing Unequal Clustering protocol (SMEBUC) for WSNs with node distribution, which chooses the nodes with more energy as cluster heads and divides all nodes into clusters of different size through the improved Shuffled Frog Leaping Algorithm (SFLA). To reduce the cluster head replacement frequency, cluster head serves continuously to determine the cluster head exchange time and nodes weight. The greedy algorithm is adopted to select the optimal relay node between cluster head and Sink. To further reduce the energy consumption, mobile Sink routing is put forward to avoid the hot-spots. We evaluate and compare the performance of SMEBUC with LEACH and EBUCP, and the results show that SMEBUC achieves more energy savings, and energy balance.

Keywords: Clustering routing protocol; energy balancing unequal clustering; shuffled frog leaping; target coverage; WSNs.

1 Introduction

Wireless sensor networks(WSNs) are one of the three major high-tech industries in the future of the world which is consisted of a set of wireless sensor nodes according to a certain communication and topology protocol [1]. WSN is a comprehensive interdisciplinary of wireless communication, sensing, microelectronics and embedded computing. WSN consists of a number of ad-hoc networks, low-power, short-lived and a number of sensor devices that collaborate with each other to accomplish a common task and report the collected data through wireless interface to a center node [2]. WSNs are widely used in many applications such as military surveillance, civilian usage, industry, agriculture, healthcare, forest fire detection, wildlife conservation and other fields [3].

Due to the small size of a sensor node, lifetime, communication capabilities, processing ability and memory are constraint of the WSNs. Therefore, a more effective topology control protocol to prolong the lifetime, efficient energy consumption and to improve coverage and the payload balance is one of the key factors in WSN design. Since sensors are often deployed in remote or inaccessible environments where replenishing the sensor energy is usually impossible, a critical issue of WSN is conserving sensor energy and prolonging the network lifetime while guaranteeing the coverage of desired areas or targets, which is called the coverage problem [4]. The coverage concept is subject to a wide range of interpretations due to the variety of sensors and applications. Generally, coverage which has direct effect on the network performance can be considered as the measure of Quality of Service (QoS) in a WSN.

The increasing demand for applications in WSN has made the QoS an interesting and hot research topic. QoS requirements of WSN raise the significant challenges. While providing QoS guarantee, the network protocols need to deal with energy constraints. With the consideration of the properties of sensor networks such as limited energy, dynamic topology, high network density and large scale deployments have posed many challenges in the design, implement, and management of WSN. These challenges have demanded energy awareness and robust protocol design at all layers of the network protocol [5].

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Efficient energy and network lifetime were and still are the main design considerations for the most proposed protocols and algorithms for sensor networks and have dominated most of the research in WSNs [6,7,8]. QoS awareness and energy conserving in different layers are important topic in research of WSNs, and have been under the focus of research community on WSNs. Related studies have shown that adopting efficient routing protocol can improve the overall performance and QoS of WSNs [9].

In the recently research, clustering is an important energy-conserving method in WSN, and the good performance of WSN is highly dependent on energy-efficient clustering algorithm. Significant efforts have attempted to develop the routing algorithms to extend the lifetime of WSN. Hierarchical routing considers data aggregation and data fusion in order to reduce the number of transmissions to the base station. These routing techniques can be classified as cluster. Through clustering and cluster head selection rules, these hierarchical approaches spread energy usages over the whole network to extend the operational time of WSN.

Low Energy Adaptive Clustering Hierarchy (LEACH) [10] algorithm is the first hierarchical routing protocol proposed in WSNs. LEACH is a classic uniform clustering routing protocol. Each node independently elects itself as a cluster head with a probability to reduce the network energy consumption. LEACH can save more energy than that of the plane multi-hop routing protocols and the static network clustering. But LEACH does not consider the location of nodes inducing a bad informal distribution of clusters, and the remaining energy of nodes leading to the early death of some nodes and the overall invalidity of the network. LEACH supposes that the initial energy of all nodes is the same, and the energy consumption of becoming cluster head node are the same in the first cluster head electing. So LEACH is not good for imbalanced-energy network. To solve this problem, researchers proposed some new algorithms like LEACH-C, and LEACH-M to improved LEACH [11].

EEUC [12] is an energy-efficient unequal clustering protocol, which divides the nodes into clusters of unequal size. The clusters closer to the base station have smaller sizes than those farther away from the base station. Thus cluster heads closer to the base station can preserve energy for the inter-cluster data forwarding.

EBUCP [13] partitioned all nodes into cluster of unequal size and combined the unequal clustering mechanism within the cluster multi-hop routing properly to balance the energy dissipation among the nodes and prolong the lifetime of WSN. Clusters closer to the sink node have smaller sizes than those farther away from the sink node. Thus cluster heads closer to the sink node can preserve more energy for the purpose of inter-cluster data forwarding. The distribution of sensor nodes is deployed according to the energy-balancing layered algorithm and therefore the energy consumption in every layer is nearly equal.

EADEEG [14] is a novel distributed clustering algorithm, which elects the cluster heads based on the ratio between the average remaining energy of neighbor nodes and the remaining energy of the node itself, which can achieve a good cluster head distribution and prolong the network lifetime. TL-EBC [15] is a centralized clustering protocol of two-layer hierarchy, which is compact, energy-aware and energy consumption balanced. In the lower layer of the protocol, the optimal clustering of all nodes uses the Particle Swarm Optimization (PSO) algorithm. In the upper layer, the chief-cluster-head is responsible for collecting, aggregating the data of all cluster heads and sending the fused data to the base station. Sine the protocol still use the uniform clustering approach, the overall network performance has not been fundamentally improved.

EEUC-based clustering algorithm [16] introduced the PSO algorithm into the network clustering process by selecting the best node as cluster head to reduce energy consumption and prolong the network lifetime. However, the algorithm does not consider the problem of Sink node closer to cluster head, which may be excessive used and cause local node premature death.

[17] proposed a mobile Sink routing algorithm based on the clustering structure. It achieved certain results on avoiding ”hot spots” through the designing of Sink mobile route. However, this strategy caused a certain network delay.

[18] proposed a clustering protocol based parameter optimization. It adjusted the size and scale of the clusters by optimizing the relevant parameters to reduce the energy consumption in the inter-cluster. But the optimization of the relevant parameters on the network coverage and connectivity needs further study.

Shuffled Frog Leaping Algorithm(SFLA) [19] is a swarm intelligence-based heuristic technology, which combines the advantages of PSO and Mimetic algorithm, and has the characteristics of strong global search capability. There is no unified understanding on how SFLA effectively applies to the discrete optimization problem at present. The common method is to redefine frog particle encoding according to the characteristics of WSN, and introduces ”the conversion gene” and ”conversion sequence” concept in the traditional local search mechanism correspond with the frog particle encoding mode to improve the algorithm search breadth and speed.

EAUCF [23] is a distributed competitive unequal clustering algorithm. EAUCF aims to decrease the intra-cluster work of the cluster-heads that are either close to the base station or have low remaining battery power. EAUCF takes the advantage of fuzzy logic to calculate competition radius. To estimate the competition radius for tentative cluster-heads, EAUCF employs both residual energy and distance to the base station parameters. However, the unsolved problem of considerable energy consumption on the cluster formation still exists. The cluster formation overhead of the clustering protocols includes packet transmission cost of the advertisement, announcement, joining, and scheduling messages from sensor nodes. Also, these protocols do not support adaptive multi-level clustering, in which the clustering level cannot be changed until the new configuration is made by the network director. Therefore, the existing protocols are not adaptable to the various node distributions or the various sensing area. If the sensing area is changed by dynamic circumstances of the networks, the fixed-level clustering protocols may operate inefficiently in terms of energy consumption.

In this paper, Sink Mobility based Energy Balancing Unequal Clustering protocol(SMEBUC) for WSNs is proposed. It elects cluster heads based on the ratio between the average remaining energy of neighbor nodes and the remaining energy of the node itself, and uses uneven competition ranges to construct clusters of uneven sizes. SMEBUC improves the local search mechanism of SFLA to determine the network clustering and cluster head replacement strategy. Through which, SMEBUC improves the long single-chain problem of multi-hop routing. SMEBUC focuses on the analysis and discussion of the unequal clustering algorithm, the inter-cluster routing and Sink mobile through controlling the network clustering process and cluster communication, which make the network clustering topology more rational, balance the energy consumption among cluster heads and prolong the network lifetime.

The rest of the paper is organized as follows. Section 2 covers WSN architecture and energy model and SFLA. Section 3 exhibits the detail of SMEBUC Protocol. In Section 4 we describe simulation efforts and the analysis of results. Finally, Section 5 concludes the paper.

2 WSN Model and SFLA

2.1 WSN Architecture

We note that in LEACH, each node randomly decides to become a cluster head(CH). Once a node decides to become a cluster head, it aggregates the data received from various nodes inside the cluster and sends to the base station. However, the method of completely independent random cluster head selection can't guarantee the number nodes in the cluster and the distribution of cluster head in each round.

One possible method is to select a node which has higher remaining energy to become the CH, but it will cause the uneven energy loss for nodes in the network and form monitoring blind spot, even will influence the network's whole performance. In this research, we assume that a set of sensor nodes are unequally deployed in the square field to continuously monitor the phenomenon under inspection.

Fig.1 presents the packet transmission from node A to B on WSN. In Fig.1, node A transmits its data packet to B and all nodes within the transmission range can overhear the packet.

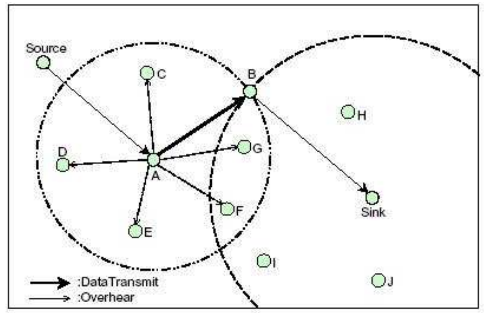

Fig. 1: Packet transmission of WSN

The nodes are distributed within the WSN monitoring area shown in Fig.2. The sensor node perceives the data in the monitoring range and sends fused data to the Sink node through communication technology. This paper assumes that M sensor nodes are unequally distributed within the rectangle monitoring area, and GC is the geometric center of the monitored area.

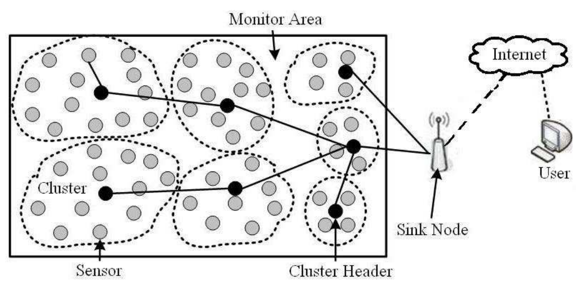

Fig. 2: WSN Architecture

According to the WSN application research background, the hypotheses in the proposed algorithm are as following.

(1)Sensor node in WSN has a unique ID: n_k(k∈[1,M]) and its location can not be moved. Sink node's energy and computing capacity is not limited, and is able to move in a predetermined position indicated by s.

(2)The sensor node has the same initial energy. The ordinary nodes are in the same layer while the cluster head is in the higher layer. The cluster head can communicate directly with Sink node shown in Fig.3.

(3)The sensor nodes have the same structure, capabilities of receiving and sending data. All nodes' transmission power can be adjusted, and the ordinary node can become a cluster head node.

(4)A sensor node has the same performance such as the initial energy, energy consumption and parameters.

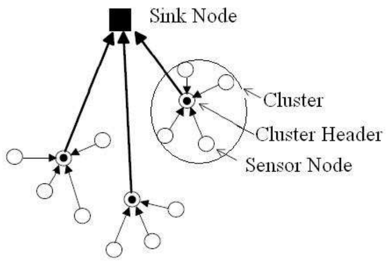

Fig. 3: the hierarchy of WSN

(5)Each node's location information is determined.

2.2 Energy Model

In wireless transmission, attenuation of sending power decreased exponentially with the increasing transmission distance. Our energy model is different from that in [16]. Here we add E_{DA} (the energy consumption of the node data fusion) to energy model of [16]. Both the free space (d^2 power loss) and the multi-path fading (d^4 power loss) channel models are used, depending on the distance between the transmitter and receiver. The electronics energy, E_{elec}, depends on factors such as the digital coding, and modulation, whereas the amplifier energy, $\varepsilon_{fs}d^2$ or $\varepsilon_{mp}d^4$, depends on the transmission distance and the acceptable bit-error rate. Equation (1) represents the amount of energy consumed for transmitting l bits of data to d distance. Equation(2) represents the amount of energy consumed for receiving l bits of data [13,23].

$$E_{TX}(l,d) = \begin{cases} l(E_{elec}E_{DA}) + l\varepsilon_{fs}d^2, d < d_{max} \\ l(E_{elec}+E_{DA}) + l\varepsilon_{amp}d^4, d \geq d_{max} \end{cases} \quad (1)$$

$$E_{RX}(l) = E_{RX-elec}(l) = lE_{elec} \quad (2)$$

In which, E_{elec} is the energy consumption per bit in the transmitter and receiver circuitry; ε_{fs} is free space model's amplifier energy consumption; ε_{mp} is multiple attenuation model's amplifier energy consumption; d_0 is a constant which relies on the application environment.

It is assumed that the sensed information is highly correlated, thus the cluster head can always aggregate the data gathered from its members into a single length-fixed packet. This assumption is impractical because the correlation degree of sensed data from different clusters is comparatively low. In this work, relay nodes don't aggregate the incoming packets. We assume that a cluster head consumes E_{DA}(nJ/bit/signal), which is the energy dissipation to perform local data aggregation and transmit the aggregate signal to a base station [24].

2.3 Evaluation Metrics of Coverage Control Algorithms

How to evaluate the performance of coverage and its algorithm is very important for the network's usability and effectiveness. The main factors are defined as follows.

Definition 1(QoS of Coverage): The QoS of coverage decides the completion of network tasks, reflects the network's sensing ability to the physical world, and is the basis standard of algorithm evaluating.

Definition 2(Number of active nodes): In the case of meeting the coverage requirements, the fewer number of active nodes are in a monitoring area, the larger effective coverage area will be with the given number of sensor nodes [25]. **Definition 3(Associating with the node location or not):** Coverage control algorithms associated with a node location depend on external infrastructure or some position mechanisms, relatively cost high and need to consume large mounts of energy.

Definition 4(Energy efficiency): Coverage control algorithms not only require lowest energy consumption in a single monitoring task, but also maintain energy balance of the network in a series of monitoring tasks.

Definition 5(Communications overhead): Data transmission is the main source of sensor node energy consumption. Coverage control algorithm with low cost in the process of communication has a greater advantage.

Definition 6(Network scalability): Coverage control algorithm should adapt to both the scale of different WSNs and the network topology dynamically changed.

In the sensor field of a WSN, a piece of Zone Z is possibly covered by several sensor nodes shown in Fig.4.

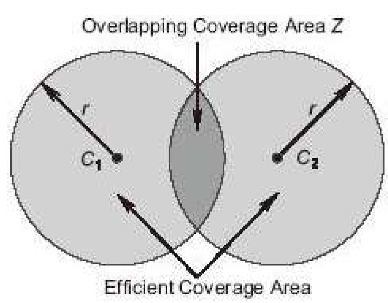

Fig. 4: Efficient Coverage Area

In this case, the coverage resulted from C1 among these nodes is redundant for Z, because the information of Z can be sensed and acquired by other nodes. Therefore, Efficient Coverage Area(S_{ECA}) and Efficient Coverage Area Ratio(R_{ECA}) are defined as follows.

Definition 7 (Efficient Coverage Area (S_{ECA})): Efficient Coverage Area S_{ECA} is the coverage area that is overlapping coverage Z's area S_Z subtracted from Node C_1's coverage range D(πr^2), namely,

$$S_{ECA} = D - S_Z = \pi r^2 - S_Z \quad (3)$$

Definition 8 (Efficient Coverage Area ratio(R_{ECA})): Efficient Coverage Area ratio R_{ECA} is as following.

$$R_{ECA} = \frac{S_{ECA}}{D} = \frac{D - S_Z}{D} = 1 - \frac{S_Z}{D} = 1 - \frac{S_Z}{\pi r^2} \quad (4)$$

2.4 Shuffled Frog Leaping Algorithm

In *SFLA*, the frog's location P_i=($p_{i1}, p_{i2}, \cdots, p_{in}$) is the solution to n dimensional problem. *F* frogs are average divided into *Q* ethnic groups after descending in accordance with the fitness *f(P_i)*. In the population, the sub-populations are constructed according to triangular mode factor probability and the frog number in sub-populations is *q*. In the various sub-populations, the sub-population is updated in accordance with worst fitness P_w through Equation(5) to complete the local search.

$$P_{new} = P_w + r[P_b(P_g) - X_W] \quad (5)$$

Where, P_b is the ethnic optimal solution; P_g is the global optimal solution; r is random number and r∈[0,1]. All frogs are re-mixed, sorted and redraw in the ethnic groups, and completing the local search. All frogs re-mixed, sorted and redraw the ethnic groups, and completed the local search until the number of iterations was reached so as to achieve the frog evolution to the global optimal solution. *SFLA* has been successfully applied to NP hard problem, and the existing literature suggests that *SFLA* has strong global search capability.

3 SMEBUC Protocol

Within the monitored region, due to the different distances of the nodes and Sink, the energy consumption of communication is also different that is the greater the distance the greater the consumption of energy. For the balance of energy, the further of the cluster, the size should be larger. And the closer to clusters, the scale is smaller. The energy consumption of the network nodes is more balanced, which is the reason of unequal clustering.

SMEBUC uses the method of combining unequal clustering and inter-cluster multi-hop routing. The communication process between cluster head and Sink node consists of two stages which are cluster establishment and data transmission. To further balance the node energy, SMEBUC adopts the cluster head competition mechanism in the process of clustering, and Sink nodes can move in the default location.

3.1 The Creation of Cluster

To avoid problem that the reincarnation clustering mechanism consumes large amounts of energy, SMEBUC has a clustering process at network launch time. At the network deployment phase, the Sink node broadcasts a signal in the network with a given transmission power. Once each sensor node receives this signal, it calculates its approximate distance to the Sink node according to the received signal strength. The cluster head is the most important node which does not only manage the cluster members, coordinate the data transmission of the member nodes, but also fuses the data collected by cluster members, and sends the processed data to the Sink node. Due to the heavy burden of cluster head, we select the node with the higher residual energy as the cluster head at the beginning of each data collection cycle and reconstruct cluster.

The cluster head selection rule is that the Sink node knows the location and energy information of all nodes in the network, cluster classification and cluster member determination is completed by Sink node because at the end of each round, the cluster members report their remaining energy to the cluster head, and the cluster head reports the sum of residual energy of all cluster members (including itself) to Sink node. Finally the Sink node calculates the total energy of the entire network, and broadcasts to all nodes. Once the cluster head is determined, the sensor node ni belongs to the cluster head to which is the closest.

The essence of creating a cluster is the optimization problem of selecting N cluster heads among M nodes. To complete the cluster partition, SMEBUC adopts the improved SFLA algorithm.

The cluster selection algorithm is described as following.

Step 1) When energy query message *ENERGY_QUERY_MSG* is received from node i
if parent.equal (i) is true, then
Send (i, *ENERGY_ACK_MSG*)
// Report residual energy information to parent node
else
Discard MSG
end if

Step 2) When the energy query reply message *ENERGY_ACK_MSG* is received from the node i
if child.equal (i) is true, then
Update EnergyInfo ()
// Update the residual energy of candidate node
else
Discard MSG
end if

Step 3) When the data forwarded message *DATA_FORWARD_MSG* is received from node i
k = SelectNextRelay ()
// select the node with the largest residual energy as cluster head
if parent.equal (i) is true,

Send (k, *DATA_FORWARD_MSG* (data))
// Send data to cluster head
else
Discard MSG
end if
Send (k, *DATA_FORWARD_MSG* (data))
// Send the collected data to the relay node k
Step 4) The message is not received
k = SelectNextRelay ()
// select the node with the maximum residual energy as cluster head
Send (k, *DATA_FORWARD_MSG* (data))
Send the collected data to the cluster head
End of the algorithm.

3.1.1 *SFLA* Encoding and Target Function

Definition 9: *SFLA* frog particle encoding is defined as following:

$P_i = (P_{1,n_1}, ..., P_{1,n_l}, ..., P_{1,n_k}, ..., P_{1,n_M})$

Where $P_{1,n_k} \in [0,N], P_i \cap [0,N] = \emptyset, \forall P_{1,n_l} \neq 0, \forall P_{1,n_k} \neq 0$.

If $P_{1,n_l} \neq P_{1,n_k}$ and $P_{1,n_k} \neq 0$, it means that the sensor n_k at the corresponding position is the cluster head. M is the number of sensors and N is the number of cluster heads.

Definition 10: D(x, y) is the Euclidean distance between x and y.

The remaining energy of sensor i at time T is the initial energy of sensor i minus the total energy consumed to transmit data to neighbors and the base station. The proposed routing algorithm uses a path with energy sufficiency as well as energy efficiency to pursue energy balance for the sensor network. By Reference[20], we have an optimal formulation maximizing the minimum remaining energy of sensors. The objective is to maximize the minimum remaining energy E of sensors with the target function (6).

$$\begin{cases} E(p_i) = a_1 \cdot A_1(p_i) + a_2 \cdot A_2(p_i) + a_3 \cdot A_3(p_i) \\ A_1(p_i) = \max_{j=1,2,\cdots,N} \sum_{\forall n_k \in C_{p_i,j}} D(n_i, CH_{p_i,j})/N \\ A_2(p_i) = \sum_{k=1}^{M} e(n_k) / \sum_{j=1}^{N} e(CH_{p_i,j}) \\ A_3(p_i) = \sum_{j=1}^{N} D(s, CH_{p_i,j})/N \cdot D(s, NC) \end{cases} \tag{6}$$

Where, $a_1 + a_2 + a_3 = 1$. $A_1(p_i)$ is the maximum average distance between the nodes and the cluster head. The smaller the value, the more compact the clustering. $A_2(p_i)$ is the ratio of the energy of all nodes and the energy of all cluster head, the smaller the value, the node with greater remaining energy can play as cluster head. $A_3(p_i)$ is the ratio of the average distance from cluster head to Sink and that from Sink to monitoring center. The smaller the value, the more cluster head nearer the region of Sink node, so as to reduce the size of the cluster. According to the energy balance principle, the optimal solution is to minimum the objective function $E(p_i)$.

3.1.2 *SFLA* Local Search Mechanism and its Improvement

The essence of the tradition *SFLA* local search mechanism is the process that the poor individuals learn from the outstanding individuals [21]. If the sub-populations update P_w only through the update P_b or P_g, it will reduce the diversity of frog particles and is not conducive for the individual's global optimal evolution, which is easy to fall into local optimum. So in order to increasing the diversity of the sample, frog P_a and P_c is randomly selected and added to the partial update mechanism. The frog particles have non-repeatability for discrete optimization problem of WSN. If it directly uses the Equation(5), it will produce a large number of infeasible solutions and seriously reduce the algorithm efficiency. This paper prompts the concept of "transforming gene" and "transforming sequence" which can improve the algorithm efficiency compared to the traditional local search mechanism.

Definition 11 Transforming gene: Let the frog particles' transforming gene H(x_i, x_j) converts the position i and j in the frog particles' coding. If *H*(x_i, x_j)= *H*(x_i, x_i), it means that the position is not changed.

Definition 12 Transforming sequence: As for the frog particle p_i and p_j, it has the transforming gene manipulation on each location according the gene sequence in frog particle p_i.

Eventually, it has M-1 transformations. Once transforming p_i, it obtains p_j.

After rearranging the M-1 transforming genes, we get the transforming sequence. Let the transforming sequence be $l_{i,j} = (p_i \;\; p_j)$ and define the transforming between p_i and p_j is $p_j = p_j + l_{i,j}$.

The improved local search algorithm is described that selecting the frog p_i and p_j $(i \neq k \neq j \neq w)$ randomly, the local search strategy is,

$$\begin{cases} P_{new} = \begin{cases} P_w + d' \times l_{w,j}, P_r \geq CR \\ P_w + d' \times l_{i,k} + d' \times l_{w,j}, P_r < CR \end{cases} \\ d' \in [d_{min}, d_{max}] \end{cases} \tag{7}$$

Once finishing the partial update, if the new frog's fitness is better than that of the original frog, the new particle will replace the original one. Conversely, it re-implements the strategy Equation (7) using $l_{w,g}$ instead of $l_{w,j}$. If the result is not improved yet, it randomly generates a new frog particle and substitutes the original particle. When all ethnic groups complete the local search, it re-mixes the sort and enters into a new round of local search, until it reached the number of iterations and output the optimal solution.

3.2 Competition and the Rotation Mechanism of Cluster Head

Because the cluster size is smaller if the cluster head is near to the sink node, while relatively larger if the cluster head is away from the sink node. To compute the competition radius, we consider not only the distance from the sink node, but also the energy of the node itself. The candidate cluster head node with higher residual energy competes for cluster head according to their competition radius. After completing the cluster division using improved *SFLA*, we can get the radius of the cluster head competition R_{CH} calculated by Equation (8) [27].

$$\begin{cases} R_C H = [1 - c * FRAC] \cdot R_{max} \\ FRAC = \frac{MAX1 - -D(n_k,s)}{MAX1 - MIN1} \\ MAX1 = max_{k=1,2,\cdots,M}(D(n_k,s)) \\ MIN1 = min_{k=1,2,\cdots,M}(D(n_k,s)) \end{cases} \tag{8}$$

Where, R_{max} is the maximum value of competition radius, is the distance from the node k to the sink node, is the maximum distance from the nodes to the sink node, is the minimum distance from the nodes to the sink node, is used to control value range. Through analysis, the farther the distance between cluster head and Sink, the greater the competitive radius, which proves rationality of clustering using *SFLA*.

However, if the network is too large, it may lead to the situation of c luster head-intensive using *SFLA* clustering which is shown in Fig.5.

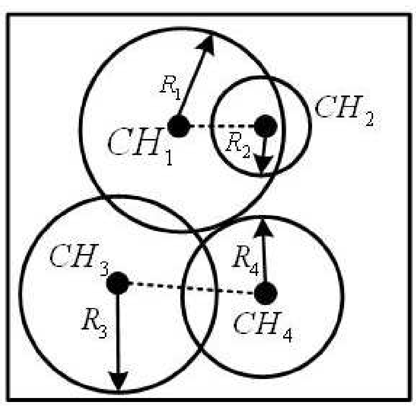

Fig. 5: Optimized seamless coverage

To solve the above problem, this paper introduces the cluster head competitive mechanism, whose principle can be described as following.

For the cluster heads CH_i and CH_j, the cluster head with larger remaining energy is selected as the new cluster head, and those with smaller remaining energy is become the ordinary nodes. Finally, it completes the final cluster division by the Sink node according to the existing cluster head.

SMEBUC takes the mechanism of cluster head served continuously, which can reduce the energy of consuming in cluster head rotationally selecting. To determine the cluster head replacement time, defining the cluster head weight CH_i(v) calculated through Equation (9).

$$CH_i(v) = \sum_{\forall n_k \in C_i} e(n_k)/|C_i| \cdot e(CH_i) \tag{9}$$

Where, $|C_i|$ is the nodes contained in the cluster, and CH_i(v) is the ratio of the mean energy of nodes in the cluster and the energy of the cluster head.

If $CH_i(v) \geq 1$, the node with the largest remaining energy in the cluster is chosen as the new cluster head.

Through introducing the mechanism of cluster head competition and rotation, SMEBUC can avoid the occurrence of cluster head becoming too dense, which makes the WSN clustering topology more reasonable. And SMEBUC always selects the node with the largest remaining energy to act as the cluster head, which is more conducive to the energy balance of the network.

3.3 Inter-Cluster Communication

SMEBUC uses the multi-hop routing communication method for inter-cluster, and the cluster heads use the greedy algorithm[22] to determine its relay nodes. The detail method is that SMEBUC chooses the nearest cluster head as its relay node until reaching the Sink node. Thereby SMEBUC completes the data transfer.

However, if it only takes the shortest distance principle, it is possible to cause a too long single chain formed by the cluster head which is shown in Fig.6(a). To avoid a single chain becoming too long, SMEBUC adopts the threshold to control the process of multi-hop routing into the chain. Therefore, the inter-cluster communication can be described as following.

The cluster head uses a greedy algorithm to determine the next relay node. Once the relay node is selected, SMEBUC calculates ratio of the distance from cluster-head to the next relay node and that from cluster head to Sink node which is shown in Equation(10).

$$T = D(CH_j, s)/D(CH_i, s) \tag{10}$$

Where, CH_j is the relay point of the next hop of CH_i. If , the cluster head is connected directly to the Sink node.

3.4 Sink node moving strategy

The multi-hop routing can effectively balance the network node energy consumption. But the closer the cluster head to the Sink node, the faster the energy consuming, which prone to the phenomenon of premature death. This is the problem of ”hot spots”. To avoid the ”hot spot” effectively, SMEBUC adopts a Sink node position mobile strategy which makes the Sink node mobile periodically in the schedule region.

The Sink moves to the node with the largest node degree, which has not been passed through by Sink. After several moving, it returns to its original position, and then the optimal mode is divided into several discrete modes solved by Newton approach. Sink node moves to the node with bigger value of node degree. This will reduce the energy consumption of data transmission within the area of the local node.

Definition 13 Node degree: Node degree refers to the number of edges associated with the node.

SMEBUC can effectively avoid the excessive use of certain cluster head, which is shown in Fig.6.

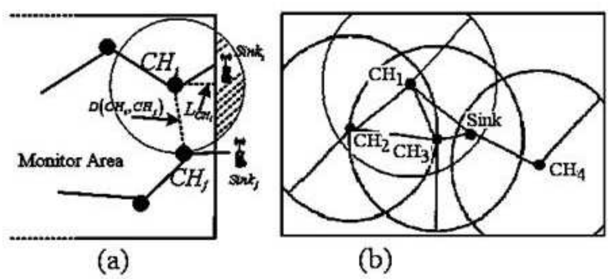

Fig. 6: Cluster head competition and inter-cluster communication

Suppose that the distance from the cluster head CH_i to the right side of the rectangular monitored region (assuming that Sink node is in the right side of the monitored region) is L_{CH}. If , CH_i is called $subCH_i$. We draw a circle with the center of cluster head $subCH_i$ and the radius of .

The part of circle outside the monitored region, the hatched portion shown in Fig.6(a), is area that the Sink Node $Sink_i$ can be placed.

Therefore, when *SMEBUC* uses the greedy algorithm to establish multi-hop routing, *SMEBUC* changes the cut-off point of the multi-hop routing to $subCH_i$. $subCH_i$ predicts the arrival time of mobile Sink node and then go to state of sleep. The ”Sleep-wakeup” mechanism can effectively save the cluster head’s energy.

When Sink node is located in area $Sink_i$, $subCH_i$ is waken up, and then transfer the data to the Sink node, which completes a whole data communication process.

During a data communication process, the energy consumed in *WSN* is calculated by Equation (11).

$$\begin{cases} E_{re} = M * E_{elec} * l \\ E_{CH} = E_{re}(CH_i) + E_{se}(CH_i) + E_{ro}(CH_i) \\ = l * E_{elec} * |C_i| + l * E_{DA} * |C_i| \\ +(l + l_{tx}) * E_{fx} * D^2(CH_i, CH_j) \end{cases} \tag{11}$$

Where, E_{re} is energy consumed by the Sink node receiving the broadcast message during the process of building the cluster, E_{CH_i} is the energy consumed by the cluster head receiving and sending the date. ltx is the packet length forwarded by cluster head. $E_{re}(CH_i)$ is the energy consumed by the cluster head fusing the data from cluster nodes and itself. $E_{se}(CH_i)$ is the energy consumed by the cluster head sending data to the other relay nodes. $E_{ro}(CH_i)$ is the energy consumed by the cluster head transferring the data from the other relay nodes.

4 Simulations and Analysis

4.1 Simulation Parameters

In this section, we implement the *SMEBUC* and evaluate its performance in NS2. In the simulation, we don’t consider calculation, data fusion, query group transceiver and energy consumption, we just only considerate energy consumption. We choose $100 \times 100m^2$ network simulation, 100 nodes are unequal distributed in the monitoring area. The initial position of the sink node is (110, 50). The minimum radius is 2, and the maximum radius is 5. The remain simulation parameters are shown in Table 1.

Table 1: Simulation Parameter of *SMEBUC*

Parameter	Value
E_{elec}	50nJ/bit
ε_{fs}	10pJ/($bit \cdot m^2$)
ε_{mp}	0.0013pJ/bit/m^4
E_{DA}	5nJ/bit/signal
Network monitor area	100m×100m
Initial node energy E_0	0.5J
The node number	100

The network topology generated by *SFLA* and *SMEBUC* is shown in Fig.7.

The cluster head nodes in SMEBUC were distributed more uniformly, because they took into account the distance that had been constrained to optimize the cluster scheme.

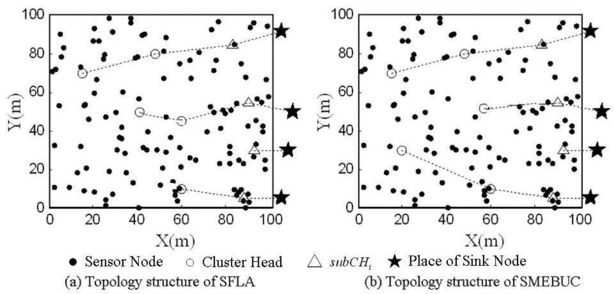

Fig. 7: The performance of *SFLA*

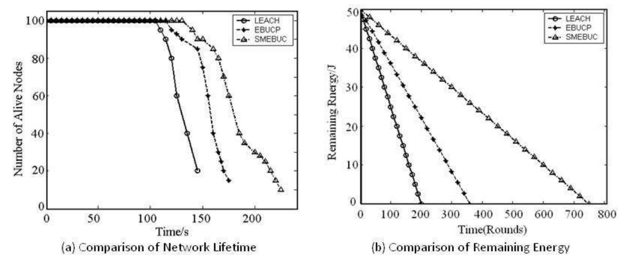

Fig. 9: Simulation for Number of Alive Nodes and Remaining Energy

4.2 *The Performance Analysis of* SMEBUC

With the energy consuming, there appears the death of the nodes in the network. The more uniform distribution of the death of the nodes, the more balanced energy consuming is on the network. To analyze the energy balance capacity for SMEBUC, this paper simulates the distribution of the network node number with death percentage reaching 50% which is shown in Fig.8(a). In addition, the size of the network sub-clustering has a greater impact on network lifetime, Fig.8(b) shows the relationship between cluster number and network lifetime.

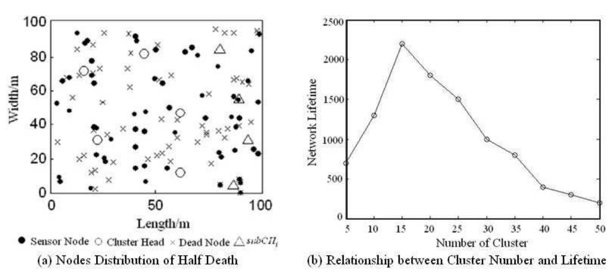

Fig. 8: the simulation performance of *SMEBUC*

From the simulation results shown in *Fig.8(a)*, the dead nodes are relatively evenly distributed within the monitored region. The simulation results illustrate that *SMEBUC* has the better energy balance capacity. It also can be seen from Fig.8 (b) that the number of clusters is too much or too little will affect the network lifetime. Therefore, the reasonable clustering size can maximize the network lifetime.

For further verifying the performance of *SMEBUC, SMEBUC, LEACH* and *EBUCP* proposed in [13]. are simulated respectively. The simulation results are shown in Fig.9.

The simulation results in Fig.9 show that the network lifetime of SMEBUC is much longer than that of the other two protocols. Also the death time of the network nodes is closer and the network remaining energy is higher than that of the other two. This is due that SMEBUC adopts the method of centralized control for the Sink node, the network clustering and the determining of the cluster head is completed by the Sink node. SMEBUC uses the unequal clustering and multi-hop routing, and the Sink node is mobile in a predetermined region. SMEBUC can effectively balance network energy consumption which makes the balance of energy and better network lifetime of WSN.

4.3 *The Character of Cluster Head*

According to section 3.2 and Equation (8), the cluster number is decided by maximum competition radius R_{max} and control range c. Fig.10 shows the relationship between the cluster head number and R_{max} of two different control range c at 0 and 0.5. It illustrates that the smaller the competition radius is, the greater the number clusters head.

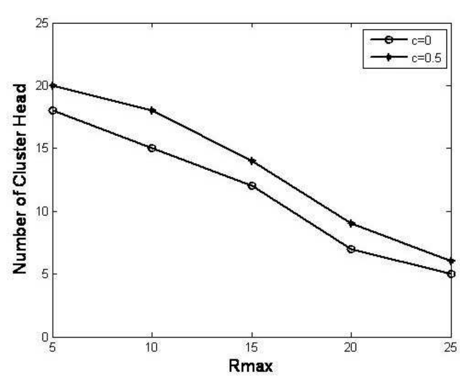

Fig. 10: Relationship between the number of cluster head and R_{max}

The cluster head number of c=0.5 is larger than that of c=0 because the competition radius of the candidate cluster head is smaller with the creasing of c when R_{max} is fixed, and the number of cluster head increases.

4.4 Simulation of Energy Consumed by Cluster Head

Since the energy consumed by the cluster head is the most important part of the energy consumption of the network, we compare the sum of energy dissipated by the cluster head in a round by *SMEBUC*, *EBUCP* and LEACH respectively. In the experiment, we select 10 rounds randomly and calculate the sum energy consumed by the cluster head in each round shown in Fig.11.

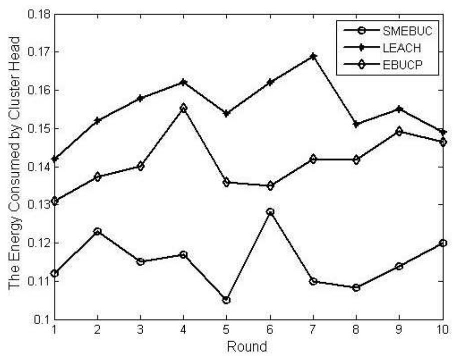

Fig. 11: the Energy Consumed by Cluster Head

From Fig.11, the energy consumed by the cluster head of *SMEBUC* is the lowest than that of LEACH and *EBUCP* because the cluster head sends data to the Sink using multi-hop communication, and reduces the energy consumption. The energy consumed by that of LEACH is the highest due to it's sending data to the Sink node by single hop communication, and it constructs slightly more cluster heads which increase the frequency of communication with the Sink node and increase the energy consumption.

4.5 Simulation of Different Deployment of Strategy

Through simulation experiments, we compare the relationship between the network life cycle and node disability ratio of the proposed *SMEBUC* with non-uniform and uniform distribution strategy shown in Fig.12.

With the operation of the network, the node energy continuously decreases while increases the node disability ratio. The node disability ratio of both non-uniform and uniform distribution strategy increases. At round 200, the node disability ratio of uniform distribution is about 20%, while that of non-uniform distribution is around 15%. At round 400, this value for uniform distribution is about 40%, and 35% for non-uniform distribution. With the extension of the network running time, node disability

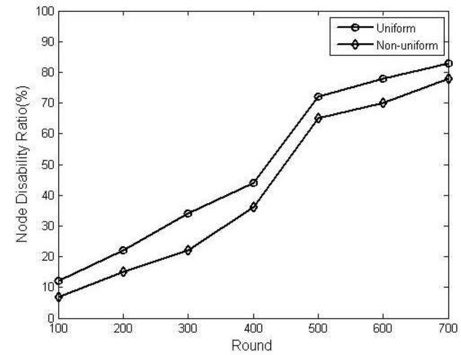

Fig. 12: Relationship between node disability ratio and run-time

ratio of non-uniform distribution strategy is always lower than that of uniform distribution strategy. It is clear that the performance of energy-saving of non-uniform distribution strategy is superior to that of uniform distribution strategy.

4.6 Simulation of Lifetime with Different Clusters under Mobile and Static Sink

To comply with the network connectivity, coverage, energy distribution, it dynamically adjusts the node deployment or location with sink mobility, which fills the network routing hole and senses coverage gaps. The Sink moves to the node with the largest node degree, which has not been passed through by Sink. When Sink moves to a new location, it will inherit take charge of the fixed sensor node's task of collecting and forwarding data, so that the energy of the fixed sensor node is preserved, and the lifetime of the entire network is extended.

To illustrate the performance of SMEBUC with Sink mobile, we simulate SMEBUC with the cluster number changing from 5 to 20 and compare it with that of sink static under the uniform distribution of WSN.

Table 2 shows lifetime of the mobile and static Sink SMEBUC algorithm can improve the network lifetime than that of static Sink.

Table 2: Lifetime comparison of static and mobile Sink

Number of clusters	Network lifetime T_{net}(Round)	
	Sink Static	Sink Mobile
5	161	218
10	354	415
15	610	760
20	435	552

5 Conclusions and Future Work

In this paper, the clustering algorithm mainly takes into account reducing the total energy consumption. This paper improved the SFLA local search mechanism to determine the network clustering and cluster head replacement to improve the problem of long single-chain in multi-hop routing algorithm. Correspondingly, the paper proposed a Sink Mobility based and Energy Balancing Unequal Clustering protocol, which is called SMEBUC. SMEBUC can efficiently balance the energy consumption of the entire network, decrease the dead speed of the nodes and prolong the network lifetime. Also SMEBUC uses the Sink location mobile algorithm to effectively avoid the emergence of the ”hot spots”. The numerical simulation results show that SMEBUC can balance the network energy and prolong the network lifetime efficiently.

We note that although in this paper we specifically study the problem of effective balance the energy consumption and prolong the network lifetime. However, the performance of WSN in terms of end-to-end transmission delay and packet delivery ratio may be degraded due to node redundancy and routing path loss. The approach can be extended to other relevant cost metrics, e.g., minimizing the end-to-end transmission delay or maximizing network throughput. The quantitative analysis of energy-delay with the appropriate definition of delay is another research topic for future work.

Acknowledgement

This work was supported in part by Natural Science Foundation of China under Grant 61202393,Natural Science Basic Research Plan in Shaanxi Province of China under Grant 2014KW03-02.

The author is grateful to the anonymous referee for a careful checking of the details and for helpful comments that improved this paper.

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