ARTICLE IN PRESS

Future Generation Computer Systems ▮ (▮▮▮▮) ▮▮▮–▮▮▮

Contents lists available at ScienceDirect

Future Generation Computer Systems

journal homepage: www.elsevier.com/locate/fgcs

Particle swarm optimization based clustering algorithm with mobile sink for WSNs

Jin Wang [a], Yiquan Cao [a], Bin Li [a], Hye-jin Kim [b], Sungyoung Lee [c,d,*]

[a] College of Information Engineering, Yangzhou University, Yangzhou, China

[b] Business Administration Research Institute, Sungshin W. University, Republic of Korea

[c] School of Computer and Software, Nanjing University of Information Science & Technology, Nanjing, China

[d] Department of Computer Engineering, Kyung Hee University, Republic of Korea

HIGHLIGHTS

- We made a survey about mobile sink and PSO based routing algorithms for WSNs.
- We proposed an Energy efficient PSO based routing algorithm with Mobile Sink (EPMS).
- We presented theoretical analysis of clustering with PSO algorithm for WSNs.
- We gave detailed packet structure and explanation.
- We performed extensive simulation and comparison with other routing algorithms.

ARTICLE INFO

Article history:
Received 30 November 2015
Received in revised form
29 December 2015
Accepted 9 August 2016
Available online xxxx

Keywords:
Sink mobility
Particle swarm optimization
Energy consumption
Wireless sensor network

ABSTRACT

Wireless sensor networks with fixed sink node often suffer from hot spots problem since sensor nodes close to the sink usually have more traffic burden to forward during transmission process. Utilizing mobile sink has been shown as an effective technique to enhance the network performance such as energy efficiency, network lifetime, and latency, etc. In this paper, we propose a particle swarm optimization based clustering algorithm with mobile sink for wireless sensor network. In this algorithm, the virtual clustering technique is performed during routing process which makes use of the particle swarm optimization algorithm. The residual energy and position of the nodes are the primary parameters to select cluster head. The control strategy for mobile sink to collect data from cluster head is well designed. Extensive simulation results show that the energy consumption is much reduced, the network lifetime is prolonged, and the transmission delay is reduced in our proposed routing algorithm than some other popular routing algorithms.

1. Introduction

With the rapid development of smart city and Internet of Things (IoT), information communication technology (ICT) is playing a more and more important role. Wireless sensor networks (WSNs) provide a novel way to collect, process and communicate data among different kinds of devices, such as RFID, sensors and actuators etc. WSNs usually compose hundreds or thousands of sensors which make up the network for monitoring the interested region and feedback end-users with data about the interest targets or events. WSNs usually include tiny, inexpensive and resource limited devices which communicate with each other with multi-hop manner. WSNs can be widely used to perform military tracking and surveillance, natural disaster relief, hazardous environment exploration and health monitoring etc. [1,2].

In order to ensure that each sensor can transmit information properly to other nodes and network connectivity, large number of sensors are deployed in the monitoring area. This prevents WSNs from dividing into several isolated areas and guarantees complete data communication. In the traditional WSNs [3–5], information is usually transmitted to the sink node in a multi-hop manner to reduce energy consumption. Even though multi-hop communication can save energy to certain degree, it also causes some problems. The well known hot spot problem is one example. Since

* Corresponding author.
E-mail addresses: jinwang@yzu.edu.cn (J. Wang), yqcao@yzu.edu.cn (Y. Cao), lb@yzu.edu.cn (B. Li), hyejinaa@daum.net (H.-j. Kim), sylee@oslab.khu.ac.kr (S. Lee).

http://dx.doi.org/10.1016/j.future.2016.08.004
0167-739X/

Please cite this article in press as: J. Wang, et al., Particle swarm optimization based clustering algorithm with mobile sink for WSNs, Future Generation Computer Systems (2016), http://dx.doi.org/10.1016/j.future.2016.08.004

Fsensor node closer to the sink need sends its own data and data from the other nodes, the energy consumption is faster than that of the other nodes. The node will die earlier than other nodes, which will cause network partition and reduced network lifetime [6].

Introduction of sink mobility into WSNs has been shown to be a very efficient way to mitigate the hot spot problem and balance energy consumption [7]. The application of mobile nodes to WSNs has brought new opportunities and challenges, and it can improve the positioning accuracy of the nodes as well [8–10]. The mobile sink node can dynamically change the network topology and make it possible to obtain the data communication with the sink. The network load is no longer focused on the set of nodes around sink. With the change of sink node, the effect of load balance can also be achieved. Mobile sink node avoids the occurrence of the bottleneck nodes and thus alleviates the well known hot spot problem for WSNs [11–15].

Particle swarm optimization (PSO) algorithm is a swarm intelligence inspired optimization technique that belongs to a category of artificial intelligence. PSO algorithm originates from the study of the nature of the behavior of predatory birds. The basic principle of PSO algorithm is that each bird is abstracted as a particle, and the optimized result corresponds to the position of the particles in the search space [16]. In each iteration step, the particles are updated by tracking the following two extremes: one is the best position of the local solution and another one is the best position of the global optimal solution. Through their learning experience and the exchange of all particles information, it determines the next step of the flight speed and direction, and it gradually moves toward the global optimal solution. Thus, the introduction of PSO algorithm can largely improve the WSNs performance in terms of load balance, energy consumption etc.

In this paper, we propose an Energy efficient PSO based routing algorithm with Mobile Sink support for WSNs, which we name it EPMS for short. EPMS routing algorithm mainly combines the virtual clustering and mobile sink techniques during routing process. Firstly, it uses the PSO algorithm to divide the network into several regions. In each region, the EPMS uses a similar clustering algorithm to select the cluster head nodes inside each cluster. It combines with the two conditions of the region of the gravity center of the distance and the energy of the node. Then, the EPMS defines three kinds of data packet formats: Hello, Message-s and Message-h packets. The Hello packet is used to determine which cluster area sends data to the mobile sink. The Message-s packet sends data to the sink node, and the Message-h sends information to the cluster head. EPMS can balance energy consumption, prolongs network lifetime and reduces the transmission delay based on the extensive simulation results.

The rest of this paper is organized as follows. Section 2 gives some related works. Section 3 presents system model. In Section 4, our proposed EPMS routing algorithm is proposed with detailed explanation and analysis. Extensive simulation results are illustrated and compared in Section 5, and Section 6 concludes this paper.

2. Related work

2.1. Mobile sink based routing algorithm

In wireless sensor networks, mobile sink nodes can be used to prolong the lifetime of network. The TRALL protocol in [8] is based on random movement strategy of mobile sink nodes and the random packet forwarding method. This protocol can enhance the management of resources and reduces the energy consumption of data acquisition. However in the process of moving, it periodically sends HELLO packets to node which consumes a huge amount of energy.

In [9], Two-Tier Data Dissemination (TTDD) protocol is proposed where sensor network is divided into a virtual grid, which is based on the mobile sink node (Data). In this protocol, the network is divided into many grids. The path of data transmission of mobile sink nodes is established by the grid node. It can diminish the energy hole effect. But the process of building the grid will consume a portion of the energy of the node. MSEERP algorithm [10] uses the method of dividing the grid, but it does not consider whether grid number is optimal. And the nodes in the process of communication will waste a lot of unnecessary energy which is not desirable.

In the literature [11], the fixed rendezvous points (RPs) in WSNs are proposed. A mobile-sink node only visits RPs periodically. It can expand the coverage area and maintain the energy consumption balance, but mobile node sink movement randomness will cause delay of network communication. In [12], sink node walks along the edge of the hexagon movement and collects other interest events with multi hop transmission. Compared with the static sinks scenario, the network's lifetime of the method is much improved.

In [13], the sink mobile strategy influences the survival time of the network directly. The authors assume therein that the network is divided into several regions, and a cluster head is selected inside each region. Mobile nodes collect data directly from cluster head. It can maintain energy balance via multi-hop transmission manner. However, it will cause some data overflow of head node and additional communication delay. In [14], the authors design a path selection probability model and use ACO algorithm to find an optimal path from processing node to the target node. But the complexity of their proposed ACO algorithm is relatively high.

Ring based routing protocol with a mobile sink is proposed in [15], which is a novel hierarchical routing protocol for WSNs. This protocol imposes three roles on sensor nodes, namely ring node, regular node, and anchor node. These three sensor roles are not static, which means that sensor nodes can change their roles during the sink movement. Once sink node moves out of the adaptive region, the location information will be updated toward the entire network. If sink frequently moves out of the adaptation area, the energy consumption to update location information will be very large.

2.2. Sink movement strategies

In mobile sink based WSNs, sink movement strategy is determined by the requirements of specific WSNs application. Random mobile strategy is the most commonly used mobile strategy in MSWSN. Literature [17] gives a random direction model which uses no memory motion mode and does not consider the moving speed and direction of sink node. Sink node randomly visits the same area and this will lead to the emergence of hot spots in certain area. The shortcoming of random mobile strategy is that it usually consumes a large portion of the energy since it needs to broadcast sink location information frequently during its moving process.

Some routing protocols might need to use predictable mobile strategy in some specific applications [18]. The moving path of the sink node is preset, and all the nodes in the network have known the path information of the sink node beforehand. The source node can predict the future location of the sink node through the path information and moving pattern. The disadvantage of this method is that the flexibility is poor, and the network cannot be extended easily. The sink node's default path will also consume a lot of energy.

The movement strategy of sink node is very crucial to the WSNs performance, and sink moving strategy can be jointly optimized with routing algorithms. The path of mobile sink node is also constrained by the parameters of the network like obstacles, specific routes in certain area etc.

The authors in [19] propose a convex optimization model inspired by the support vector regression technique to determine an optimal trajectory of a mobile sink without considering predefined structures such as a virtual grid or rendezvous points. Their proposed model yields a substantial gain in the lifetime of event-driven applications with single-hop data delivery.

2.3. PSO based routing algorithm

Particle swarm optimization (PSO) algorithm [20] is an intelligent algorithm which is proposed by Kennedy and Eberhart in 1995. It has been applied in many fields, such as mechanical design, neural network, communication and image processing. It can also be applied to the WSNs routing issues to achieve improved network performance.

The authors in [21] propose a modified version of binary PSO to search for the best task allocation solution for WSNs. The authors take energy consumption, task execution time and energy distribution into account. This algorithm considers the appropriate trade-off that between the fitness function and the different index, then get the best overall performance.

With the aim to maximize the lifetime of heterogeneous WSNs, authors in [22] apply PSO algorithm to sensor deployment problem followed by a heuristic of scheduling. After computing the optimal locations, sensor nodes are scheduled using PSO algorithm so as to achieve the theoretical upper bound of network lifetime. This heuristic algorithm performs better than the random deployment method. And it can extend the network lifetime and minimize the energy consumption as well.

A hybrid PSO algorithm based on for WSNs is proposed [23], where sensor network is divided into a set of clusters by geographical position. In each cluster, a chain with hybrid PSO algorithm is constructed. According to the residual energy and distance factor, the cluster head is selected by the hybrid PSO algorithm to construct a cluster head chain. And the final cluster head transmits the fused date to the base station.

3. System model

3.1. Network model

In the sensor network, all sensor nodes are randomly deployed in a circular area with a radius of R. The network model can be described as an undirected connectivity graph $G(S, E)$, where S is the set of all sensor nodes and $E(i, j)$ is the set of wireless link between node i and node j. All the sensor nodes are homogeneous and stationary. We divide the entire sensor network into several equal sectors with one mobile sink. According to the distance to target nodes, source nodes can adjust their transmission power.

3.2. Energy model

The first order radio model [12,24,25] is used as energy model. We only consider energy consumption during communication process. The total energy consumption during transmission can be divided into two parts below: which are the emission energy of the emission circuit, the energy consumption of the power amplifier, and the energy of the receiving circuit. As shown in the formula (1):

$$E_{tx}(k, d) = E_{elec}(k) + E_{amp}(k, d) \tag{1}$$

where $E_{tx}(k, d)$ is the total energy consumption to transmit k bits data over distance d. $E_{elec}(k)$ means energy consumption for hardware circuit to transmit k bit data, and $E_{amp}(k, d)$ means energy consumption of the amplifier to transmit k bits data over distance d.

Depending on the distance between source node and destination node, a free space (d^2 power loss) or multipath. fading (d^4 power loss) channel model will be used, as is shown in formula (2).

$$E_{tx}(k, d) = \begin{cases} k \times E_{elec} + k \times \varepsilon_{fs} \times d^2, & d < d_o \\ k \times E_{elec} + k \times \varepsilon_{mp} \times d^4, & d \geq d_o \end{cases} \tag{2}$$

where E_{elec} means energy consumption per bit. ε_{fs} and ε_{mp} represent free space and multipath fading model respectively. d indicates transmission distance, and d_o is a constant value whose value is represented in formula (3):

$$d_o = \sqrt{\varepsilon_{fs}/\varepsilon_{mp}}. \tag{3}$$

To receive k-bit data, the following E_{rx} amount of energy will be consumed:

$$E_{rx}(k) = E_{elec}(k) = k \times E_{elec}. \tag{4}$$

The following basic assumptions are made in this paper:

- Sensors are homogeneous;
- Sensors have the same initial energy;
- Wireless links are bi-directional and symmetric;
- Sink node is energy unconstraint with free movement;
- There is no obstacle between each pair of sensor nodes.

4. The proposed algorithm

In this section, a mobile sink is utilized to collect data from different WSNs sectors. Besides, the clustering and PSO techniques are utilized together to improve the whole WSNs performance in terms of average energy consumption, network lifetime etc.

4.1. Clustering with PSO algorithm

For a typical sensor network with N sensors, the network is divided into M clusters. The average number of nodes is $[N/M]$ inside each cluster. First, the network region partition line is determined by using the PSO algorithm, so that the network is divided into two areas.

$$L = (x, y, \theta_x, \theta_y) \tag{5}$$

where (x, y) is the horizontal and vertical coordinates of point line segmentation, θ_x is the angle between the line and the X axis, θ_y is the angle between the line and the X axis.

In formula (6), the fitness value F of K particles are calculated as below:

$$F = \alpha \sqrt{\sum_{i=1}^{2}(c_i - f_i)^2} + \beta \sqrt{\sum_{i=1}^{2}\left(\frac{E_i}{c_i} - \frac{E_{sum}}{N}\right)^2}, \quad (\alpha + \beta = 1) \tag{6}$$

$$f_i = \frac{M_i}{M} \tag{7}$$

where $c_i (i = 1, 2)$ is the number of sensor nodes in region i, E_i is the total energy consumed in region i, and E_{sum} is total energy. M_i means the number of cluster head in the whole network.

The clustering algorithm is described as follows:

Step 1: All sensor nodes in the network broadcast their status information to the base station, which includes their position information and energy information etc.;

Please cite this article in press as: J. Wang, et al., Particle swarm optimization based clustering algorithm with mobile sink for WSNs, Future Generation Computer Systems (2016), http://dx.doi.org/10.1016/j.future.2016.08.004

Step 2: After the base station receives the message, the PSO algorithm is executed to clustering the whole network, and the K particles are defined;

Step 3: The parameters of particles $(x, y, \theta_x, \theta_y)$ are randomly assigned. The region partition line is determined by formula (5). Thus, the entire sensor network is divided into $2K$ different sub-regions. Since the location information of nodes is known, the corresponding F values of each node can be calculated based on formula (6);

Step 4: Each sensor will confirm the above K different fitness values, and then compare the minimum fitness obtained with the last search result. Finally, the minimum value ρ_{gd} is obtained. Its corresponding particles can be used as the global extreme value. In the same way, the minimum fitness value obtained by a single particle is taken as the individual extreme value ρ_{id}. Then updated $(x, y, \theta_x, \theta_y)$ values are adopted by the following equations:

$$\begin{aligned} X_{xid}(t+1) &= X_{xid}(t) + V_{xid}(t) \\ X_{yid}(t+1) &= X_{yid}(t) + V_{yid}(t) \\ X_{\theta_x id}(t+1) &= X_{\theta_x id}(t) + V_{\theta_x id}(t) \\ X_{\theta_y id}(t+1) &= X_{\theta_y id}(t) + V_{\theta_y id}(t) \end{aligned} \tag{8}$$

where X_{xid} and X_{yid} represent the position of particles, $X_{\theta_x id}$ and $X_{\theta_y id}$ are the angles of the dividing line.

$$\begin{aligned} V_{xid}(t+1) &= \omega V_{xid}(t) + c_1 \times rand() \times [\rho_{id}(t) - X_{xid}(t)] \\ &\quad + c_2 \times rand() \times \left[\rho_{gd}(t) - X_{xid}(t)\right] \\ V_{yid}(t+1) &= \omega V_{yid}(t) + c_1 \times rand() \times \left[\rho_{id}(t) - X_{yid}(t)\right] \\ &\quad + c_2 \times rand() \times \left[\rho_{gd}(t) - X_{yid}(t)\right] \\ V_{\theta_x id}(t+1) &= \omega V_{\theta_x id}(t) + c_1 \times rand() \times \left[\rho_{id}(t) - X_{\theta_x id}(t)\right] \\ &\quad + c_2 \times rand() \times \left[\rho_{gd}(t) - X_{\theta_x id}(t)\right] \\ V_{\theta_x id}(t+1) &= \omega V_{\theta_x id}(t) + c_1 \times rand() \times \left[\rho_{id}(t) - X_{\theta_x id}(t)\right] \\ &\quad + c_2 \times rand() \times \left[\rho_{gd}(t) - X_{\theta_x id}(t)\right] \end{aligned} \tag{9}$$

where c_1 and c_2 are two learning factors, ω is weight factor, t is the number of iterations.

Step 5: The particles get new $(x, y, \theta_x, \theta_y)$ values to update formula (5). Then, it goes to Step 3 in an iterative way until the fitness value F converges to the minimal value;

Step 6: After the segmentation of region, the two sub regions continue to be split, until the final M clusters are formed.

4.2. Selection of cluster head

Since each sensor node has very limited energy, the cluster head needs to collect all the information of the nodes and then forward it. So the remaining energy of the node should be considered when choosing the cluster head. The cluster head selection process is as follows:

Step 1: According to the coordinates of the nodes in each region, the center of gravity of the region is calculated. The area of the center of gravity (X_c, Y_c) should be satisfied with the least square and minimum distance of any node in the region, and the concrete calculation method is shown in the formula (10);

$$(X_c, Y_c) = \min \sum_{i=1}^{N} \left[(x - x_i)^2 + (y - y_i)^2\right] \tag{10}$$

where (x_i, y_i) is the coordinates of each node;

Step 2: The distance from the node to the center of gravity is obtained by formula (11) based on node's coordinates(x_i, x_j);

$$d = \sqrt{(x_c - x_i)^2 + (y_c - y_j)^2}. \tag{11}$$

Step 3: Calculate the average residual energy of all nodes in each cluster;

Step 4: If the node residual energy is greater than all the nodes of the average residual energy, the sensor node is elected head. Otherwise, choose the next node. Finding a sensor node that the remaining energy of its own is greater than the average remaining energy of all nodes in the cluster is cluster head;

Step 5: After the mobile sink visits the entire cluster heads, a round of data transmission is finished. In order to balance the network energy consumption, the election of the cluster head is needed to carry on the next round of data transmission. Each round of data transmission cycle is set as T. The method of calculating T is shown in the formula (12):

$$T = \frac{\sum_{i=0}^{n-1} \sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2}}{V} \tag{12}$$

where V is sink moving speed.

4.3. Mobile strategy of sink node

The mobile strategy of our proposed EPMS algorithm is illustrated below.

Step 1: Mobile sink node in the two hop range from each cluster head will broadcast a Hello packet, which is used to notify mobile sink to visit proper cluster head one by one.

The cluster ID number and the average residual energy of the sensor nodes are encapsulated inside the Hello packet. Besides, cluster head location as well as time period T is also provided, where the value of the period T is calculated in the formula (12). The average energy E_c is calculated below.

$$E_c = \frac{\sum_{i=0}^{n-1} E_i}{n} \tag{13}$$

where E_i is the residual energy of the node, n is the number of nodes in the cluster.

Step 2: Compare the average residual energy of each cluster, then cluster with the maximum average remaining energy is selected by the mobile sink. Next, the packet Message-c is broadcasted, which contains cluster ID and cluster head data. Message-c is the packet which will be sent by cluster head to mobile sink directly. It contains the fusion data and the cluster head position.

Step 3: when the mobile node determines a certain cluster head that sends the data to the mobile node, the data packets received from the Message-m are ready to send to the cluster head. The Message-m is data packets. It represents the member nodes that send data to the cluster head node. The Message-m contains the collecting data information, the remaining energy of the node and dormancy time;

Step 4: When the mobile sink moves to the cluster head, the cluster head will transmit its collected data to the mobile sink. After mobile sink stay for certain time during collection, it will then broadcast the hello packet again and move to the next position.

5. Performance evaluation

To evaluate our proposed EPMS algorithm performance, EPMS is compared with other three common algorithms, namely LEACH, Mobile-P and TTDD algorithms.

In the experiments, the whole network contains 100 sensor nodes in an $100 \times 100\ m^2$ area. All sensor nodes have the same

Please cite this article in press as: J. Wang, et al., Particle swarm optimization based clustering algorithm with mobile sink for WSNs, Future Generation Computer Systems (2016), http://dx.doi.org/10.1016/j.future.2016.08.004

Table 1
Network parameters.

Parameter	Definition	Unit
E_{elec}	Energy consumption on circuit	50 nJ/bit
ε_{fs}	Free space model of transmitter amplifier	10 pJ/bit/m^2
ε_{mp}	Multi-path model of transmitter amplifier	0.0013 pJ/bit/m^4
l	Packet length	2000 bits
d_0	Distance threshold	$\sqrt{\varepsilon_{fs}/\varepsilon_{mp}}$
N	Number of nodes	100
E_o	Initial energy	0.5 J

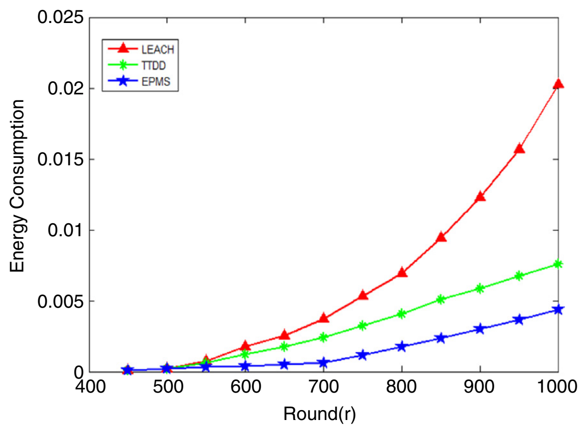

Fig. 1. Comparison of energy consumption.

initial energy of 0.5 J and they are randomly deployed inside the network. Some relevant network parameters are listed in Table 1.

From Fig. 1, it can be seen that as the number of round increases, energy consumption of the whole network increases accordingly. The energy consumption of LENCH is much higher than the other two algorithms, since TTDD and EPMS algorithm use mobile sink technique. In the TTDD algorithm, it takes passive random mobile strategy, and the sink nodes frequently pass through the same area, which will cause more energy consumption. Our EPMS algorithm consumes the least energy among three algorithms.

Lifetime is an important metric to evaluate routing protocol performance. It is usually defined as the time when the first sensor node dies out of energy. Fig. 2 shows the number of alive node as time increases for three algorithms. We can see that the first node dies around 900 rounds for LEACH, while it is about 1500 for EPMS algorithm. Compared with LEACH algorithm, EPMS algorithm significantly improves the network performance. Compared with the TTDD algorithm, EPMS algorithm also prolongs the network lifetime. This is because EPMS algorithm takes the average energy of each cluster into account in the selection of mobile sink mobile path.

The amount of packets delivered by sink node is studied in Fig. 3. It can be seen that EPMS algorithm can deliver the amount of data packets about 4.6 times that of LEACH and 1.5 times that of TTDD at round 1800. This is because LEACH uses fixed sink to collect data, while the other two algorithms use mobile sink to collect data. In the TTDD algorithm, each data source should establish a virtual grid network, which will cost additional energy to maintain the grid.

From Fig. 4, it can be seen that as sink speed increases, the average delivery delay decreases accordingly. The average delivery delay of Mobile-P routing protocol is higher than the other two algorithms. In TTDD, the sink uses flooding method to broadcast information and each data source should establish a virtual grid, which will cause a certain delivery delay. In EPMS algorithm, it adopts the controllable mobile strategy, which can effectively overcome the shortcomings of the other two algorithms and reduce the average delivery delay.

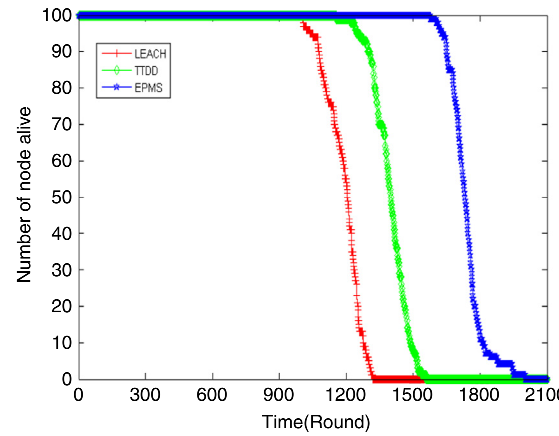

Fig. 2. Comparison of network lifetime.

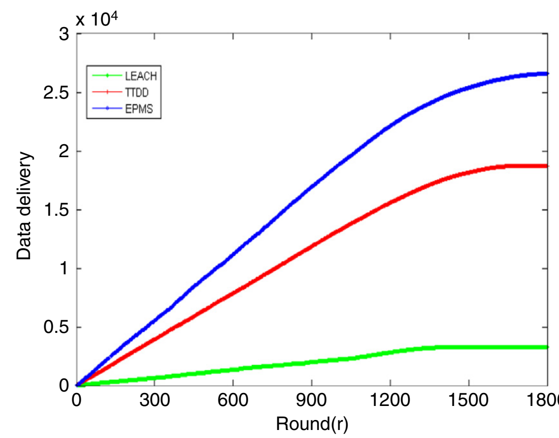

Fig. 3. Comparison of packet delivery.

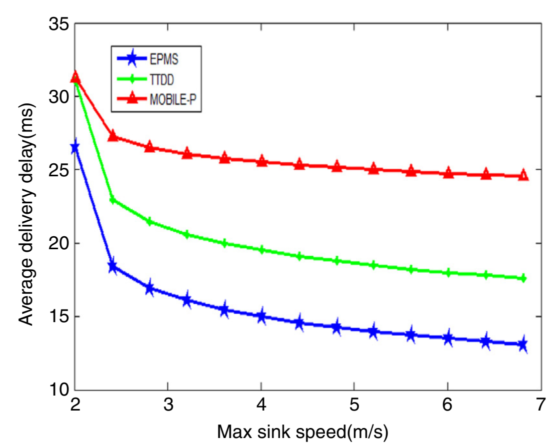

Fig. 4. Comparison of average delivery delay.

6. Conclusions

In this paper, we present a particle swarm optimization based clustering algorithm with mobile sink support for WSNs. We describe the principle of our EPMS algorithm in detail, where the virtual clustering technique combined with PSO algorithm is utilized to improve the network performance. The remaining energy and node position information judge the selection of cluster head. The controlling strategy of mobile sink node is based on the reception of data from various cluster heads. Through extensive simulation, it can be concluded that better performance is

Please cite this article in press as: J. Wang, et al., Particle swarm optimization based clustering algorithm with mobile sink for WSNs, Future Generation Computer Systems (2016), http://dx.doi.org/10.1016/j.future.2016.08.004

achieved by EPMS than other three traditional routing algorithms for WSNs.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (61402234, 61402235, 61472344), the Project of six personnel in Jiangsu Province (2013-WLW-012), the talent project of "Green Yangzhou and golden phoenix" under contract 2013-50. It was also supported by the Industrial Strategic Technology Development Program (10041740) by the Ministry of Trade, Industry and Energy (MOTIE) Korea and the Industrial Core Technology Development Program (10049079) funded by MOTIE Korea.

References

[1] J. Yick, B. Mukherjee, D. Ghosal, Wireless sensor network survey, Comput. Netw. Int. J. Comput. Telecommun. Netw. 52 (12) (2008) 2292–2330.
[2] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, Wireless sensor networks: a survey, Comput. Netw. 38 (4) (2002) 393–422.
[3] A.S. Zahmati, B. Abolhassani, A. Beheshti Shirazi, A.S. Bakhtiari, An energy-efficient protocol with static clustering for wireless sensor networks, Int. J. Electron. Circuits Syst. (2007) 69.
[4] O. Younis, S. Fahmy, HEED: A hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks, IEEE Trans. Mob. Comput. 3 (4) (2004) 366–379.
[5] D. Wei, Y. Jin, S. Vural, An energy-efficient clustering solution for wireless sensor networks, IEEE Trans. Wireless Commun. 10 (11) (2011) 3973–3983.
[6] W. Heinzelman, A. Chandrakasan, H. Balakrishnan, Energy-efficient protocol for wireless microsensor networks, in: Proc. of Hawaii International Conference on System Sciences, 2000, pp. 3005–3014.
[7] W. Liang, J. Luo, X. Xu, Prolonging network lifetime via a controlled mobile sink in wireless sensor networks, in: Proc. of IEEE Global Telecommunications Conference, 2010, pp. 1–6.
[8] K. Tian, B. Zhang, K. Huang, J. Ma, Data gathering protocols for wireless sensor networks with mobile sinks, in: Proc. of IEEE Global Telecommunications Conference, 2010, pp. 1–6.
[9] H. Luo, F. Ye, J. Cheng, S. Lu, L. Zhang, TTDD: Two-tier data dissemination in large-scale wireless sensor networks, Wirel. Netw. 11 (1–2) (2005) 161–175.
[10] H. Chen, Q. Shi, R. Tan, H. Poor, K. Sezaki, Mobile element assisted cooperative localization for wireless sensor networks with obstacles, IEEE Trans. Wireless Commun. 9 (3) (2010) 956–963.
[11] H. Salarian, K.W. Chin, F. Naghdy, An energy-efficient mobile-sink path selection strategy for wireless sensor networks, IEEE Trans. Veh. Technol. 63 (5) (2014) 2407–2419.
[12] Z. Lin, H. Zhang, Y. Wang, F. Yao, Energy-efficient routing protocol on mobile sink in wireless sensor network, Adv. Mater. Res. 787 (2013) 1050–1055.
[13] Y. Gu, Y. Ji, J. Li, B. Zhao, ESWC: Efficient scheduling for the mobile sink in wireless sensor networks with delay constraint, IEEE Trans. Parallel Distrib. Syst. 24 (7) (2013) 1310–1320.
[14] W. Zheng, S. Liu, L. Kou, Dynamic mobile agent routing algorithm in sensor network, Control Decis. 25 (7) (2010) 1035–1039.
[15] C. Tunca, S. Isik, M.Y. Donmez, C. Ersoy, Ring routing: An energy-efficient routing protocol for wireless sensor networks with a mobile sink, IEEE Trans. Mob. Comput. (2014) 1–14.
[16] Y. Liang, H. Yu, PSO-based energy efficient gathering in sensor networks, Lecture Notes in Comput. Sci. 3794 (2005) 362–369.
[17] M. Zhong, K. Shen, J. Seiferas, The convergence-guaranteed random walk and its applications in peer-to-peer networks, IEEE Trans. Comput. 57 (5) (2008) 619–633.
[18] S. Campello Oliveira, G. Andrade Duarte, H. Beltrao Cunha, Unified coordination-communication strategy to swarm controlled mobile wireless sensor network, IEEE Lat. Am. Trans. 12 (5) (2014) 951–956.
[19] F. Tashtaria, Y.M. Hossein, K. Sohraby, S. Effati, On maximizing the lifetime of wireless sensor networks in event-driven applications with mobile sinks, IEEE Trans. Veh. Technol. 64 (7) (2015) 3177–3189.
[20] J. Kennedy, R. Eberhart, Particle swarm optimization, in: Proc. of IEEE International Conference on Neural Networks, 1995, pp. 1942–1948.
[21] J. Yang, H. Zhang, Y. Ling, C. Pan, W. Sun, Task allocation for wireless sensor network using modified binary particle swarm optimization, IEEE Sens. J. 14 (3) (2014) 882–892.
[22] S. Mini, S.K. Udgata, S.L. Sabat, Sensor deployment and scheduling for target coverage problem in wireless sensor networks, IEEE Sens. J. 14 (3) (2014) 636–644.
[23] B. Singh, D.K. Lobiyal, A novel energy-aware cluster head selection based on particle swarm optimization for wireless sensor networks, Hum.-Centric Comput. Inf. Sci. 2 (1) (2012) 1–18.
[24] P. Guo, J. Wang, B. Li, S.Y. Lee, A variable threshold-value authentication architecture for wireless mesh networks, J. Internet Technol. 15 (6) (2014) 929–936.
[25] J. Shen, H. Tan, J. Wang, J. Wang, S.Y. Lee, A novel routing protocol providing good transmission reliability in underwater sensor networks, J. Internet Technol. 16 (1) (2015) 171–178.

Jin Wang received the B.S. and M.S. degrees from Nanjing University of Posts and Telecomm., China in 2002 and 2005, respectively. He received Ph.D. degree from Kyung Hee University Korea in 2010. Now, he is a professor at Yangzhou University. His research interests mainly include routing protocol and algorithm design, performance evaluation for wireless ad hoc and sensor networks. He is a member of IEEE and ACM.

Yiquan Cao obtained his B.S. degree in the Computer and Software Institute from Yangzhou University of Information Science and technology, China in 2014. Now, he is working toward the M.S. degree in the Computer and Software Institute. His current research interests are in performance evaluation for wireless sensor networks, and energy efficient routing protocol and algorithm design.

Bin Li received the B.S. degree from Fudan University, China in 1986, M.S. and Ph.D. degrees from Nanjing University of Aeronautics & Astronautics, China in 1993 and 2001 respectively. He is now a professor at Yangzhou University. He has published more than 100 journal and conference papers. His main research interests include artificial intelligence, multi-agent system and service oriented computing.

Hye-jin Kim received her B.A. in Child Welfare and M.E. in Child Education from Woosuk University, Korea, and Ph.D. in Computer Science from the University of Bristol, UK. After working with Science & Engineering Research Support society for 2 years as a managing director, she is currently working at Sungshin W. University, Korea. And she is an adjunct professor of Vision University of Jeonju, Korea. She published about 20 papers by 2015. Most of her publications are indexed by SSCI, SCI(E) and SCOPUS. She is a member of IEEE, ACM, KIIT and SERSC. Currently, her research topics are E-learning and U-learning.

Sungyoung Lee received his B.S. from Korea University, Seoul, Korea. He got his M.S. and Ph.D. degrees from Illinois Institute of Technology (IIT), Chicago, USA in 1987 and 1991 respectively. He has been a professor in the department of Computer Engineering, Kyung Hee University, Korea since 1993. His current research focuses on Ubiquitous Computing and Applications, Wireless Ad-hoc and Sensor Networks, Context-aware Middleware, Sensor Operating Systems, Real-Time Systems and Embedded Systems.

Please cite this article in press as: J. Wang, et al., Particle swarm optimization based clustering algorithm with mobile sink for WSNs, Future Generation Computer Systems (2016), http://dx.doi.org/10.1016/j.future.2016.08.004