An Energy-Efficient Data Gathering Method in Wireless Sensor Networks (EEDGM)

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In wireless sensor networks (WSNs), resource constraints such as limitations on energy, bandwidth, range of communications, low storage and weak processing capacity motivate researchers to investigate on solving these problems. Therefore, several algorithms have been presented on mobile agent-based data gathering methods. Some important advantages of mobile agent-based data gathering methods are: significant reduction in bandwidth usage by locally data gathering at each node, fault-tolerance and stable behavior in confronting with node or connection failure in networks, and having application-oriented and user-centric processing code. In this paper, a new data gathering method that uses multiple mobile agents called Energy- Efficient Data Gathering Method in WSNs (EEDGM) has been proposed. Two existing approaches for data dissemination task which take the advantages of them and can provide energy and bandwidth efficiency and prolong network life time in wireless sensor networks are combined. EEDGM benefits from a clustering and a routing algorithm (to determine optimal set of cluster heads and optimal routes from cluster heads to sink nodes). Next, this new technique uses the idea of vector which leads to efficient usage of energy and increasing network life time. After implementing EEDGM, the experimental results demonstrate that the method performs better than DIPMA approach, in terms of various metrics such as energy consumption of sensor nodes, total remaining energy and hop count.

Keywords: Wireless sensor networks, data gathering, mobile agents, clustering, particle swarm optimization, energy efficiency

1. INTRODUCTION

Wireless sensor networks (WSNs) are formed by small nodes with the capabilities of sensing, processing and calculation. The main objective of these networks is collecting data from environment using wireless sensor nodes F et al. [2002]. Flexible, self-organized and low cost nature of wireless sensor nodes lead to rapid development of these types of networks in recent years Mianxiong et al. [2014]. We can use WSNs in various applications such as: early detection of forest fires Mohamed and Majid [2007], healthcare Hande and Cem [2010], detection of landslides Vinodini [2014], disaster management Ab and Ab [2011] and military applications Đurišić Milica Pejanović et al. [2012]. Despite these advantages, resource constraints such as bandwidth and energy limitations, limited communication range, low storage and weak processing capacity in WSNs induce researchers to solve these problems by introducing new algorithms such as efficient data gathering methods Divya et al. [2014; Jennifer et al. [2008].

The earliest data gathering approach in WSNs is client-server model M and Arokya [2013]. In this model, each node itself is responsible for sending sensed data either in single hop or multi hop way to the sink. Such behavior can lead to excessive waste of bandwidth, unbalanced energy consumption and ultimately which leads to hotspot-problem in the nodes close to the sink Min et al. [2007].

To solve the problems raised in the client-server model, approaches based on mobile agents have been introduced. A mobile agent is a software program that locally gathers sensed data from the nodes located in a specific itinerary P et al. [2014; Qishi et al. [2004]. Data gathering methods based on mobile agents have important advantages including: significant reduction in bandwidth usage by locally data gathering at each node, fault-tolerant behavior and stability in confronting with node or connection failure in network, having application oriented and user-centric processing code P et al. [2014; Hairong et al. [2001].

One of the main advantages of using mobile agents for data gathering in WSNs is high efficiency. The efficiency of mobile agent based data gathering to a large extent affected by the itinerary planning of mobile agents. In order to determine itinerary of a mobile agent, one can use static or dynamic itinerary planning Ab and Ab [2011]. In static planning, itinerary of mobile agent determines by sink; according to global information of network topology. After determination of migration path, the sink dispatches mobile agents into the network. In contrast, in dynamic planning, mobile agent specify the path direction or next hop at each node on running time and sink does not require to know global information of network P et al. [2014; Qishi et al. [2004].

Using dynamic planning performs flexibility and fault-tolerant behavior of mobile agents over node failure in network. However, failure can disrupt static itinerary and mobile agent task P et al. [2014; Qishi et al. [2004]. In large networks, using single mobile agent cause wasting of bandwidth and energy of network and increases duration of task execution, because when the number of network's nodes increases, the size of packets of single mobile agent increases too. In order to complete data gathering task using multiple mobile agents which are able to work simultaneously single mobile agent approach is preferred Divya et al. [2014].

In this paper, we propose a dynamic planning based data gathering method that uses multiple mobile agents called Energy- Efficient Data Gathering Method in WSNs (EEDGM). Our new proposal can support energy and bandwidth efficiency and also prolong network life time.

Since clustering is an effective method in WSNs, we use clustering in our solution too. Using clustering in WSNs helps to increase energy efficiency and network lifetime by grouping sensor nodes into clusters and determining cluster heads (CHs) for all the clusters. CH nodes have responsibility of collecting data from respective cluster member (CM) nodes and sending them to base station. Our method, at the beginning, performs clustering task to determine the optimal set of cluster heads and cluster members by considering energy efficiency, network coverage and cluster quality as metrics in the phase of cluster head selection. Then, each mobile agent is responsible for collecting sensed data from CMs of a particular cluster which is determined by features of its sensed data using vectors.

The rest of the paper is organized as follows: we briefly review related works in data gathering using mobile agents in section 2. In section 3, we describe our proposed method in detail. Section 4 compares our protocol with other protocols with respect to the selected metrics of interest. The simulation setup and performance analysis are respectively presented in section 5 and 6. Finally, section 7 concludes this paper.

2. RELATED WORK

In this section, three related works on the methods based on mobile agents for data gathering in WSNs are reviewed as follows:

- In Mianxiong et al. [2014], authors proposed a mobile agent-based data gathering method, focusing on some important goals such as time and energy efficient, intelligent and user-centric data collection in wireless sensor networks. Their proposed approach consists of two systems: MAMS and DIPMA. The first system, called MAMS, includes mobile agent (MA) and mobile server (MS). In the first system, a mobile server and a number of mobile agents gather sensed data from sensor nodes in a collaborative way. The second system is a dynamic itinerary approach for a mobile agent (DIPMA) that tries to find an optimal itinerary for MAs to satisfy demands of users.
In Mianxiong et al. [2014], MAMS system, MS moves among sensor nodes randomly and at the same time sends MAs to gather sensed data from nodes and return these aggregated data to MS. Because of the mobility of MS, MAs have to find the latest location of MS to return data, after completing their data collection task. To find the current location of MS, they proposed a method that MAs can estimate the location of MS and come back to using geographic routing navigation. Although MAMS model cause to balance energy consumption in network and increase the network life time, it can take longer time especially in large networks to collect sensed data from sensor nodes by random migration strategy.
In the second proposed method Mianxiong et al. [2014], DIPMA, researchers introduce a dynamic itinerary planning for mobile agents that intelligently gather data from nodes considering user demands. Since moving among all sensor nodes to gather their data may take longer time in large networks, MAs use an intelligent search mechanism for having an efficient data collecting. In this mechanism, MAs only collect data from those nodes that have valuable data. In contrast to the MAMS model that MAs randomly migrate among sensor nodes to collect data, there is no searching mechanism to improve execution time of data gathering.
In DIPMA, a vector is defined to have an intelligent data collection. Vectors consist of data features that are sensed by sensor nodes. MAs decide and choose the direction that has valuable information to collect by considering and analyzing vectors that stored in neighbors of current node. Using vectors leads to avoiding extra migration among nodes and decreases execution time of data gathering. Better execution time and search accuracy in DIPMA were obvious features toward MAMS in their simulations.

- In P et al. [2012], authors proposed a data gathering method in WSNs. Their method considers energy and trustiness as selected criteria in determination of migration path by mobile agents at running time. In addition, it considers malicious node detection as a critical security issue beside energy efficiency in itinerary planning. Presence of malicious or compromised nodes in network can cause disruption in proposed approaches by altering the agent code or itinerary and declining service requests. At first, they proposed a reliability evaluation framework to identify malicious or compromised nodes based on the behavior of sensor nodes (dropping or wrong routing of packets, altering agent data and etc.) against neighbor nodes. MAs using this framework and monitoring results of node's behavior, calculate trust value of sensor nodes. Eventually, they propose an energy-efficient and trust-aware dynamic itinerary planning protocol in MA-based data gathering in WSNs (ETMAM). Besides establishing reliable itineraries, this protocol uses cloning method by dispatching MAs in parallel, to improve efficient energy consumption and decrease payload of mobile agents. In ETMAM, malicious nodes are omitted by trust evaluation method in the early stages. The performance of ETMAM is better than the existing protocols in presence of security problems by considering energy and trustworthiness of sensor nodes in next node selection for the agent migration and using the advantages of cloning.

• In another paper Keisuke et al. [2013], proposed a mobile agent based data gathering approach in mobile WSNs that its goal is reducing traffic and bandwidth consumption in dense MWSNs. In such MWSNs, a geographical point in sensing area can be sensed simultaneously by many sensor nodes because of densely existence of sensor nodes. Since gathering data from all sensor nodes wastes energy and bandwidth of sensor nodes, they proposed a mobile agent based data gathering approach. In this approach, mobile agents try to gather sensing data from the minimum number of sensor nodes to either fully cover sensing area and also improving quality of service requirements specifically reducing communication cost.
Geographical granularity of sensing in monitoring applications necessitate sink node to partition the sensing area into sub-areas and appoint center of sub-areas as sensing point. In this approach, the sink node generates mobile agents and allocates them on nearest sensor nodes from sensing points in each sub-area. Every time mobile agents try to locates near sensing point by moving from current sensor node to the nearest sensor nodes from sensing points using geographical routing. In each sensing time, sensor nodes (that containing mobile agents) began to sense the environment and send data to the sink.
Updating routing tables of sensor nodes by sending packets containing routing table of nodes in MWSNs is infeasible, because of no-stationary nature of network topology and large amount of sensor nodes. Exchanging update packets may lead to consume high energy and bandwidth in MWSNs. Considering these problems, they used geo-routing protocol that forwards agent's data and sensing data based on position of sensor nodes. Their MA-based data gathering approach could efficiently reduce network traffic by considering energy and bandwidth limitations of sensor nodes in MWSNs comparing other proposed methods.

3. PROPOSED METHOD: EEDGM

Here, we present our proposed method called Energy-Efficient Data Gathering Method in WSNs (EEDGM) which efficiently uses energy and also is aware of content. Our method combines the benefits of two approaches from related works, as follows:

(1) TPSO (two-tier particle swarm optimization protocol) in SY and CE [2015] that introduced two algorithms based on Particle Swarm Optimization (PSO). A clustering algorithm that determine optimal set of cluster heads among sensor nodes and its goal is to improve efficient use of energy, cluster quality and network coverage in WSNs. A routing algorithm that finds optimal routes from CHs (cluster heads) to sink nodes.
(2) The idea of vector in Mianxiong et al. [2014] that is a searching mechanism in the process of itinerary planning lead to efficient use of energy and bandwidth and decreasing time consumption in networks.

In the next two sections, first, we describe TPSO and vectors, then we describe detailed behaviors of our proposed method.

3.1 TPSO

Clustering techniques are one of the main methods of effectively dealing with constraints mentioned in WSNs Ahmed and Mohamed [2007]. Searching among N number of sensor nodes for determining cluster nodes, finding optimal set of CHs and also finding optimal routes among available set of routes after clustering phase, both are known as NP-hard optimization problems which require searches through large spaces of possible solutions. In order to find a solution for NP-hard problems, we need optimization algorithms such as PSO and genetic algorithm (GA).

High-speed convergence, ability of escaping from local optima, finding better solutions, easy implementation and Success in producing intended results in NP-hard problems lead to employing PSO in selecting optimal set of CHs. Our proposed method is a centralized method in a sense that the process is first done on base station side and then the nodes get informed of the results. In this way, the evolutionary algorithms are not energy consuming, since they are not processed in the nodes. PSO is a population based stochastic optimization technique developed by Eberhart and Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling James and RC [1995]. In SY and CE [2015] they used the latest standard PSO (SPSO-2011). It has been proved that SPSO-2011 has an outstanding performance than other versions SY and CE [2015]. In SY and CE [2015], they proposed two PSO-based protocols for clustering and routing problems in WSNs. The first protocol organizes sensor nodes into clusters, and elects CHs by considering three metrics in fitness function including energy efficiency, network coverage and quality of clusters. The PSO-based routing protocol finds the best favorable routes between CHs and base station. Energy efficiency and quality of the link are two metrics in fitness function of this protocol. The combination of these two protocols provides an efficient clustering model.

3.2 Vectors

Suppose that while monitoring a forest's wildfire, mobile agents (MAs) are dispatched to collect temperature data from sensors deployed in the forest and to find places where the temperature exceeds a particular threshold. Moving among all sensor nodes to gather their temperature values may take longer time in the large networks such as forest fires detection applications. Therefore, in order to have an efficient data collecting, MAs in DIPMA use an intelligent search mechanism. In this mechanism, MAs only collect data from those nodes that have valuable data. Using the mechanism, an MA constructs its migration path to collect sensory data for predicting forest fire. In Mianxiong et al. [2014] a concept with the name of vector to have an intelligent data collection is defined. Vectors consist of data features which are sensed by sensor nodes. MAs decide and choose the direction that has valuable information to collect by considering and analyzing vectors that stored in neighbors of current node. It is important to know that the size of vectors is very smaller than the sensed data packets. So using vectors leads to efficiently use of network bandwidth. Vector vi comprises n kinds of data, and each bit of data represents the amount of change according to time Δd_n Mianxiong et al. [2014]:

$$v_i = (\Delta d_1 + \Delta d_2 + ... + \Delta .d_n) \tag{1}$$

where Δd_n is a function of time for the nth data and its output is the data observed at time t Mianxiong et al. [2014]:

$$\Delta d_n = f_n(t + \Delta t) - f_n(t).f_n(t) \tag{2}$$

For example, we use one kind of data, temperature, to predict forest fire; in this case, the vector can be expressed such that . Vector is updated by sensor nodes in sensing times. Each node stores square root of vector in its memory. A node calculates the magnitude of vector, such as Mianxiong et al. [2014]:

$$m_i = |v_i| = \sqrt{\sum_{j=1}^{n} \Delta d_n^2} \tag{3}$$

Using vectors lead to avoiding extra migration among nodes and decrease execution time of data gathering Mianxiong et al. [2014].

3.3 Our Method

We propose a data gathering method that uses multiple homogenous mobile agents and advantages of two proposed approaches: TPSO in SY and CE [2015] for finding optimal sets of cluster heads and relay nodes by using PSO based on clustering and routing protocols, and vectors in Mianxiong et al. [2014] for data dissemination task; they both can support energy and bandwidth efficiency and also prolong network life time.

Here, we describe our proposed method in detail. Operating time of our proposed method is separated into rounds and each round consists of a set-up phase and a steady-state phase. Configuration of network and determination of optimal set of cluster heads and routes are done in setup phase.

The main steps of the set-up phase are as follows:

(1) In the first step, sensor nodes broadcast their ID in hello packets. Sensor nodes that receive these packets, begin to update ID and receive signal strength indicator of neighbors in their tables.
(2) In the second step, all sensor nodes broadcast a packet including their ID, remaining energy and neighboring table data, until these packets reach base station. Base station (BS) is a control center which all the sensor nodes send their data there. Then, base station decides on each node's duty.
(3) In the third step, after receiving all control packets by BS, BS starts to find optimal set of CHs and route using TPSO algorithm. Our selected metrics in fitness function of PSO are as follows: energy efficiency, network coverage and cluster quality.
(4) In the final step, BS floods configuration packets to all sensor nodes. Sensor nodes that receive these configuration packets modify their status (which shows the node is either a CH, a cluster member, or a relay node). Each cluster member updates its respective CH and relay nodes update their next hop to the BS.

In the steady-state phase, after sensing the environment, each CM transmits its vector's magnitude to its respective CH. When a CH receives these magnitudes of vectors, it calculates average amount of vectors, and uses its next relay node to forward this amount to the BS. When a CM finishes its vector magnitude transmission slot, it enters into sleep mode to save energy. After receiving magnitudes from all CHs, the BS selects those clusters that their average amount is greater than a threshold and sends a MA for each CH of these clusters. Each mobile agent is responsible for collecting sensed data from CMs (cluster members) of a particular cluster with attractive sense data. Using the optimal routes that configured in setup phase, each MA goes to the CH and gathers the data of all CMs that belong to that CH, and come back to BS (Figure 1). In methods which only use clustering, all CMs send their data packets to CHs and then after gathering these data, CHs send them to BS. On the other hand, the methods which only make use of mobile agents, BS sends lots of agents to network senor nodes to gather the data related to all grids on the network. In both of these methods, the energy and bandwidth used will be high, due to the fact that lots of data packets which do not have important information also get sent to BS. Whereas in our method, after clustering, CMs distribute vectors which have a small size to CHs. BS then tries to identify clusters which have more important data packets and sends only one mobile agent per cluster to gather CMs' data packets.

In our proposed method, instead of sending sensed data packets of all CMs to their CHs and also to BS, we use the idea of small size vectors and TPSO algorithm. In our proposed method, nodes just send their vectors to CH, in order to decrease the resource consumption spe-

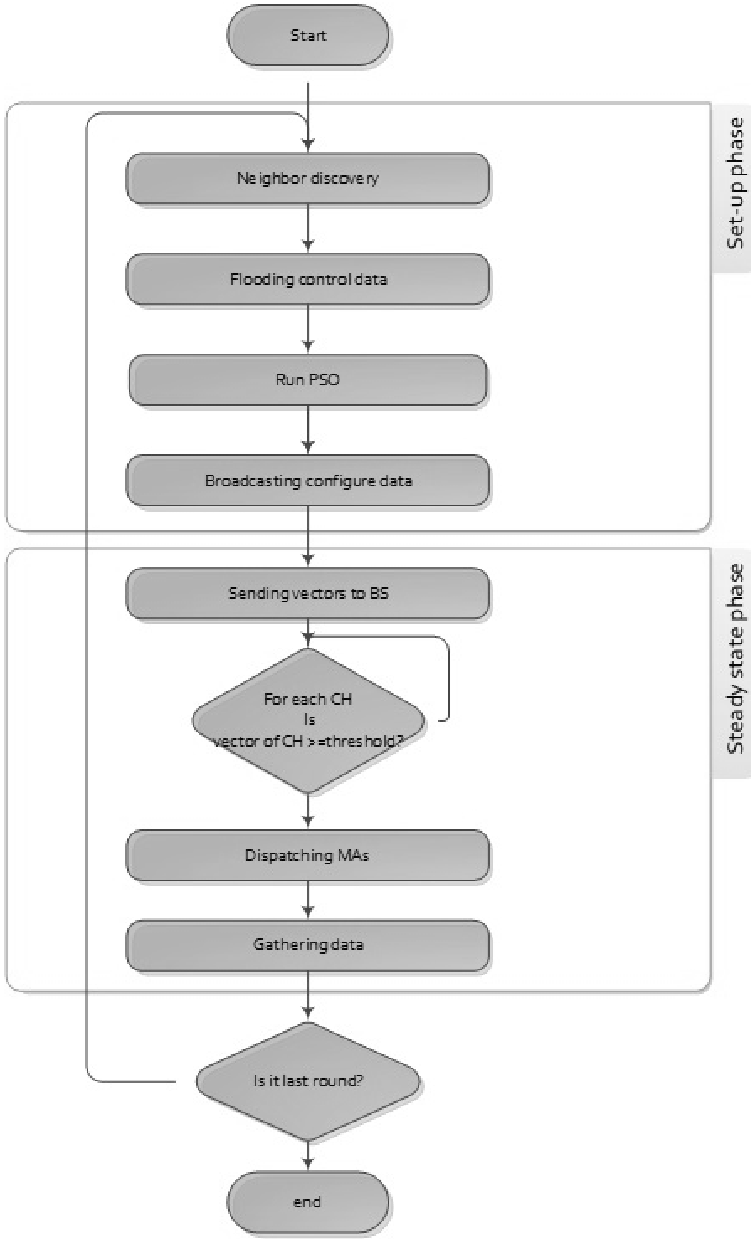

Figure 1. The flowchart of our method: EEDGM

cially energy consumption of network. Then, by dispatching of multiple MAs we simultaneously gather sense data from interested clusters. In this method, for more efficiency in resource usage, CMs send magnitude of their vectors to CHs instead of vectors.

3.4 Scenario

Assume that we have 30 sensor nodes in our area and a base station at position (0, 0). As shown in figure 2, after receiving all control packets by BS, the base station starts to find optimal set of CHs and routes using TPSO algorithm. Nodes 25, 13 and 17 are determined as cluster heads and nodes {1, 14, 16, 23}, {1}, {1, 13, 11, 10} as relay nodes of them respectively. In the steady-state phase, each CM transmits its vector magnitude to its respective CH, after sensing the environment (Figure 3). After receiving magnitudes from all cluster members, the CH nodes send mean amount of their received vectors to the base station. BS selects those clusters that their average amount is greater than threshold T, and sends a MA for each CH of these clusters. For example, in figure 4, base station selects CH numbers 17 and 25 (because these cluster heads have valuable data) and send two mobile agents simultaneously to gather their data.

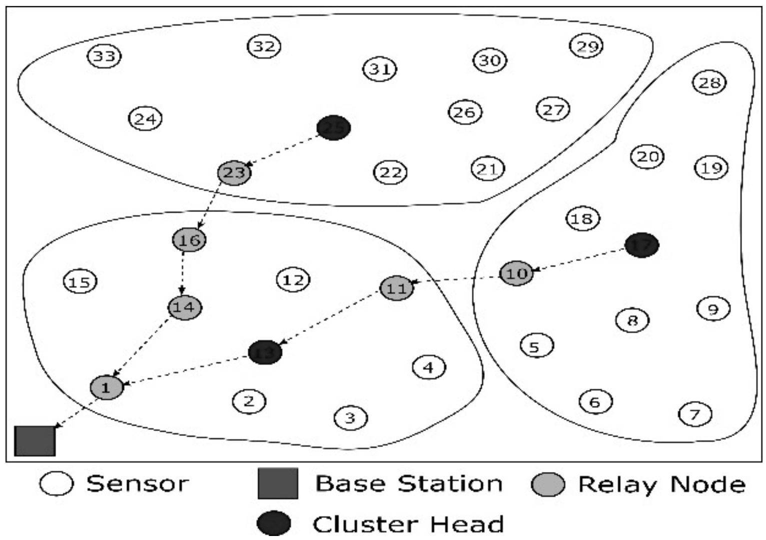

Figure 2. Finding optimal sets of CHs and routes

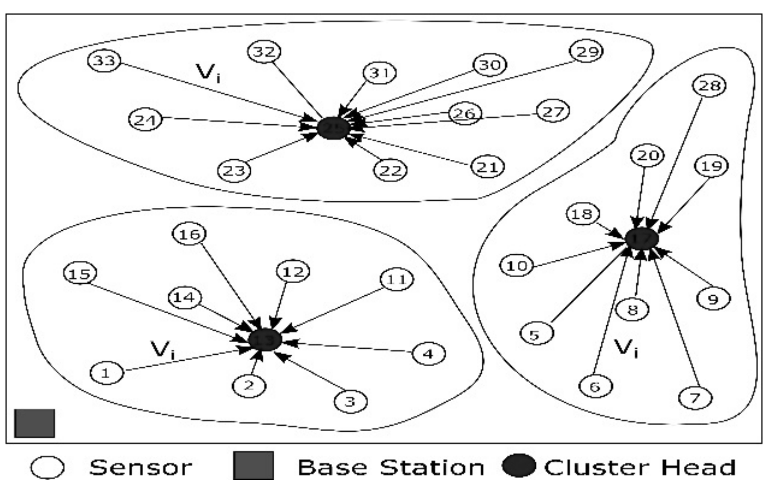

Figure 3. Transmitting of vectors

4. COMPARISON

For comparison, we use a number of metrics which are illustrated in table 1. Our proposed method combines both dynamic and static itinerary approaches. First, the base station statically finds

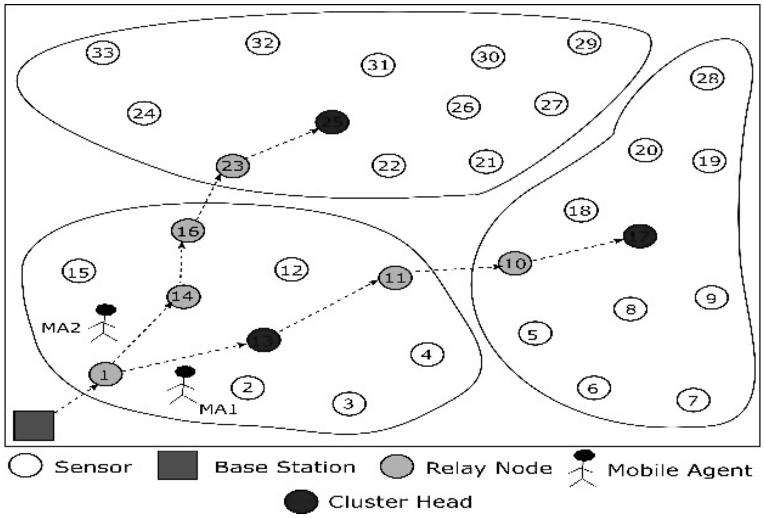

Figure 4. Sending MAs to important clusters

optimal sets of cluster heads and determines interested cluster heads according to information received from vectors. Then, the MAs dynamically dispatch in network and collect data form determined clusters and cluster member inside them in parallel way. The sensor nodes were deployed in static position in the area and their position will be fixed until the end of project. Table 1 summarizes the differences between our proposed protocol and relevant related works.

Table I: Comparison of Multi agent based approaches for data gathering in WSNs

Algorithms	**Itinerary planning**	**Multi/single agent**	**Sensor nodes**	**Itinerary planning approach**	**Performance metrics**	**features**
Proposed approach for MWSNs (Goto et al., 2013)	Dynamic	Multi agent	Dynamic	Geo-routing based	Delivery ratio Delay Traffic	Considering mobility of nodes Guarantee geographical granularity of sensing
MAMs (Dong et al., 2014)	Dynamic	Multi agent	static	Random	Energy consumption	Considering hotspot problem
DIPMA (Dong et al., 2014)	Dynamic	Multi agent	static	Using vector	Energy consumption Time Search accuracy	User centric Considering search accuracy
ETMAM (Gupta et al., 2014)	Dynamic	Multi agent	static	Agent cloning	Energy consumption Response time Network life time PDR Security	Considering malicious node attack
Our proposed method: EEDGM	Dynamic and static	Multi agent	static	Clustering and using vectors	Energy consumption Bandwidth consumption Network life time	Considering network time Energy efficiency

5. IMPLEMENTATION AND SIMULATION OF EEDGM

We simulated EEDGM in MATLAB. The reason why MATLAB is used in this project is the use of evolutionary algorithms which have a matrix-based nature. This simulator does better in matrix-based operations than other simulators. Furthermore, other simulators are better for distributed systems but since our proposed algorithm is a centralized method we preferred to use MATLAB. The sensor nodes were deployed randomly in an area of 300mx300m sensor field. The BS was located at the field's corner at position (0, 0). The percentage of CHs was set to 5% of the total nodes. The energy consumption model is as according to the research on Rabiner et al. [2000] which as follows:

$$\begin{cases} E_{TX}(k,D) = k.(E_{elec} + E_{amp}.D^2) \\ E_{RX} = (k) = k.(E_{elec}) \end{cases} \tag{4}$$

where k is size of the packet in bits, D is the radio transmission range, is the energy consumed by the transceiver electronics ($E_{elec} = 50nJ/bit$) and is the energy consumed by the transmitter amplifier ($E_{amp} = 10pJ/bit/m^2$). In this simulation experiment, the number of sensor nodes varied from 100, 200 to 300 to study their impact on the performance of the proposed protocol. For result analysis, each network scenario is executed 10 times. The related parameters in the simulation experiments are given in table 2.

Table II: Simulation parameters

Parameter	**Value**
Size of monitoring field	$300m^2$
Number of nodes	$100, 200, 300$
Number of cluster heads	5% of sensor nodes in area
Transmission range of nodes	$75m$
Initial energy of nodes	$1j$
Size of vector	$1024bits$

6. PERFORMANCE EVALUATION

In this section, we analyze the results of simulation experiments based on performance evaluation of our proposed method and compared those results to the DIPMA approach.

6.1 Energy consumption

In the first set of experiments, we evaluated the average energy consumption of nodes per round for each method by changing the number of nodes from 100 to 300. Average energy consumption per round is the amount of energy consumed by nodes in performing the set-up phase of one round.

Figure 7 shows the performance comparison of our method with respect to other existing protocol in terms of average energy consumption per round with varying number of nodes. Results show that our method performance outperformed the DIPMA Mianxiong et al. [2014] approach by changing the number of nodes from 100 to 300. For example, in figure.7, in round 5 the proposed protocol consumes 0.0139 j energy, but DIPMA consume 0.2981 j energy. This is due the fact that in DIPMA approach, all the nodes broadcast their vectors. Thus, networks consume more energy because of huge number of send/receive message. In our proposed method, nodes just send their vectors to CH. Therefore, energy consumption of proposed method is significantly less than DIPMA.

Total energy consumption of DIPMA and EEDGM has been illustrated in Figure 8. Results represented that, the proposed method has less energy consumption in comparison with DIPMA approach. Also, when the number of nodes increases, the proposed protocol consumes less energy in comparison with DIPMA. For example, when the number of nodes is 300, the proposed protocol consumes 0.4566 j energy, but DIPMA consumes 27.7414 j energy. This is due the fact that when number of nodes is increases, the number of broadcast message is increases too.

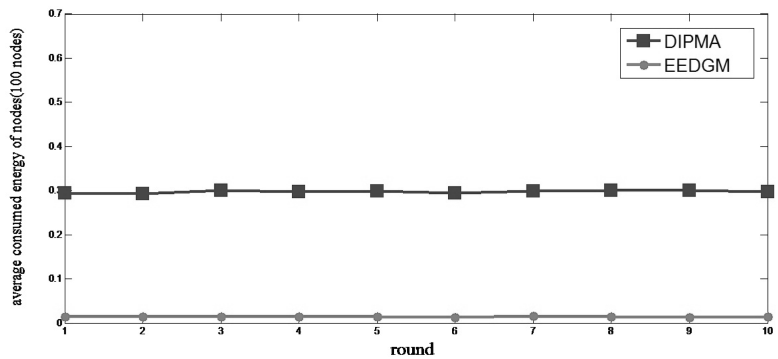

Figure 5. Average consumed energy by 100 nodes in DIPMA and EEDGM methods

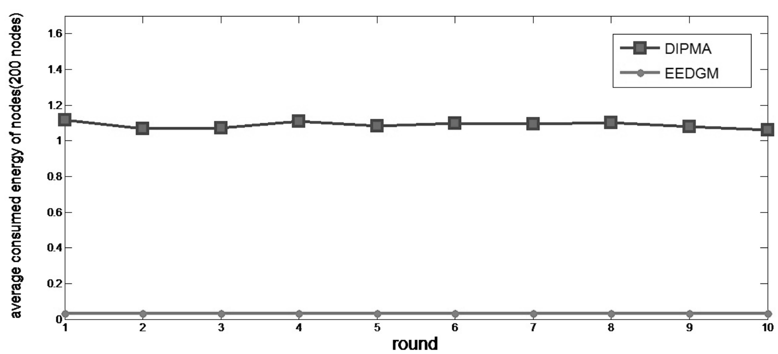

Figure 6. Average consumed energy by 200 nodes in DIPMA and EEDGM methods

6.2 Hop count

In this section, comparison of hop count amount for the best group among all sensor groups in DIPMA and best CH between all CHs by varying the sensor nodes from 100 to 300 on both approaches is illustrated. Investigation of results is Figure 9 shows that the proposed protocol has significantly lower amount of hop count than the DIPMA protocol. For example, in 300 nodes scenario, the number of hop count should pass to gather all results is 14, but the number of hop

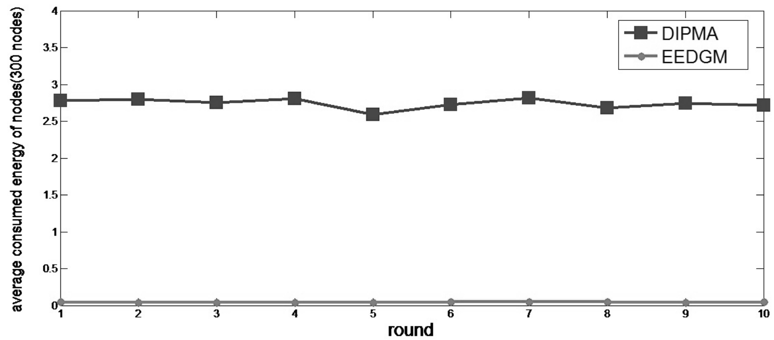

Figure 7. Average consumed energy by 300 nodes in DIPMA and EEDGM methods

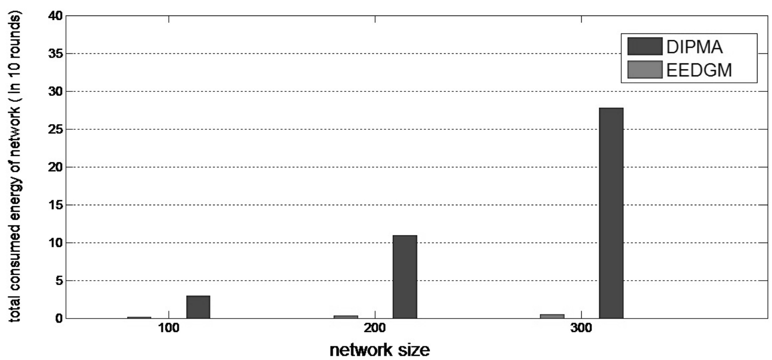

Figure 8. Total energy consumed by nodes in DIPMA and EEDGM methods

count should pass to reach CH is 8. This is due the fact that clustering approach significantly decreases hop count to gather useful information.

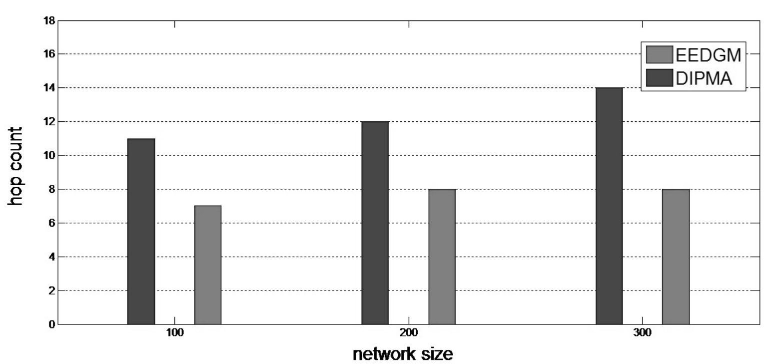

Figure 9. Hop count in DIPMA and EEDGM methods

7. CONCLUSION AND FUTURE WORK

In this paper the problem of data gathering in WSNs is studied. We proposed a mobile agent based system for data gathering approach. Our new proposal, called EEDGM, is an energy-efficient and content-aware data gathering method that uses multiple mobile agents and also uses advantages of TPSO algorithm and vectors. In this method, each mobile agent is responsible for collecting sensed data from CMs of a particular cluster containing important sense data.

Simulation results showed that our method provides better performance against the well-known protocol DIPMA in terms of various metrics. By using the advantages of vectors and TPSO algorithm in WSNs, our approach can decrease energy consumption and hop count especially in resource constrained applications of WSNs and increases network life time by efficiently usage of bandwidth and energy of network.

In our future work, we will try to improve the fitness function of clustering phase by adding information which are gained from vectors as selection metrics to adapt with network conditions better. We will employ a new fitness function in our method and investigate its results in performance of our method.

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