An Auction-based Cluster Head Selection Approach for Real Wireless Sensor Networks

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ABSTRACT:
In this paper, a hierarchical routing approach based on network clustering and using mobile sinks is proposed in WSN. The first, second, and third levels of hierarchy are composed of sensors, cluster heads (CHs) and mobile sinks (gateways), respectively. The most important challenges in the second level of hierarchy are: 1) election of the most suitable node as CH, and 2) reduction of communication overhead of CH election algorithm. Mobile gateway uses different data transfer technologies (e.g. SMS, WiFi, and 3G) and each communication technology has different characteristics in terms of cost, energy consumption pattern, etc. However, the characteristics of available mobile gateway(s) are ignored in designing CH election algorithm in previous studies. Designing CH election algorithm without considering the characteristics of gateways may lead to problems such as increasing data transfer costs and network fragmentation. Thus, unlike previous studies, a new fitness function is designed with respect to *local fitness value of a sensor* and *fitness value of its available mobile sink(s)*. In addition, an auction-based method is adopted to control communication overhead of CH election algorithm. The performance of the proposed approach in name DACMS is evaluated in OPNET 14.5 simulation platform. The simulation results show that DACMS outperforms MECA.

Keywords: Wireless Sensor Network, Energy Management, Mobile Gateway, Cluster Head; Auction.

1. INTRODUCTION

A wireless sensor network (WSN) is formed by a number of sensors which are capable of collecting, processing and transmitting data to the base station (BS) for further analysis. These sensors are sensitive to energy consumption due to have limited battery capacity. Therefore, designing energy management approaches is an important concern for WSN. In previous studies, it is proved that using of mobile sink as a gateway between the sensors and BS and adopting network clustering techniques are the two common approaches those have great impact on reducing energy consumption and increasing network lifetime (e.g. [1-4]). Consequently, in this paper a new hierarchal approach based on the combination of network clustering technique and using mobile gateways is introduced in order to transmit the sensed data to the BS. In this approach, first of all, clusters are formed and a cluster head (CH) is elected for each cluster. Then, each CH collects data from its surrounding nodes and passes it to the BS or one gateway. This decision is made with respect to various parameters such as sensor's remaining energy and distance. Electing the most suitable node as CH and reducing number of exchanged messages in CH election algorithm are the two most important challenges in this data transmission hierarchical approach.

To the best of our knowledge, the characteristics of available mobile gateway(s) are ignored in designing CH election algorithm in huge number of previous studies. Having a suitable CH (with respect to parameters like: remaining energy, number of neighbors, distance, etc.) but unsuitable available mobile sink may lead to problems such as increasing data transfer costs and network fragmentation in real WSN. Mobile gateway uses different data transfer technologies (e.g. SMS, WiFi, and 3G). The number of available communication technologies depends on the environment opportunities. Each communication technology has different characteristics in terms of cost,

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energy consumption pattern, etc. Therefore, compared to existing approaches, our first contribution is to propose a new CH election algorithm with respect to the realistic assumptions about the network environment. To do this, fitness of a node which shows suitability of that node for executing CH duties is calculated based on: (1) local fitness of the node, and (2) fitness of its available mobile sink. Consequently, each node and its available mobile sink are considered as a group and total fitness value related to the made group is calculated. Thus, the early mentioned problems will be encountered. The local fitness of a node is calculated based on following parameters: (a) sensor's remaining energy, (b) mean distance between sensor and its available access points, (c) number of neighbor nodes, and (d) mean distance between sensor and its neighbors. In addition, fitness of a mobile sink is calculated based on following parameters: (a) sink's remaining energy, (b) mean distance between mobile sink and its available access points, and (c) data transfer cost.

Our second contribution is to adopt auction-based mechanism to reduce number of exchanged messages in the process of CH election. The auction is the well-known market mechanism that can be used in CH election process to achieve energy balance amongst sensor nodes and reduce communication overhead. In our model, the current CH who cannot continue executing cluster head's responsibilities acts as an auctioneer and the cluster members act as bidders.

The paper is organized as follows: section 2 reviews the related works. System model and assumptions are explained in section 3. The details of the proposed approach based on network clustering and using mobile sinks are explained in section 4. Then, the simulation results and discussions are given in section 5. Finally, conclusions and future works are presented in section 6.

2. RELATED WORKS

In this section, some of the previous works in the field of wireless sensor network clustering are reviewed.

A new fuzzy multi-hop clustering protocol in name FMSFLA is proposed using Shuffled Frog Leaping Algorithm (SFLA) [5]. This protocol is composed of two phases in names CH selection phase and parent selection phase. The fuzzy rules are optimized for both phases using SFLA with the purpose of achieving trade-off between delay and energy. The parameters used in [5] are: 1) energy, 2) distance from the BS, 3) the number of neighbors, 4) real distance from BS, 5) mean rout load, 6) overlap, and 7) the problem of hot spots. The main limitations of FMSFLA are: 1) high time complexity, and 2) high energy consumption for executing the proposed idea in real sensors. Thus, the FMSFLA is not able to run on all sensors due to limited processing power, memory, and energy.

Singh Mehra *et al.* [6] propose a new fuzzy-based CH selection algorithm in name FBECS. The idea of [6] is formed based on following fuzzy descriptors: node density, separation distance from the BS, and remnant energy of the node. The simulation results show the suitable performance of [6] in terms of stability period, network energy, and throughput. However, the proposed idea is not able to run on all real sensor and mobile devices due to limited processing power, memory, and energy. In addition, the amount of energy consumed for executing fuzzy method is ignored in [6]. Therefore, the reported results are not trustable.

Adabi *et al.* [3] propose a new hierarchical routing protocol that is formed based on using mobile sink and network clustering technique. The contributions of [3] are: 1) adopting a new fuzzy-based approach for CH election, 2) adopting a linear prediction method to predict the next location of mobile sink aims at reducing the overhead of control messages. The fuzzy descriptors used in [3] increase the accuracy of CH election algorithm. The simulation results show the suitable performance of [3] with respect to the residual energy and delay performance metrics. However, the fixed fuzzy system structure leads to unsuitable functionality of [3] in different types and configurations of networks.

Ghosh *et al.* [1] propose a new hierarchical routing protocol that is formed based on using mobile sink and network clustering technique. To do this, a new fuzzy-based CH selection approach aims at balancing energy consumption is introduced. Then, a PSO (Particle Swarm Optimization)-based method is adopted to optimize the fuzzy membership functions. In addition, an ant colony-based optimization for mobile collector movement is proposed. The simulation results show suitable performance of [1] in terms of network lifetime and packet delivery. The main limitations of [1] are: 1) the reactive networks are not supported, 2) some unrealistic assumptions about mobile sinks are assumed, 3) network coverage is not fully satisfied, and 4) the proposed methods are not able to run on all real sensor and mobile devices due to limited processing power, memory, and energy.

A new distributed on-demand clustering algorithm is proposed in [7]. The two main contributions of [7] are: 1) designing a clustering technique by dynamically adjustment of cluster radius using Alternating Direction Method of Multiplier (ADMM), and 2) designing On-demand, oPTImal Clustering (OPTIC) algorithm to select CH. The re-clustering algorithm is carried out based on the detection of an event of interest. Some realistic factors like battery model of sensors are considered in forming the idea of [7] however, implementation of the idea in real WSN environments is too complex.

Stephan *et al.* [2] propose an energy and spectrum aware unequal cluster based routing in name ESUCR. In equal clustering the number of nodes is uniform per cluster and thus, size of clusters is equal. However, in unequal clustering the cluster size varies proportionally to the distance to BS. Unlike equal clustering, unequal clustering overcomes hot spot problem. Two objectives of [2] are: (1) maximizing the communication efficiency, and (2) minimizing the energy consumption. To achieve the mentioned objectives, following steps are designed: 1) selecting the optimal channel by means of a new ranking technique that takes into account energy, channel distance, and neighbor parameters, 2) adopting an energy-efficient spectrum sensing technique to improve accuracy, 3) selecting CH by means of an intelligent selection technique, and 4) selecting suitable gateway for sending data to the BS. The main limitation of [2] is that, suitable performance of ESUCR cannot be guaranteed in all network scenarios.

The problem of secure data transmission and balanced energy is addressed in [8]. To do this, an energy-aware convex hull algorithm is introduced to identify data collection points. A convex node is of type of sensor and has the responsibility of sending data of other sensors to the mobile sink. The convex node is selected with respect to remaining energy and distance. In [8], data are transmitted through elliptic curve cryptography. Some unrealistic assumptions about mobile sinks are assumed in [8]. In addition, making a trade-off between cost and consumed energy by applying mobile sinks is ignored.

In [9] a mobile sink based inter- and intra-cluster routing algorithm is proposed. The main objectives of [9] are balancing energy consumption of CHs and balancing energy consumption of cluster members. The main contribution of the authors is to consider time constraint in sojourn locations optimization to enhance network performance. While better performance with respect to the network lifetime, number of alive nodes and coverage time metrics is achieved, making a trade-off between cost and consumed energy by applying mobile sinks is ignored.

Wang *et al.* [10] propose two algorithms in names EMCA (Energy-efficient Multi-sink Clustering Algorithm) and MECA (Mobile-sink based Energy-efficient Clustering Algorithm) to optimize both clustering algorithm and deployment strategy of sink nodes. In addition, a cost function aims at finding the optimal number of mobile sinks in different scales of WSN is designed. The main drawbacks of [10] are: 1) high overhead, 2) short network lifespan when the number of mobile nodes passed the definite point.

In [11] a new data collection scheme in name MASP (Maximum Amount Shortest Path) is proposed. The MASP is formulated as an integer linear programming problem and solved by using GA (Genetic Algorithm). The main idea is to adopt a predetermined movement pattern to overcome the problems related to random walk of mobile sinks. To do this, the monitored range is divided into two parts in names Direct Communication Area (DCA) for sensors with one hop distance from mobile sink and Multi-hop Communication Area (MCA) far-off sensors according to the mobile sink's communication range. The simulation results show the success of the proposed idea in maximizing the amount of data collected by mobile sinks and balancing energy consumption. The main two drawbacks of [11] are: 1) involving large number of multi-hop communications, and 2) decreasing network life time in some types of network configurations.

Khodashahi *et al.* [4] propose a new hierarchical routing protocol that is form based on using mobile sink and network clustering technique. The main focus of the authors is on designing a distributed algorithm to determine new location of mobile BS based on the most efficient energy consumption for delivery of CHs' data. The simulation results demonstrate the efficiency of [4]. The two main drawbacks of [4] are: 1) un-scalability (due to applying just one mobile BS that cannot cover the large-scale networks), and 2) large amount of message overhead.

Marta and Cardei [12] propose an approach based on movement of the sinks along the hexagon perimeters in order to overcome hot-spot issue. The achievements of [12] are: (a) balancing the network energy among the sensors in an efficient manner, and (b) extending the network working period. The simulation results show that, the network lifetime is improved compare to the static sink case. The idea of [12] is formed based on an unrealistic assumption. That is, it is assumed that the mobile sinks are deemed to move in a free space. Thus, the functionality of [12] in network environments with obstacles is questionable.

In [13] a modified version of LEACH protocol is proposed. The two phases in clustering based protocol in names setup phase and steady state phase are focused by the authors of [13]. In setup phase, following parameters are taken into account for CH election: 1) remaining energy, 2) times of being CH, 3) distance between CH and BS, 4) number of neighbors, and 5) average energy of sensors in the current round. Also, unlike LEACH, in steady phase a modified TDMA schedule is presented. In their idea, duration of steady state phase for each cluster is not the same. The simulation results show that, the modified LEACH outperforms LEACH, VLEACH, and ALEACH in terms of network lifetime, throughput, and number of

CH. The main drawback is that if any CH dies, there will be no use of that cluster.

Alazab *et al.* [14] propose an intelligent technique in name modified optimization algorithm (ROA) for CH selection in IoT clusters with respect to three parameters delay, distance, and energy. However, The main limitation of [14] is that, selecting the weaker node as cluster head is possible.

Elmonser *et al.* [15] modify the LEACH protocol by considering both multi-hop and node mobility issues aims at balancing the energy consumption for sensors. The main drawback of [15] is unbalanced energy dissipation.

It can be concluded that, there is a need for designing hierarchal routing algorithm with respect to the advantages of clustering technique and using mobile sinks in which the technical characteristics of sensor nodes and its available mobile sinks are both considered. Also, the communication overhead in such an algorithm should be kept low. Likewise, the possibility of implementing this algorithm in real WSNs should be guaranteed.

3. SYSTEM MODEL AND ASSUMPTIONS

The wireless sensor network is deployed in a two-dimensional area of $Z \times Z$ m^2. The initial number of sensor nodes and the initial number of gateways (or mobile sinks) are n and g, respectively. The sensor nodes and mobile sinks are randomly deployed in the region to be sensed. The sensor node i and gateway j are denoted by S_i and G_j, respectively. Our WSN is used in environmental applications where the aim is to sense a physical phenomenon such as the amount of air pollution, temperature, humidity, etc. The access point of a sensor for data transmission is defined as the BS or mobile sink. Also, the access point of a mobile sink (gateway) for data transmission is defined as the BTS, modem, or BS. In addition, the number of base transceiver station (BTS) and modems are b and m, respectively. The BTS k and modem l are denoted by BTS_k and M_l, respectively.

Mobile sinks uses three data transfer technologies: SMS, WiFi, and 3G. The number of available communication technologies depends on the environment opportunities. In our scenario, some kind of appropriate mobile or web application exchanges data with a web service. Thus, three architectures for transmitting data from mobile sinks to the web services can be defined. In the first architecture, data is sent from mobile application to the web service by using one or more SMSs. The SMSs are received by mobile telecommunication provider and then the content is transferred to the web service by that provider. In the second architecture, by using GPRS technology, the mobile application is connected to the internet through its mobile telecommunication provider. Obviously, data are sent directly from applications to the web server by establishing the connection. In the third architecture, first, data are sent to the wireless router using WiFi technology. Then, data are forwarded to the web service through the ADSL internet provider.

An overview of the network model and its components are shown in Figure (1). Also, assumptions made for the system model are summarized as follows:

- The network consists of one BS whose location is at the center of the two-dimensional area.
- Sensor nodes are homogeneous and all sensors have the same radio range.
- All sensor nodes have the same amount of initial energy.
- Each sensor node has a memory to save required data.
- The energy models of the sensor for transmitting, receiving, and processing data are derived from [3].
- Both mobile sinks and sensors are equipped with GPS, so they are aware of their coordinates in the network.
- Both mobile sinks and sensors are battery-driven.
- All mobile sinks have the same amount of initial energy which is higher than the sensor's initial energy.
- The mobility model of mobile sink nodes is random way point (RWP) [16].
- The scheduling method of mobile sink is the same.
- The distance metric in this WSN is the Euclidean distance.
- The data transfer cost through any communication technologies is available and determined based on costs in Greece [17].
- Without loss of generality, it is assumed that during time period between receiving data from CH and transmitting the received data to the BS, network configuration is not changed.

4. PROPOSED APPROACH

In this paper a new CH election approach aims at minimizing energy consumption and communication overhead is proposed. Details related to our proposed approach are as follows:

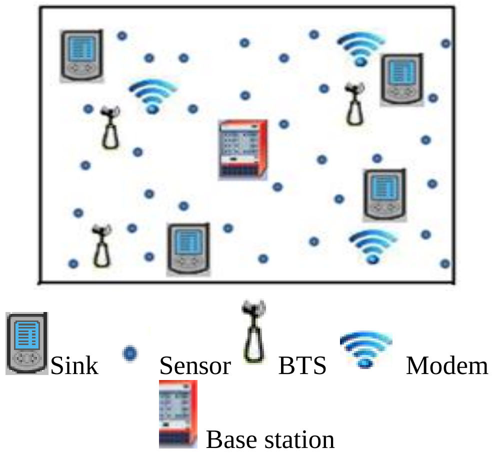


Fig. 1. Overview of network model and its components.

In the first round, each sensor generates a random number between 0 and 10 and broadcasts a message containing sensor’s ID and the generated number. Following, a sensor with the highest number is considered as CH with respect to the received messages. In other rounds, an auction-based method is adopted to elect a node as CH. By adopting such a method, communication overhead is controlled. To do this, current CH who cannot continue executing cluster head’s responsibilities (due to runs out of energy or inaccessibility of any access point) holds an auction to select the next CH. In the auction, current CH acts as an auctioneer and cluster members act as bidder. To make a bid, first of all, local fitness of a sensor is calculated by that sensor. Then, the sensor nodes ask the available mobile sinks to calculate their fitness values. Following, the mobile sink with the highest fitness value is chosen and the total fitness value (or bid) is determined based on the linear combination of sensor’s local fitness and fitness value of the chosen mobile sink. By receiving all bids from cluster members, a node whose bid has the highest value is elected as new CH. Finally, all nodes are informed about the identifier of new CH. This procedure is repeated until 95% of sensor nodes are dead. The flowchart of the proposed CH election algorithm is shown in Figure (2).

The total fitness of a sensor node (i.e., $Fitness_t$) is computed by linear combination of the sensor's local fitness (i.e., $Fitness_s$) and the best fitness of its available gateways (i.e., $Fitness_g$) based on Eq. (1):

$$= Fitness_g \; Fitness_t \qquad (1)$$
$$+Fitness_s$$

Following, the calculation methods of $Fitness_g$ and $Fitness_s$ are discussed in details in sections 4.1.and 4.2, respectively.

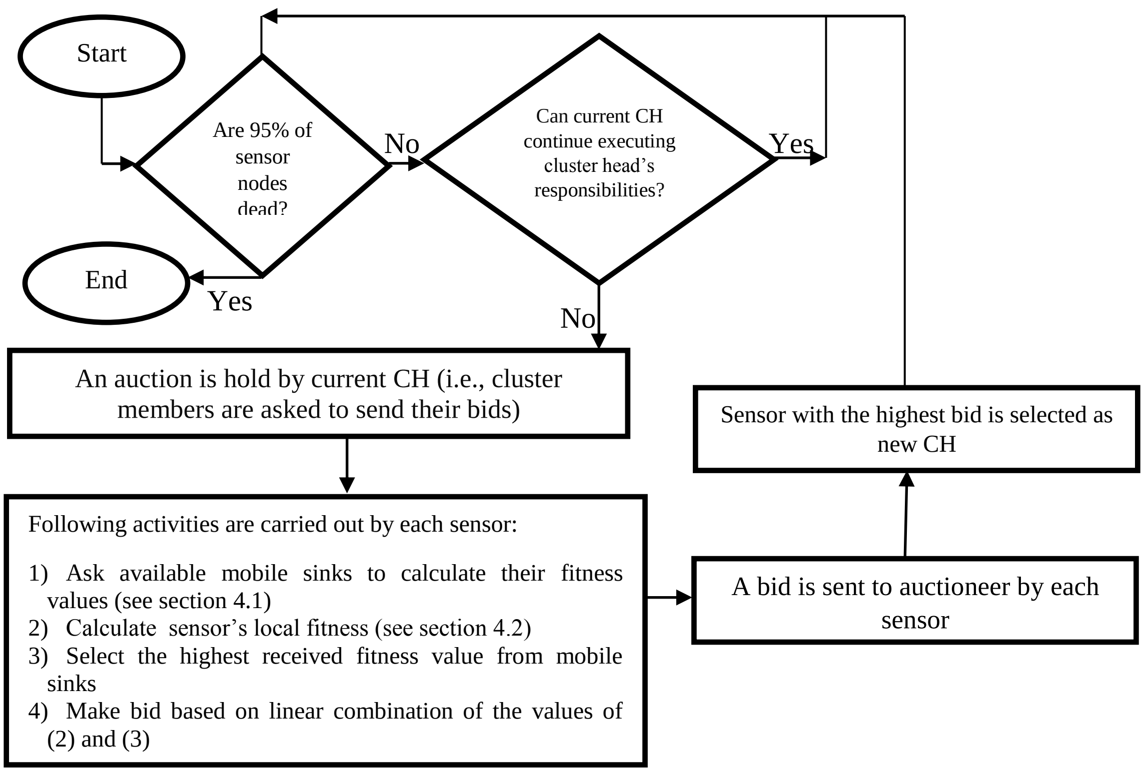


Fig. 2. Flowchart of the proposed CH election algorithm.

4.1. Computation of mobile sink's fitness

The mobile sink's fitness value determines the deservedness of the mobile sink (or gateway) for transmitting the received data from CH to the BS. The fitness value of each mobile sink is calculated based on fitness function $Fitness_g$ (see Eq. (2)).

$$Fitness_g = \frac{(\sigma RE_g + \sigma Dis_g^{BTS,M,BS} + \sigma Cost_g)}{3} \quad (2)$$

Where σRE_g, $\sigma Dis_g^{BTS,M,BS}$, and $\sigma Cost_g$ denote mobile sink g's remaining energy, distance between mobile sink g and its access points and minimum data transfer cost charged by mobile sink g, respectively. The symbol σA indicates the normalized value of A. If the objectives have unequal weights, Eq. (2) will be replaced with a weighted linear combination (WLC) method.

Following, details related to these parameters are discussed.

- **Remaining energy of mobile sink (σRE_g)**

The amount of energy consumed by mobile sinks to transmit data to the BS depends on their hardware configurations. It should be highlighted that, the computation of energy consumed by a mobile sink for data transmission is carried out by that mobile sink not a sensor. Thus, design of energy consumption calculation model for mobile sinks is out of our research scope. In other words, any calculation method can be adopted without any undesirable impact on the proposed idea. Thus, without loss of generality, these values are defined based on the descriptions of [18]. Then, the amount of remaining energy (i.e., RE_g) is normalized through Eq. (3):

$$\sigma RE_g = \frac{(RE_g - RE_{min})}{(RE_{max} - RE_{min})} \quad (3)$$

Where RE_{min} and RE_{max} are the lowest and highest amount of remaining energy, respectively. The lowest amount of remaining energy is set to ε_1 and the highest amount of remaining energy is set to the initial capacity of mobile sink's battery.

- **Distance between mobile sinks and its access points ($\sigma Dis_g^{BTS,M,BS}$)**

Recall that, the access point of mobile sinks can be of type BTS, modem, or BS. In this paper, distance to the access point is estimated using RSSI (Received Signal Strength Indicator) described in [19]. The mean distance between mobile sink and its access points is calculated as Eq. (4):

$$Dis_g^{BTS,M,BS} = \frac{\sum_{w=1}^{t} \sqrt{(x_g - x_w)^2 + (y_g - y_w)^2}}{t} \quad (4)$$

Where (x_w, y_w) and (x_g, y_g) denote coordinates of the access point and coordinates of the mobile sink, respectively. Also, t is the number of available access points where $t << (b+m+1)$. Recall that, there is only one BS in the network environment and b and m are the number of BTSs and modems, respectively. The stability period of a mobile sink to continue transmitting data to the BS by means of any access point is considered in defining Eq. (4). In other words, the fitness value of a mobile sink with regards to the mean distance from all access points determines whether that mobile sink can efficiently continue transmitting data to the BS in case of missing currently used access point or not. The normalized value of $Dis_g^{BTS,M,BS}$ is calculated through Eq. (5):

$$\sigma Dis_g^{BTS,M,BS} = 1 - \frac{(Dis_g^{BTS,M,BS} - Dis_{min})}{(Dis_{max} - Dis_{min})} \quad (5)$$

Where Dis_{min} and Dis_{max} denote the lowest and highest mean distance between mobile sink and its access points, respectively.

- **Data transfer cost through communication technologies ($\sigma Cost_g$)**

The mobile sinks may use the following communication technologies: 1) 3G, 2) WiFi, and 3) SMS. As previously mentioned, the number of available communication technologies depends on the environment opportunities. In addition, data transmission cost through any communication technology is available and determined based on costs in Greece [17]. The mobile sinks compute data transfer cost through each of their available technologies and then select the lowest amount as data transfer cost $Cost_g$ (see Eq. (6)).

$$Cost_g = min(Cost_{3G}, Cost_{WiFi}, Cost_{SMS}) \quad (6)$$

Where $Cost_{3G}$, $Cost_{WiFi}$ and $Cost_{SMS}$ denote data transfer cost through 3G, WiFi, and SMS, respectively. The normalized value of $Cost_g$ is calculated through Eq. (7):

$$\sigma Cost_g = 1 - \frac{(Cost_g - Cost_{min})}{(Cost_{max} - Cost_{min})} \quad (7)$$

Where $Cost_{min}$ and $Cost_{max}$ denote the lowest and highest cost of using the communication technologies, respectively. These values can be set based on the pricelists of the mobile service costs formed by National Mobile Telecommunication or Internet

Providers in each country. Likewise, total data transfer cost of the mobile application during a time period of monitoring phase is calculated as $\sum_{q=1}^{TM}(cost_q \times F_q)$, where the data transfer cost and the frequency of the qth measurement type are denoted by $cost_q$ and F_q, respectively. Also, TM denotes total number of measurements used by the mobile sink. Following, calculation of data transfer cost through 3G, WiFi, and SMS are explained in details.

A: Data transfer cost through 3G

Among different solutions for transmitting data from mobile sink to the BS, in the chosen scenario, CSV (comma separated value) data format and HTTP transfer method are adopted. Thus, the message has a simple format and small length. The message is sent through HTTP using REST protocol. The data transfer cost through HTTP is given by Eq. (8):

$$= V_{message} \times Cost_{byte} Cost_{message,HTTP} \quad (8)$$

Where $Cost_{byte}$ and $V_{message}$ are the cost of sending one byte using mobile internet and overall volume of a message, respectively. In Greece, the transfer cost of 20MB of data in one day through 3G is 1€. Also, the measurement unit for data volume is byte. The overall volume of a message (i.e., $V_{message}$) is calculated as Eq. (9):

$$V_{message} = V_{PM} + V_0 \quad (9)$$

Where V_0 is the volume of the overhead data and V_{PM} is the volume of the pure message. V_0 is calculated thus:

$$= V_{TCP/IP-overhead} + V_0 \; V_{HTTP-Overhead} \quad (10)$$

Where $V_{\mathrm{TCP/IP-overhead}}$ and $V_{\mathrm{HTTP-Overhead}}$ are TCP/IP overhead and HTTP overhead, respectively. The TCP/IP overhead and HTTP overhead are set to 650 bytes and 750 bytes, respectively.

B: Data transfer cost through WiFi

In the chosen scenario, CSV (comma separated value) data format and WiFi transfer method are adopted. Here, the data transfer cost is calculated as Eq. (8). The only difference is that, in Greece, the transfer cost of 24 MB of data in one month through WiFi is 22€.

C: Data transfer cost through SMS

Among different solutions for transmitting data from mobile sink to the BS, in the chosen scenario, CSV (comma separated value) data format and SMS transfer method are adopted. The data transfer cost through SMS is given by Eq. (11):

$$= N_{SMS} \times Cost_{SMS} Cost_{message,SMS} \quad (11)$$

Where N_{SMS} and $Cost_{SMS}$ are the number of SMSs needed to send a message of volume $V_{message}$ (see Eq. (9)) and the current cost of sending an SMS (which is determined according to the annually pricelists of the mobile telecommunication provider), respectively. In Greece, data transfer cost through SMS technology is 0.06 €/SMS. N_{sms} is calculated through Eq. (12):

$$N_{sms} = \left\lceil \frac{V_{message}}{CH_{SMS}} \right\rceil \quad (12)$$

Where $V_{message}$ and CH_{SMS} are the volume of a message and the maximum number of characters of an SMS, respectively. The measurement unit for data volume is character. In Greece, the number of characters of an SMS is 160.

For the benefit of readers, following an example of how to calculate the data transfer cost with respect to the three data transfer technologies in names WiFi, 3G, and SMS is provided. Recall that, CSV format is used in this paper.

Let assume that, the message format which is sent through SMM is defined as:

AreaName: value1,value2,..,valueH

Also, the message format which is sent through HTTP is defined as:

<host>?message = value1,value2,…,valueH

In our example, three values in names sulphur dioxide (SO_2 (µg/m^3)), nitrogen dioxide (NO_2 (µg/m^3)), and particulate matter (PM_{10} (µg/m^3)) are measured by air pollution sensors. In addition, the time of measurement, date of measurement, and name of the area that is monitored by the sensor should be reported for further analysis in the BS. Thus, the number of H is equal to 5 in our example. Consequently, by having message in format {AreaName: Date, Time, PM_{10}, NO_2, SO_2}one sample message can be {Thermi:15/12/2019, 14:40:00, 114.6, 5.6, 6.6}. Also, by having message in format {AreaName, Date, Time, PM_{10}, NO_2, SO_2}one sample message can be {Thermi,15/12/2019, 14:40:00, 114.6, 5.6, 6.6}. The former format is used when HTTP transfer method is adopted and the latter format is used when SMM transfer method is adopted. The data transfer costs through SMS, 3G, and WiFi technologies are shown in Table 1.

4.2. Computation of Sensor's Local Fitness

The sensor's local fitness value determines the deservedness of the sensor for executing CH's responsibility. The local fitness value of each sensor is calculated based on fitness function $Fitness_s$ (see Eq. (13)).

$$Fitness_s = \frac{(\sigma RE_s + \sigma Dis_s^{G,BS} + \sigma N_s + \sigma Dis_s^{n})}{4} \quad (13)$$

Where σRE_s, $\sigma Dis_s^{G,BS}$, σN_s, and σDis_s^n denote remaining energy of sensor s, mean distance between sensor s and its access points, number of neighbor nodes and mean distance between sensor s and its neighbors, respectively. The symbol σA indicates the normalized value of A. If the objectives have unequal weights, Eq. (13) will be replaced with a weighted linear combination (WLC) method. Following, details related to these parameters are discussed.

Table 1. Data transfer cost in Greece through SMS, 3G, and WiFi.

Data transfer technology	Message	V_{PM}	V_0	$V_{message}$	N_{sms}	$Cost_{message}$
SMS	Thermi: 15/12/2019, 14:40:00, 114.6, 5.6, 6.6	35 (based on character)	45 (based on character)	80 (based on character)	⌈80⁄160⌉=1	0.06 €
3G	Thermi: 15/12/2019, 14:40:00, 114.6, 5.6, 6.6	40 (based on byte)	650+750 = 1400 (based on byte)	1440 (based on byte)	-	72×10^{-6} €
WiFi	Thermi: 15/12/2019, 14:40:00, 114.6, 5.6, 6.6	40 (based on byte)	650+750 = 1400 (based on byte)	1440 (based on byte)	-	1310.4×10^{-6} €

- Sensor's remaining energy (σRE_s)

The sensor node consumes energy for performing the following duties: 1) packet transmitting, 2) packet receiving, and 3) data processing and sensing. Energy consumption models for executing the early mentioned duties are derived from [3]. Then, the calculated amount of remaining energy (i.e., RE_s) is normalized through Eq. (14):

$$\sigma RE_s = \frac{(RE_s - RE_{min})}{(RE_{max} - RE_{min})} \quad (14)$$

Where RE_{min} and RE_{max} are the lowest and highest amount of remaining energy, respectively. The lowest amount of remaining energy is set to ε_2 (where $\varepsilon_2 << \varepsilon_1$) and the highest amount of remaining energy is set to the initial capacity of sensor node's battery.

- Distance between sensor and its access points ($\sigma Dis_s^{G,BS}$)

Recall that, the node's access point can be of type mobile sink or BS. The mean distance between sensor node and its access points is calculated as Eq. (15):

$$Dis_s^{G,BS} = \frac{\sum_{w=1}^{a} \sqrt{(x_s - x_w)^2 + (y_s - y_w)^2}}{a} \quad (15)$$

Where (x_s, y_s) and (x_w, y_w) denote coordinates of the sensor and coordinates of the access point, respectively. Also, a is the number of available access points where $a <<$ (g+1). Recall that, there is only one BS in the network environment and g is the number of gateways (mobile sinks). The intra-cluster distance is considered in our CH election algorithm by defining Eq. (15). The normalized value of $Dis_s^{G,BS}$ is calculated through Eq. (16):

$$\sigma Dis_s^{G,BS} = 1 - \frac{(Dis_s^{G,BS} - Dis_{min})}{(Dis_{max} - Dis_{min})} \quad (16)$$

Where Dis_{min} and Dis_{max} denote the lowest and highest mean distance between sensor and its access points, respectively.

- Number of sensor's neighbors (σN_s)

Number of sensor's neighbors (i.e., N_s) is the number of sensor nodes those locate in transmission range of that sensor. Then, the calculated N_s is normalized through Eq. (17):

$$\sigma N_s = \frac{(N_s - N_{min})}{(N_{max} - N_{min})} \quad (17)$$

Where N_{min} and N_{max} are the lowest and highest number of neighbors, respectively. The lowest number of neighbors is set to 1 and the highest number of neighbors is set to n -1 (where n is the initial number of sensor nodes).

- Distance between sensor and its neighbors (σDis_s^n)

The mean distance between sensor node and its neighbors is calculated as Eq. (18):

$$Dis_s^n = \frac{\sum_{w=1}^{N_s} \sqrt{(x_s - x_w)^2 + (y_s - y_w)^2}}{a} \quad (18)$$

Where (x_s, y_s), (x_w, y_w), and N_s denote coordinates of sensor s, coordinates of neighbor w, and number of neighbors, respectively. The inter-cluster distance is considered in our CH election algorithm by defining Eq. (18). The normalized value of Dis_s^n is calculated through Eq. (19):

$$\sigma Dis_s^n = 1 - \frac{(Dis_s^n - Dis_{min})}{(Dis_{max} - Dis_{min})} \quad (19)$$

Where Dis_{min} and Dis_{max} denote the lowest and highest mean distance between sensor and its neighbors, respectively.

5. PERFORMANCE EVALUATION

In this section, the performance of our proposed algorithm is evaluated against MECA algorithm [10] through simulation. We use OPNET 14.5 simulation platform. Table 2 illustrates the simulation parameters and their values. It should be highlighted that, the authors design an agent that automatically controls the location and state of the modems (i.e., on or off) and locations of the BTSs to dynamically change the network environment. This agent has a great impact on making real network environment. In this paper, the average of achieved results from simulations is reported.

The performance metrics used in our simulations are: 1) remaining energy, 2) throughput, and 3) data transfer cost. Hereinafter and for the sake of simplicity in writing and reading, the proposed algorithm is called DACMS (Distributed Auction-based Clustering algorithm using Mobile Sinks).

Table 2. Input parameters for setting simulation environments and their possible values.

Simulation Parameters	Numerical Value	Simulation Parameters	Numerical Value
Network size	500×500 m^2	Initial energy of each mobile sink	7 J
Number of BTSs	[2,6] Is generated by controller agent based on scenario	Initial energy of each sensor	2 J
Number of sensor nodes	{50,100,200}	Energy consumption in circuit	0.00005 nJ/bit
Number of modems	[2,6] Is generated by controller agent based on scenario	Free space model of transmitter amplifier	10 pJ/bit/m^2
Radio range of each sensor	2 m	Multipath model of transmitter amplifier	0.0013 pJ/bit/m^4
Radio range of each mobile sink	10 m	Stop time of sink	1s
Packet size	160 Bit		

5.1. Results and Discussion

The comparison of DACMS and MECA [10] with respect to the performance metric in name average of remaining energy is depicted in Figures (3)-(5). To better analyze the impact of both designed $Fitness_g$ and $Fitness_s$, first of all, the average of remaining energy of nodes is reported in Figure (3). Second, the average of remaining energy of mobile sinks is reported in Figure (4). Finally, the average of remaining energy of overall network (including sensor nodes and mobile sinks) is reported in Figure (5).

The results demonstrate that, for 50-nodes, shown in Figure (3-a), in average 0.25 J of the sensors' energy remains at round 300 for MECA, which is 12.5% of the initial energy. On the contrary, 1.26 J (i.e., 62.5% of the sensors' energy) remained in the proposed DACMS at the same simulation round. Also, for 50-nodes, shown in Figure (4-a), in average 4.1 J of the gateways' energy remains at round 500 for MECA, which is 58.57% of the initial energy. On the contrary, 5.3 J (i.e., 75.71% of the gateways' energy) remained in the proposed DACMS at the same simulation round. In addition, for 100-nodes, shown in Figure (5-b), in average 4.8 J of the overall network energy remains at round 400 for MECA. On the contrary, 6.1 J remained in the proposed DACMS at the same simulation round. Therefore, it can be observed that, DACMS achieves better performance against MECA with respect to different simulation rounds and number of nodes. It should be highlighted that, the low distance between two curves of Figure (4-b) and Figure (4-c) is because of low diversity in CHs' access points of type modem and BTS. In other words, low number of choices is available and thus the same access points are used by mobile gateways in most of the times. However, the proposed DACMS outperforms MECA if any better opportunities to send data to the BS arises. The reasons of the achieved results from Figures (3)-(5) can be summarized as follows:

1) By designing total fitness function based on both sensor's local fitness and fitness of its available mobile sink, the number of re-clustering executions has greatly decreased. The reason is that, selecting a node that has the highest local fitness value but its available gateway has the lowest fitness value is avoided. In summary, compared to DACMS, in MECA each node must communicate with its neighbors in more number of times in order to re-form cluster which is caused by missing mobile sinks as intermediate nodes. The exchange of messages during the re-clustering phase needs an important amount of energy to be consumed, which explain the premature death of the sensor nodes in MECA.

2) In designing total fitness function two following types of energy are considered: (a) node's remaining energy, and (b) mobile sink's remaining energy. Thus, instead of energy evaluation of start point of the route from node to BS, the energy of whole route from node to BS is evaluated (i.e., the energy of intermediate nodes is also considered).

4) The energy consumption mainly depends on the distance. Thus, in designing total fitness function three following types of distance are considered: (a) distance from neighbors of type sensor, (b) distance between node and its access points, and (c) distance between mobile sink and its access points. Therefore, long-distance communication between a cluster member and its corresponding CH, long-distance communication between a CH and its access points, and long-distance communication between a mobile sink and its access points are avoided. Obviously, the distance-based strategy leads to saving more energy.

3) By adopting a distributed auction-based mechanism in CH election, the proposed approach does not suffer from drawbacks of the centralized process.

The comparison of DACMS and MECA with respect to the performance metric in name throughput is depicted in Figure (6). Throughput of the network presents the total numbers of packet transmit through CH to BS by network in the whole lifetime. Because of the constitute parameters of total fitness function, the network throughput of the proposed algorithm is much higher than that of the MECA. As an example, according to Figure (6), in case of the 200-node scenario the proposed DACMS sends 237028 data packets that is 19.66% more than MECA. In addition, for the scenario with 100-nodes, the proposed DACMS sends 105346 data packets that is 18.05% more than MECA. Finally, for the scenario with 50-nodes, the proposed DACMS sends data packets that is 11.80% more than MECA.

The percentage of improvement with respect to data transfer cost is reported in Figure (7). While the gateway selection in MECA is only carried out based on distance between CH and gateway, the gateway selection in DACMS is carried out based on both distance and data transfer cost. Thus, the results are justifiable.

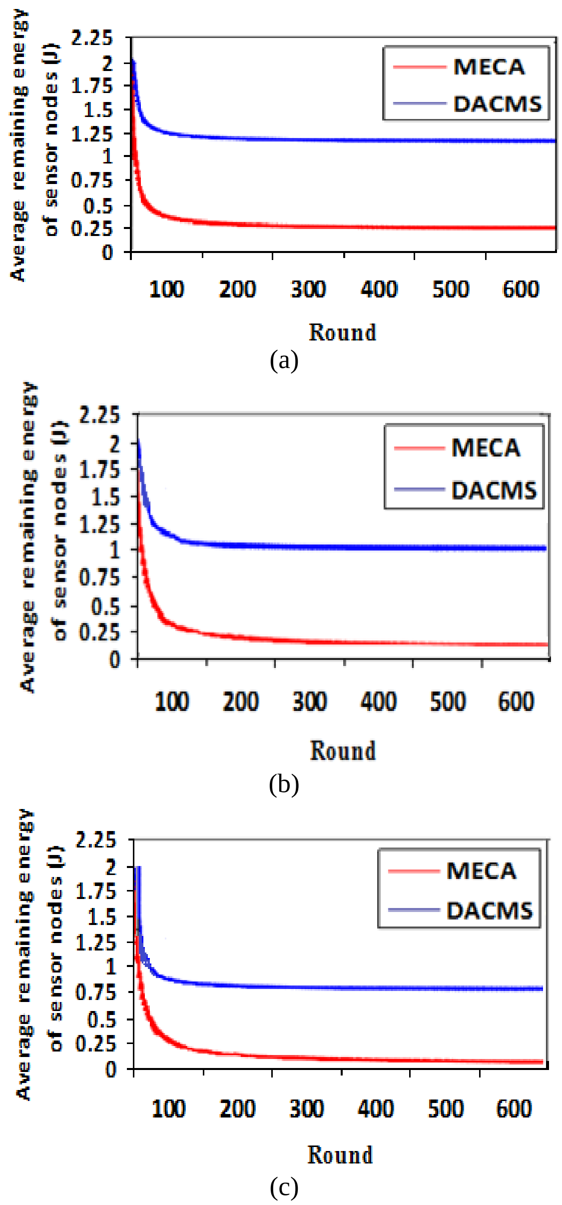
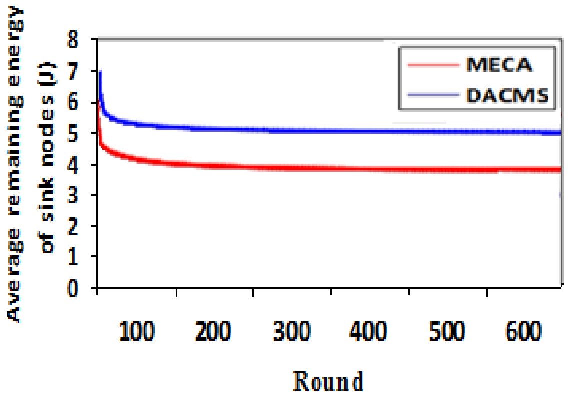
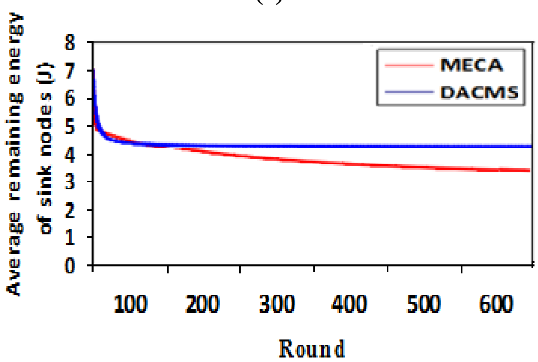


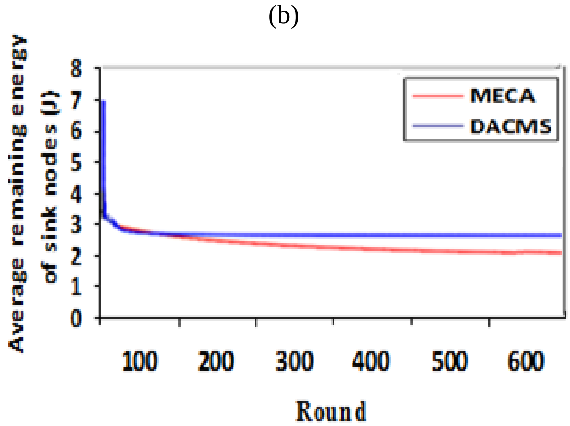
Fig. 3. Remaining energy of the sensor nodes with respect to the number of rounds. (a) node number is 50, (b) node number is 100, and (c) node number is 200.



(a)

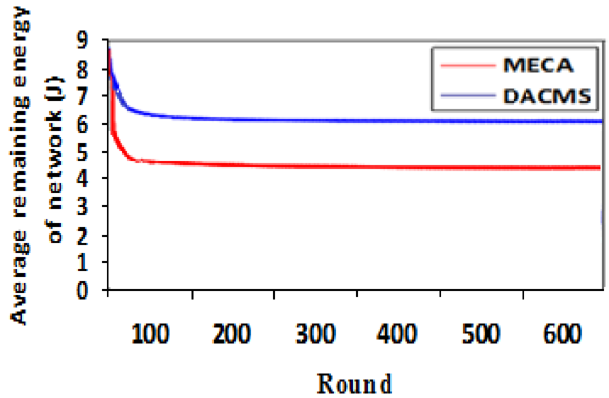


(b)

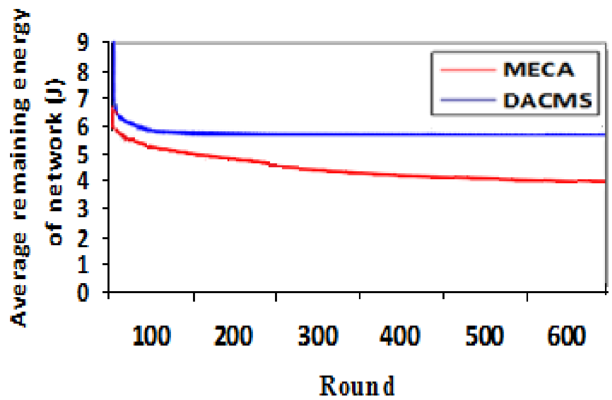


(c)

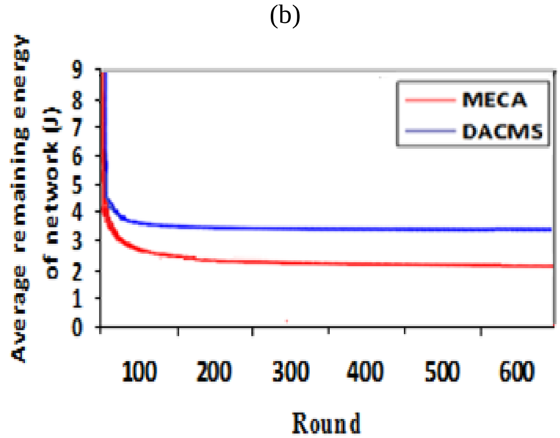
Fig. 4. Remaining energy of the mobile sinks with respect to the number of rounds: . (a) node number is 50, (b) node number is 100, and (c) node number is 200.



(a)



(b)



(c)

Fig. 5. Remaining energy of the overall network with respect to the number of rounds: (a) node number is 50, (b) node number is 100, and (c) node number is 200.

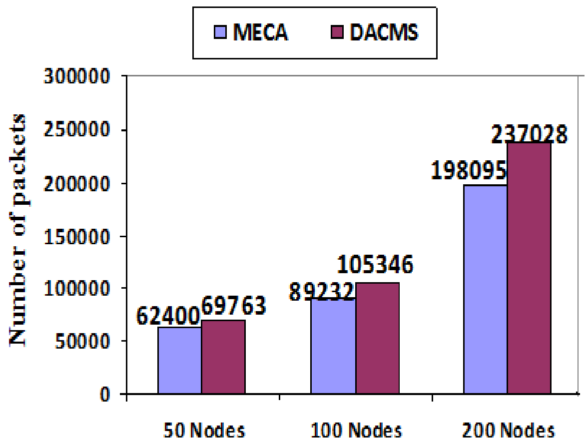


Fig. 6. Number of transmitted packets to BS, for 50-node, for 100-node, and for 200-nodes scenarios.

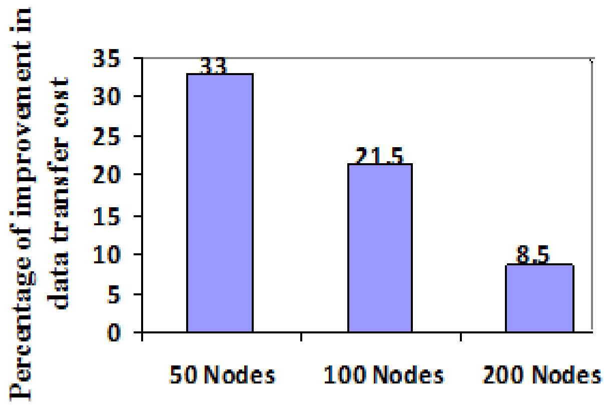


Fig. 7. Percentage of improvement in data transfer cost.

6. CONCLUSIONS AND FUTURE WORKS

According to the advantages of using mobile sinks (gateways) as intermediate nodes and network clustering technique in energy management of WSNs, a combinational approach based on these techniques is proposed in this paper. The main contributions of the proposed approach are: 1) designing new fitness function to elect CH with respect to the characteristics of sensor nodes and its available mobile sinks, and 2) adopting an auction-based method to control communication overhead in CH election algorithm. In designing our fitness function the unrealistic assumptions about network environment are avoided. Thus, it can be implemented in real WSN. Also, problems such as increasing data transfer costs and network fragmentation those may be caused by having unsuitable intermediate node near the selected CH are encountered. The local fitness of node is calculated based on the following parameters: (a) sensor's remaining energy, (b) mean distance between sensor and its available access points, (c) number of neighbor nodes, and (d) mean distance between sensor and its neighbors. In addition, fitness of available mobile sink is calculated based on the following parameters: (a) sink's remaining energy, (b) mean distance between mobile sink and its available access points, and (c) data transfer cost through different data transfer technologies in names 3G, WiFi, and SMS. Finally, the total fitness of the sensor is calculated based on the linear combination of the sensor's local fitness and the best fitness of its available mobile sinks. The linear combination method is applied due to the suitable performance in terms of computation overhead.

Simulation results show that the proposed DACMS algorithm outperforms MECA [10] in terms of the following performance metrics: 1) remaining energy, 2) data transfer cost, and 3) the number of transmitted packets from sensor node to the BS. (i.e., throughput).

In our future works we will work on following challenges: 1) re-designing fitness function of mobile sinks with regards to other parameters such as availability time and motion pattern, 2) adopting lightweight soft computing method for calculating total fitness value of the sensor, and 3) evaluating the performance of the proposed algorithm in various data volumes and types.

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