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A Hierarchy Topology Design Using a Hybrid Evolutionary Algorithm in Wireless Sensor Networks

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A B S T R A C T

Wireless sensor network a powerful network contains many wireless sensors with limited power resource, data processing, and transmission abilities. Wireless sensor capabilities including computational capacity, radio power, and memory capabilities are much limited. Moreover, to design a hierarchy topology, in addition to energy optimization, find an optimum clusters number and best location of cluster heads are two important issues. Many routing protocols are introduced to discover the optimal routes in order to remove intermediate nodes to reduce the sensors energy consumption. Therefore, for energy consumption optimization in a network, routing protocols and clustering techniques along with composition and aggregation of data are provided. In this paper, to design a hierarchy topology, a hybrid evolutionary approach, a combination of genetic and imperialist competition algorithms is applied. First, the genetic algorithm is applied to achieve an optimal clusters number where all effective network parameters are taken in into account. Aftermath, the optimal positions of cluster heads inside every cluster are calculated utilizing the imperialist approach. Our results show a significant increment in the network lifetime, lower data-packet lost, higher robust routing compared with standard LEACH and the ICA based LEACH.

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1. INTRODUCTION

Today, an intelligent network of wireless sensors, called WSN[2], contains hundreds or thousands miniaturized sensors makes observing and controlling different physical phenomena possible [1].Today, WSNs are utilized in many industrial, military, economic or even cultural applications [2]. Resources of wireless sensors such as radio power, computation capability, and memory capacity are much bounded. For interaction with an environment, the sensors use a low-power battery [3].

In WSNs, the network coverage along lifetime, deployment type, localization, robust routing and redundancy reduction of collected data are some of the WSN design issues. The energy optimization become the main issue of the WSNs topology design [4]. Inside a sensor, most parts of energy are consumed for data transmission, collected from the application domain. The events are reported directly or indirectly to a stationary BS[3], established in the far distance from the WSN using different routing algorithms [5].

Many protocols and algorithms are proposed to find optimal paths for data communication. The hierarchy architecture, a high-performance topology, divides the field of interest into some sub-areas to group the sensor nodes, called clusters. It reduces the network energy conservation and manages the data packets routing to increase the lifespan of a WSN [6]. A sensor detects those CHs[4], located inside its radio range to find the nearest and available CH. Moreover, members of a cluster communicate with the BS via the corresponding CHs using single-hop or may multi-hop communication paths regarding the transmission power of the nodes [7].

In this architecture, different duties are assigned to each node every round. Compared with ordinary sensors, the CHs consume more communication energy due to data communication over long distances. Hence,

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[2] Wirteless Sensor Network
[3] Base Station
[4] Cluster Heads

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find the optimum number of clusters and select the appreciate sensors to act as CHs are two main open issues in the WSNs clustering [8].

In a WSN topology design, the importance parameters are inconsistent and different variable that may effect in the WSNs design oppositely. Minimizing energy consumption damages to the network connectivity and coverage and vice versa. Hence, a WSN topology design problem turns an NP-Hard problem [9]. To find an optimal solution for a WSN topology design, the Meta-Heuristic algorithms can be applied. Two powerful evolutionary algorithms, the GA[5], a common and famous evolutionary algorithm and the ICA[6] based on a political and social process to solve the WSN topology design problem [10].

In this paper, calculation and discovery of an optimum clusters number and selection of the best sensor to operate in CH mode to reduce sensor energy consumption, data packet-lost and improve connectivity and coverage, and increase the lifespan of the network are desirable. Furthermore, through applying a hybrid approach, a combination of GA and ICA, the WSNs clustering improvements were investigated. In our proposed clustering algorithm, we used GA to find the optimum number of clusters and ICA to calculate the best positions of CHs in all clusters. For the accuracy validation, our experimental results will be compared with the standard LEACH[7] and ICA-LEACH methods.

The rest of this article is organized as section 2 provides issues of the WSNs Design, section 3 describes related works, section 4 describes Genetic Algorithm, section 5 deals with imperialist competition algorithm, section 6 the proposed method, section 7 explains evaluation function, section 8 deals with the result and discussions, and the last section concluded the paper.

2. LITRITURE REVIEW

2. 1. WSNs Clustering Issues In WSNs topology design and implementation, many special issues exist. Essentially, scalability needs energy balance and suitable utilization of resources and nowadays, the hierarchy topology is an impressive method to optimize the energy consumption of sensor nodes [11]. The sensors are grouped in some predefined or random created clusters base on the applied algorithm. Members of every cluster transmit the sensed data to the associated CHs for further processes [12].

The clustering can improve the energy consumption efficiency of sensors, the network lifetime and scalability. It improves the network stability, conserves bandwidth, prevents collisions through makes limitations on the attraction domain and prevents data redundancy. It is an efficient method when an application needs the huge number of sensor nodes. The ordinary sensors are maintained while connected to the associated CHs and do not get any influence from the network changes during CHs selection phase [13, 14].

Most of the clustering algorithms select and form clusters probably or randomly. In result, in all rounds, completely different clusters are created. Also, a large number of CHs leads to the increment of network energy consumption, and an insufficient number of CHs damages the network connectivity and coverage extremely. In predetermined clustering algorithms, to select and form clusters based on the determinate nodes, some special constraints are existed, while in the probabilistic methods, a node uses a probability value to switch and operate in the CH mode [15].

The centroid clustering algorithms are based on characteristics and functions of sensor nodes in clusters, while distributed clustering algorithms emphasize the used methods of clustering forming. A few numbers of algorithms use centroid techniques or a mix of the centroid and distributed techniques. In the distributed approach, a sensor node decides to act in the CH mode by executing its own algorithm while in the central approach, the BS or the coordinating node determines and selects a group of CHs. Sometimes, a combination of both approaches is desired [16]. Mostly, in all proposed methods, using TDMA[8] protocol for data transmission is proposed, which a sensor can schedule sleeping time frequently to save more energy [17].

2. 2. Related Work Heinzelman [18] introduced LEACH, a routing protocol, used to cluster a WSN. The LEACH is TDMA-based MAC protocol and a distributed algorithm, which integrates two-tire clustering with a simple routing (single-hop). The nodes are clusters randomly every round. The main objective of the LEACH protocol is to reduce the total network communication energy to extend a WSN lifespan.

The residual energy of nodes is not considered, when any node decides to operate in a CH mode. Moreover, the clusters are not uniformly distributed, and their number is not optimized. Unlike the LEACH algorithm, LEACH-C utilized a centralized approach for the WSNs clustering. The sensors information, including residual energy and location of sensors, is transmitted to BS for CHs selection and clusters forming. The clusters number is bound, and CHs are selected randomly. Due to the difficulty of sending situation of far-distance nodes to the BS, this protocol is not suitable for a large network size. It leads to increasing the latency and idle times of nodes [19].

[5]Genetic Algorithm
[6]Imperialist Computation Algorithm
[7]Low-Energy Adaptive Clustering Hierarchy
[8]Time-Division Multiple Access.

The HEED[9] algorithm improves the LEACH algorithm based on using the residual energy of homogeneous nodes in CHs selection phase. Nodes degree or density are the main parameters to balance energy in the cluster forming step. Minimizing energy consumption of nodes, making cluster distribution uniform, terminating clustering with fixed numbers of rounds and increasing the network lifetime through the uniform balance of sensors energy consumption are the principal parameters in the HEED algorithm [20, 21].

GA is applied to adapt and optimize a WSN with grid deployment type and an optimum number of sensors [16]. The gathered data is transmitted via single-hop data paths. By optimizing the number of living sensors, the communication energy is minimized, while the lifetime of the network is increased. Moreover, the network connectivity is satisfactory.

Hosseinirad et al. [22] improve the LEACH algorithm through the imperialist approach. In a standard LEACH, clusters are distributed unbalanced across the entire network because CHs are selected probably without any restrictions. Cluster forming phase of the LEACH algorithm is improved through the ICA. It is demonstrated that the introduced protocol can improve the network topology based on the standard LEACH satisfactory. ICA is utilized to select the best candidate to function in CH mode [18]. Creating optimized clusters and selecting suitable CHs effect on the efficiency and performance of the used routing algorithm extremely.

In another research [23], the authors proposed an approach to optimize energy utilization of the WSNs and elongate the network lifetime based on GA. All living sensors of the network are considered as a gene inside a chromosome using binary encoding. The Euclidean distance of the BS is the main criterion in the defined fitness function. At the end, the topology of the network is constructed based on the best chromosome which contains an optimal arrangement of clusters. Karaboga et al. [24] proposed a solution based on the Artificial Bee Colony algorithm (ABC) for routing improvement in a WSN. The obtained results represented that the proposed protocol is more efficient compared with the standard LEACH algorithm [25].

2. 3. Genetic Algorithm

The GA is a special evolutionary algorithm, introduced in the 1970s. In the GA, genes are coded to represent the different parameters of a WSN. A collection of genes is calleda chromosome. It deals with an individual of a population, where each individual is a potential solution represented as a chromosome. Each population evolves through a generation number. Representing and encoding parameters in the GA can be done in different ways such as binary, decimal or any other bases. A cost or fitness function is applied to every chromosome of the population. The chromosomes are selected for recombination based on fitness values. Elite chromosomes find higher chances of being carried on to the afterward generation. In the crossover step, two different chromosomes (parents) are selected for recombination from which two children are created. To prevent a premature convergence in local optimal, a mutation operator is utilized [23]. One example is a chromosome five genes representing five sensors in the network, shown in Figure 1.

In this paper, chromosomes are considered as an array of binary numbers in array size or number of genes considered being the size of sensors in the WSN.

2. 4. Imperialist Competition Algorithm

The ICA, introduced in 2007, is a novel paradigm in optimization algorithm and intelligence systems. Utilizing political, social and cultural processes to create an evolutionary algorithm is unique. First, in the ICA, a population of countries with different characteristics is created. Those countries having better quality and more power decide to colonize other weaker countries to establish an imperialism [24].

In fact, an intra-empire competition leads to improving the solution, while the main competition occurs among different imperialists (Figure 2). In this algorithm, assimilation and revolution are two important concepts. In the colonialism process, an imperialist imposes a set of policies on the colonized society with some changes to assimilate the target society into the dominant culture. Based on the same manner, every colony moves toward its empire. Those policies arenamed assimilation policies. The colony movement may be done in one or two directions. The direct movement is not desirable [26].

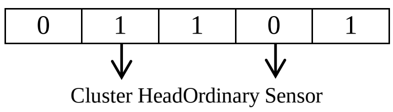

Figure 1. A Schematic View of a Chromosome with 5 Genes

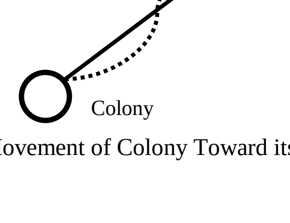

Figure 2. Movement of Colony Toward its Imperialist

[9] Hybrid Energy-Efficient Distributed.

Comparing colonies with their corresponding imperialists, evaluating imperialists based on the cost function, the weakest colony elimination from the weakest imperialist and assigning it to any other imperialist randomly, converting the colony-less imperialist to a colony and assigning it to any other imperialist randomly and reporting the best imperialist are some of the other ICA steps.

3. THE PROPOSED METHOD

In this article, a dynamic intelligence method to cluster a WSN through a hybrid evolutionary algorithm is proposed. The GA is used to find the optimum number of clusters, and the imperialist approach investigates a cluster to discover the best location of the CH. The main objective of this study is the reduction of sensors rate death without any data-packet lost to optimize energy consumption dramatically, which increases the network lifetime favorably.

As, the sensor power limitation is an important issue in the WSNs design, the propose method optimizes energy consumption and increases the network lifetime favorably. Regarding the previous studies, we have tried to increase the network lifespan by grouping the sensors in certain clusters. In most studies, network life is elapsed time up to the death of the first or last node in the WSN. To increase the performance of the proposed algorithm, the network benchmark can be changed in such a way that the network terminates when not covering much of the area under consideration. In this paper, when the WSN fails to cover min 50% of the application area, the network will be destroyed.

In our proposed method, the operation of WSN is started by collecting data from the sensors. It involves calculating and estimating the residual energy of all sensors to make the first network clustering of nodes. The algorithm makes the nodes clustering done by knowing the physical location of the sensors in every round. The associated CHs gather sensed data from the members of clusters and forward the base station after applying some local data fusion. Furthermore, the proposed clustering algorithm consists of two phases: finding the minimum number of clusters and discovering the optimal locations for CHs.

In the first step of the suggested algorithm, the GA is applied to determine the optimum CHs number to increase the network performance compared with other methods, including uniform distribution of clusters, energy consumption and the network lifetime. We used the GA because it is a powerful evolutionary algorithm which is a flexible method to solve a dynamic or discrete problem. In the second step, after determining the optimum number of clusters, the optimal location of CHs in the clusters is determined through ICA. The pseudo code of the purposed method is:

```
1. Initialize the network using the
   gathered data of sensors.
2. The number of clusters determinations
   using the GA.
3. Determining the optimum location of
   the CHs using the ICA.
4. The sensors data transmission to the
   base station through the CHs.
5. The network termination conditions
   satisfied? If yes go step 6 to
   otherwise update the sensors and go to
   step 2.
6. Terminate the network.
```

3. 1. Evaluation Function

The most important step of a problem optimization is the evaluation function clarification, obtained from the conversion of object parameters, supposed to be optimized. The fitness function evaluates every chromosome by a numeric value to specify its quality. Chromosome with higher quality (as an answer to the problem), find more chance to be elected to the afterward generations. In the multi-objective optimization of a WSN design, different parameters (P_1 to P_5) should be taken into an evaluation function. We formularize the multi-objective optimization, named cost function, represented by Equation (1).

$$\text{Cost Function} = \min\left\{\sum_{i=1}^{5} W_i P_i\right\} \tag{1}$$

whereW_i shows the different weights of parameters of the cost function, represented in Table 1.

In this study, a comprehensive study is done and the objective function is divided into five factors, considered as the following parameters. This function is a weighted summation of these five factors and considered as a cost function. If the total amount of consumed energy by members of cluster i is represented by E_{M_i} and the consumed energy of CHi, is represented by E_{CH_i}, therefore, the first parameter, P_1 is summation rate of members energy consumption of m clusters to their associated CH energy consumption, calculated by Equation (2):

$$P_1 = \sum_{i=1}^{m} \frac{E_{MCH_i}}{E_{CH_i}} \tag{2}$$

TABLE 1. Different weight values of the cost function for GA, ICA

	W_1	W_2	W_3	W_4	W_5
GA	10^2	10^3	1	10	10
ICA	10^4	10^2	1	10^2	10

The second parameter, $P_2$is defined to find the wide cluster regardless the number of members and the max of the average of intra-cluster distance, given by Equation (3).

$$P_2 = \max_{i=1...m}\left(\frac{\sum_{j=1}^{N_i} Dist_{i,j}}{N_i}\right) \tag{3}$$

The total value of standard division of the distances for the cluster members over the total number CHs, is represented byP_3, may be represented by Equation (4).

$$P_3 = \sum_{i=1}^{m}\left(\frac{\sigma[Dist_{i,j}]_{j=1}^{N_i}}{N_i}\right) \tag{4}$$

The $Dist_{i,j}$ is the distance between i^{th} sensor and its CH, and N_i is the total number of i^{th} cluster members. Moreover, the energy consumption of a cluster is approximately calculated by Equation (5).

$$E_{Cluster} = \sum_{i=1}^{m}\sum_{j=1}^{k_i}\left(D_{i,j}{}^{x} \times E_x\right) \tag{5}$$

where d_0 is a threshold distance defined as $d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$. If the distance of K_i members of i^{th} cluster with the associated CH is less than d_0, x=2 and E_x is ε_{fs} (the transmitting amplifying energy in free space model), otherwise the distance of K_i members of i^{th} cluster with the associated CH is greater than d_0, x=4 and E_x is ε_{amp} (the transmitter amplifier energy). Finally, the total value of the network consumed energy is represented by Equation (6).

$$P_4 = \sum_{i=1}^{m} E_{Cluster_i} \tag{6}$$

The size of clusters influences the performance of the WSN significantly. By optimizing the size of a cluster, members of a cluster become closer to each other. Moreover, the energy consumption of the cluster decreases too. Due to the importance of this parameter, it is represented by Equation (7).

$$P_5 = \frac{1}{\sum_{i=1}^{m}\left(\frac{1}{N_i}\right)} \tag{7}$$

4. RESULTS AND DISCUSSIONS

In this simulation, we use the following values parameters for the GA-ICA algorithm for a WSN clustering design. The maximum generation of is 500 and *nPop* (the population size) is 50, in the GA and ICA. In the GA, thep_s (the selection probability) is 0.3, p_m (mutation percentage) is 0.08, p_{mu} (mutation rate) is 0.02, p_{cr} (crossover probability) is 0.8, β (selection pressure) is 8. For the selection method, the roulette wheel selection, and two-point crossover are used. In the ICA algorithm, α (selection pressure) is 1, β (assimilation coefficient) is 8, p_{re} (probability of revolution) is 0.1, μ (revolution rate) is 0.05, and ξ (colonies mean cost coefficient) is 0.1.

The monitoring area size is 10m×10m. The GA-ICA is coded in MATLAB version 9 on Intel(R) Core i7-4500U CPU @ 1.8GHz 2.4 GHz running Windows 8 Ultimate. In addition, the value of ε_{fs} is 10$pJ/bit/m^2$, ε_{mp} is 0.0013$pJ/bit/m^2$, R_{rx} (radio communication radius) is 5m (in OS mode) and R_{sen} (sensing radius) is 1m. The sensors are stationary, homogeneous and randomly deployed with different sizes of living sensors 100 and 200 inside a desired square application area; the BS is taken out of the environment in coordinates (20m, 20m). Data communication is done using single-hop data path to a CHwith the min latency. First, the GA is used to find an optimized collection of clusters.

Then, the ICA obtains the optimal position of the CHs, generated by the GA. The cost function of GA is the same as the cost function of the ICA. The first parameter of investigation is the living nodes number. This parameter determines the value of the network lifetime over rounds. The number of living nodes is an effective parameter to evaluate a clustering algorithm is in every round. Figure 3 illustrates three LEACH, ICA and GA-ICA methods for the total number of living sensors per round in the WSN with 100 sensor nodes. It is investigated to collect the full environmental information. In the LEACH method, when the distance of nodes and BS is increased, they die more quickly. Finally, the closer sensors to the BS will remain alive, while the rest of them will die. In conclusion, as seen in Figure 1, although the termination condition of all three methods is the same, the proposed method is terminated with a lower number of living nodes in a WSN with 100 sensors compared to the LEACH and the ICA methods. It means that the rate of death of sensors is uniform. The second parameter is the clusters number, where the total clusters number is determined dynamically during the network lifespan and a preferred used method is a more efficient way for CH selection. Furthermore, the total created clusters number should be sufficient. By merging closer clusters, nodes can reduce the communication energy consumption that is shown in Figure 4. Compared with other methods, the LEACH method fluctuates more in the total clusters number; because of the random CHs selection, while the proposed method has a better stability.

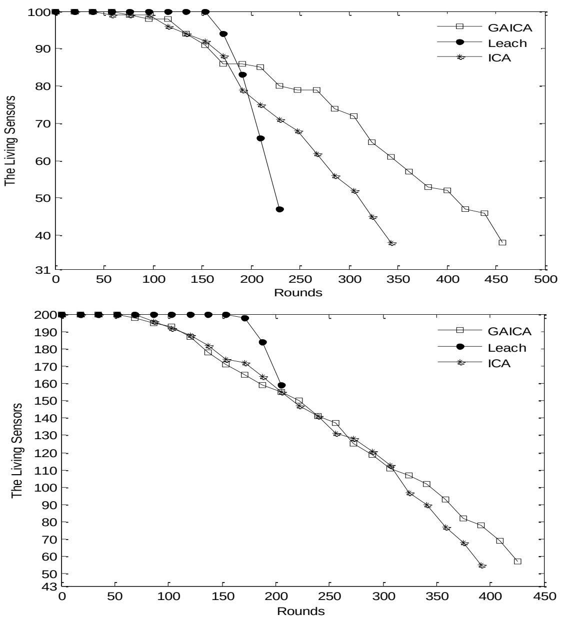

Figure 3. The Number of Living Sensors per Round for a WSN with 100 and 200 Sensors

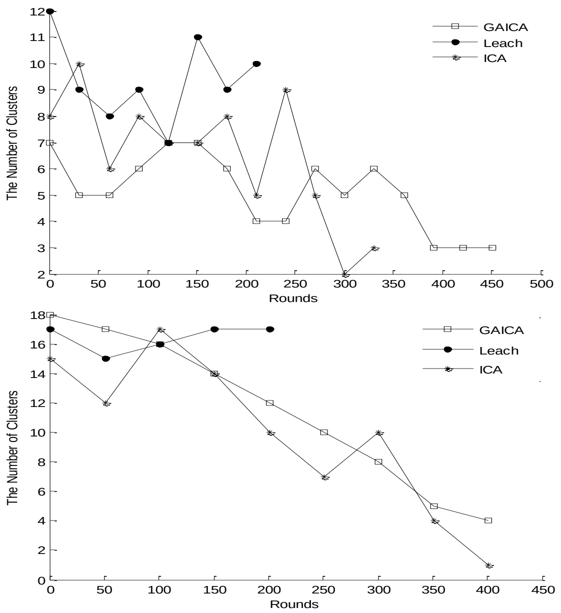

Figure 4. The number of clusters per for a WSN with 100 and 200 sensors

A more efficient algorithm will use an optimum number of living nodes with a higher value of the residual battery to the network lifetime increment.

The total value of data packet-loss is another parameter, studied in every round, examined in three methods of this simulationfor different sizes of the network, in which the result of a WSN with 200 nodes is illustrated in Figure 5.

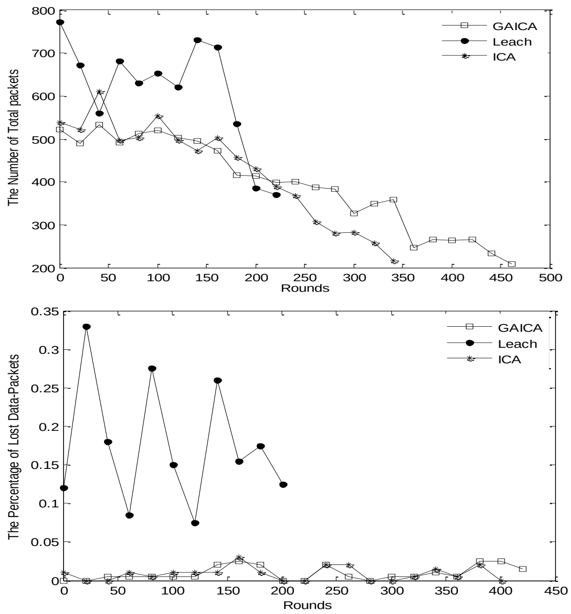

Figure 5. Total data-packets lost versus rounds for a WSN with 100 and 200 sensors

In comparison with the other methods, the amount of data-packet lost in the LEACH algorithm is more, because of the mistaken selection of suitable CHs. In the consideration of the GA-ICA method, it is seen that at the beginning of the algorithm, there is not any data-packet lost. As the number of living sensors reduces in the application area, it is clear that less-crowded clusters are generated. Furthermore, it reduces the number of CHs and, as a result, leads to less communication between the ordinary sensors and CHs. All these factors will result in the loss of data.

Considering the previous parameter, collecting meaningful reliable data from the application area is the most important function of a WSN. Therefore, the data transfer rate is another important parameter, because it is more popular to study the network behavior than the prior parameters. In all methods, data transmission diagrams have fluctuations, as CHs are selected randomlyin all rounds.

The results of simulation represent that the effectiveness of LEACH data transmission is not satisfactory. Despite the chaos in the behavior of the LEACH, it should mentionthat the data exchanging on the LEACH method is dropped if the rate of dead nodes increases during the networklifespan. Other methods prove the chaos with less fluctuation compared with the LEACH algorithm, due to the great optimization of CHs locations. The performance of the proposed method is satisfactory including the defined parameters in comparison with other algorithms during all rounds.

5. CONCLUSION

One of the main shortcomings of the LEACH routing algorithm is the based method fails to take appropriate criteria to determine the locations of the CHs. This factor has a considerable influence on the quality of the routing algorithm. It can be responsible for increasing the energy consumption of sensors, and thus reducing the network lifetime. This article proposes an optimized clustering method using evolutionary algorithms.

A hybrid approach (GA-ICA) is used, which aims to find the best number of clusters through the GA and the optimal location of CHs using the proposed method compared with the ICA-LEACH. In comparison with the LEACH algorithm, the proposed method dramatically reduces energy consumption. Thereby the network lifetime increased in the proposed work. The GA uses a cost function that has five basic factors in the network. Each factor consists of one or more parameters that effect on the optimal clustering.

In our proposed method, the experimental results show the network lifespan is favorably increased and the sensors livefor longer rounds. It means that the rate of death of sensors is uniform across the application area. In comparison with the other methods, the amount of data-packet lost in the LEACH algorithm is more, because of the mistaken selection of suitable CHs. In the consideration of the GA-ICA method, it is seen that at the beginning of the algorithm, there is not any data-packet lost. In the result, the proposed method improves energy consumption compared with the standard LEACH and ICA-LEACH methods which lead to the network lifetime favorably. Clustering of a WSN improving with a sleep scheduling is considered in the future work.

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Network Lifetime

چکیده

شبکه‌های حسگر بی‌سیم ازصدهاویاشایدهزارانسنسورباانرژی وتوان پرداز شی محدود تشکیل می شوند. توانایی‌های یک سنسور بی‌سیم شامل توان رادیویی، ظرفیت محاسباتی وحافظه بسیارمحدود می باشد. بنابراین با توجه به این محدودیت‌ها،علاوه بر بهینه‌سازی انرژی مصرفی، یافتن مقدار بهینه خوشه‌ها و مکان سرخوشه‌هااز مهمترین چالش در طراحی یک توپولوژی سلسله مراتبی در شبکه‌های حسگر بی‌سیم است. الگوریتم‌های مسیریابی بسیاری برای یافتن مسیرهای بهینه به هدف حذف گره‌های واسط وکاهش انرژی مصرفی سنسورها معرفی شده‌اند. ازاین رو برای کمینه‌سازی انرژی مصرفی شبکه،پروتکل‌های مسیریابی و تکنیک‌های خوشه‌بندی همراه باادغام وتجمیع داده‌ها فراهم شده است. دراین مقاله برای طراحی یک توپولوژی سلسله مراتبی، یک الگوریتم تکاملی ترکیبی شامل الگوریتم ژنتیک والگوریتم رقابت استعماری بهره گرفته شده است. ابتدا با استفاده از یک تابع هزینه که تمامی پارامترهای شبکه در بر می گیرد، به کمک الگوریتم ژنتیک تعدادب هینه خوشه‌ها معین شده وسپس بااستفاده ازالگوریتم رقابت استعماری مکان بهینه سرخوشه برای تمامی آنان محاسبه می‌شود. نتایج حاصل هافزایش بسیار مطلوب طول عمر شبکه،کاهش تعداد بسته‌های گمشده وافزایش اطمینان الگوریتم‌های مسیریابی در مقایسه باالگوریتم‌های LEACH و LEACH- ICA را نشان می‌دهد.

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