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An Comparison of Different Cluster Head Selection Techniques for Wireless Sensor Network

E. Akila[1], Baby Deepa[2]

[1]Bharathiar University, Coimbatore

[2]Government Arts College, Karur, INDIA

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Abstract:

Wireless Sensor Network is based on the hierarchical cluster and hence the Cluster Heads (CHs) will consume some more energy owing to the additional overload for the receiving and the aggregating of data from that of their member sensor nodes and this transmits all the aggregated data to its Base Station (BS). So the proper selection of the CH has a vital role to play in conserving the energy of the sensor nodes for the purpose of prolonging the WSNs and their lifetime. Here in this work, a proposed Low Energy Adaptive Clustering Hierarchy (LEACH), the Genetic Algorithm (GA) and finally the Chemical Reaction Optimization (CRO) algorithm is considered. The LEACH is a popular clustering algorithm wherein the sensor nodes will elect themselves to be the CH having a certain probability. But the main disadvantage of this algorithm will be that it may choose a CH having low energy that will be able to die quickly and thereby degrades the network performance. So there is a large number of algorithms that are developed for improving the LEACH. These results have been compared with certain currently existing algorithms for being able to demonstrate the proposed algorithm and its superiority.

Keywords: Wireless Sensor Network (WSN), Clustering, Cluster Head (CH) Selection, Low Energy Adaptive Clustering Hierarchy (LEACH), Energy Efficient Hierarchical Clustering (EEHC), Hybrid Energy-Efficient Distributed Clustering (HEED), Distributed Weight-based Energy-efficient Hierarchical Clustering protocol (DWEHC) and Genetic Algorithm (GA).

1. Introduction

Wireless Sensor Network (WSN) based technology is a major opportunity in networking and the Internet of Things (IoT) owing to the potential role it plays in the digitising of the smart physical environments like the wild remote areas, the regions having access risk and the natural habitats. On one hand, the Sensor Nodes (SNs) will be powered by the battery having a limited operating time and will be highly sensitive to any failure. At the same time, design with energy efficient protocol of the WSN for prolonging the lifetime of the network will be a very challenging task owing to its unique nature with a strong networking constraint in the WSNs (Kumar & Sharma 2012). Found are many key attributes which have to be considered by the designers that will be of particular importance in the WSNs. The cost of the nested clustering, the choice of the Cluster Head (CH) and the sub CHs, their data aggregation, synchronization, repair mechanisms, Quality of Service (the QoS) are to be considered.

The research community has proposed various protocols of routing for optimizing the process of routing in the WSN. Ideally, these routing protocols in the WSN may be grouped into three, the flat, location and a hierarchical based routing. In case of the flat routing, all the nodes will have an identical

functionality working with its sense and route. The location based routing protocols will depend on the information of position for every node to discover and also build the optimal paths of routing. On being compared to the earlier two categories in case of the hierarchical routing based approaches, the field of sensing has been subdivided within a set of some administrative domains known as the clusters. Every cluster will have one organized leader or a root node known as the CH. The main aim of this CH will be the collection of data from the associated and the attached downstream node and this is forwarded to the next best upper level upstream in the neighbour node. The data gets forwarded in that of a hop-by-hop manner till the time it reaches the BS. This BS will be able to send this data by using a wired or the wireless Internet connection for an end user who is located outside its sensing field (Eshaftri et al., 2015).

The protocols of clustering in communication have been executed in two different steps and the first one will be intra-cluster which means inside these clusters there will be a second inter-cluster and this is that between all the clusters and also its BS. Furthermore, this clustering protocol in the WSN may be taken up by either employing a single hop based transmission or also a multi-hop based routing (Gupta & Pandey 2016). The Clustering of SNs is a very effective technique that has been employed for conserving the SNs and their energy. In the clustering process, the network has been divided into various groups known as the clusters. Every cluster will have a leader called the CH that is responsible for the collection of local data form all the member SNs inside the clusters and will aggregate them and send them to the remote Base Station (BS) either directly or by means of the other CHs. This BS will be connected to one such public network like the Internet for that of the event and its public notification (Mittal et al., 2017).

2. Related Works

Rao et al., (2016) proposed an Energy efficient CH Selection algorithm which is based on PSO called PSO-ECHS. The algorithm is developed with an efficient scheme of particle encoding and fitness function. For the energy efficiency of the proposed PSO approach, the author consider various parameters such as intra-cluster distance, sink distance and residual energy of SNs. The author also present cluster formation in which non-CH SNs join their CHs based on derived weight function. The algorithm was tested extensively on various scenarios of WSNs, varying number of SNs and the CHs.

Rao & Banka (2017) proposed Unequal Clustering and Routing Algorithms (UCRA) based on novel Chemical Reaction Optimization (nCRO) paradigm (nCRO-UCRA). In clustering, it partition the network into unequal clusters such that smaller size clusters near to the sink and larger size clusters relatively far away from the sink. For this purpose, it develop the CH selection algorithm based on nCRO paradigm and assign the non-CH SNs to the CHs based on derived cost function. Then, a routing algorithm is presented which is also based on nCRO based approach. All these algorithms are developed with the efficient schemes of molecular structure encoding and novel potential energy functions. The nCRO-UCRA is simulated extensively on various scenarios of WSNs and varying number of sensors and the CHs.

Bhardwaj & Kumar (2019) proposed the multi-objective fitness function based on the energy, delay, traffic rate, distance, and the cluster density. The energy-aware routing is done based on the proposed Multi-Objective Fractional Particle Lion algorithm (MOFPL). The proposed MOFPL algorithm finds

the optimal CH from various CH nodes in the WSN. Then the optimal routing path is established based on the proposed multi-objective function. The proposed MOFPL algorithm has 5, 8, 10 alive nodes at the iteration round of 2000 for the WSN with 50, 75, and 100 nodes, respectively. Also, the proposed MOFPL algorithm has achieved higher normalized network energy of 0.05877 and 0.06022 for the WSN with 50 and 100 nodes, respectively.

Mann & Singh (2017) presented Bee Swarm, a SI based energy-efficient hierarchical routing protocol for WSNs. The protocol consists of three phases: (1) Set-up phase-Bee Cluster, (2) Route discovery phase-Bee Search and (3) Data transmission phase-Bee Carrier. Integration of three phases for clustering, data routing and transmission, is the key aspect of the proposed protocol, which ultimately contributes to its robustness. Evaluation of simulation results show that Bee Swarm perform better in terms of packet delivery, energy consumption and throughput with increased network life compared to other SI based hierarchical routing protocols.

Tsai et al., (2017) presented a high-performance hyper-heuristic algorithm to enhance the clustering results of WSN called Hyper-Heuristic Clustering Algorithm (HHCA). The proposed algorithm was designed to reduce the energy consumption of a WSN, by using a high-performance metaheuristic algorithm to find a better solution to balance the residual energy of all the sensors so that the number of alive SNs will be maximized. To evaluate the performance of the proposed algorithm, it is compared with LEACH, LEACH with GA, and hyper-heuristic algorithm alone in this work. Experimental results show that HHCA is able to provide a better result than all the other clustering algorithms compared in this work, in terms of the energy consumed.

3. Optimization And Its Methods

Optimization problems are of importance for the industrial as well as the scientific world in many applications. There are many optimization problems that present attributes, such as high nonlinearity and multimodality, the solution of this kind of problems is usually a complex task. Moreover, in many instances, complex optimization problems present noise and/or discontinuities which make traditional deterministic methods inefficient to find the global solutions. Meanwhile, global optimization methods based on meta-heuristics are robust alternatives to solve complex optimization problems and do not require any properties of the objective function have been developed (Rizk-Allah et al., 2013).

Due to the computational drawbacks of existing numerical methods, researchers have to rely on meta-heuristic algorithms based on simulations to solve some complex optimization problems. A common feature in meta-heuristic algorithms is that they combine rules and randomness to imitate natural phenomena. These phenomena include the biological evolutionary process, animal behavior and the physical annealing process. Over the last decades, many meta-heuristic algorithms and their improved algorithms have been successfully applied to various engineering optimization problems. They have outperformed conventional numerical methods on providing better solutions for some difficult and complicated real-world optimization problems.

Genetic Algorithm (GA) can be viewed as an optimization method which is based on the Darwinian principles of biological evolution, reproduction and “the survival of the fittest”, pioneered by Holland and his colleagues in the 1960s and 1970s.It is an evolutionary algorithm which is categorized as a global search heuristic. It uses random search in the decision space via selection, crossover and

mutation operators in order to reach its goal. Selection mechanism selects individuals (parents) for crossover and mutation. Crossover exchanges the genetic materials between parents to produce offspring, whereas mutation incorporates new genetic traits in the offspring. Elitism is an operator of GA which is used to store the best or elite chromosomes with best fitness values for the next generation (Uraiya & Gandhi 2014).

3.1 Methodology

The clustering is a very efficient scheme used for the aggregation of data in the WSN. The performance of the aggregation process is done on the data received from the other members and this is sent to the BS. For the homogeneous sensor network the CH will die out soon and the re-clustering will have to be done causing consumption of energy. Here for this section, the LEACH, EEHC, HEED, DWEHC and GA has been discussed as follows.

3.3.1 Low-Energy Adaptive Clustering Hierarchy (LEACH) Protocol

The LEACH that was proposed by Heinzelman et al. is a pioneering clustering routing approach with a basic idea of being an inspiration for the subsequent routing protocols. The objective of the LEACH will be to choose the SNs by rotation to ensure that the high dissipation of energy that is in the communication of the BS has been spread for all the SNs within the network (Liu 2012).

The LEACH and its operation have been broken up into two phases which are the set-up phase and the steady-state phase. In the former, the clusters are organized, and every node will become a part of the CH for the current round. In the latter, the clusters will be delivered to the BS. The decision has been made by the node by choosing a random number falling between 0 and 1. This node is a CH for its current round in case the number is lower than that of the threshold below (3.1):

$$T(n)=\begin{cases}\dfrac{P}{1-P\left(r \bmod \dfrac{1}{P}\right)}, & if\ \ n\in G\\ 0, & otherwise\end{cases} \tag{3.1}$$

In which the P will be the percentage of the CH that is desired and r being the current round with G as the set of its nodes not chosen in the previous 1/P rounds. If a node is chosen to be a CH it will broadcast the message of advertisement and based on this the other nodes joins as the member of the cluster. Based on the strength of the signal the nodes will decide as to where this cluster can distribute the energy evenly among the SNs. For such even distribution, the rotation of the CH has been performed for every round by means of generating one more new phase of advertisement that has been based on the equation (3.1). At the time of the steady-state phase, these SNs will sense and also transmit data into the CHs. The CHs further compresses the data that arrives from various nodes belonging to its respective cluster. Aside from this, the LEACH makes use of the Time Division Multiple Access (TDMA)/Code-Division Multiple Access (CDMA) and the Medium Access Control (MAC) for reducing the inter-cluster and also the intra-cluster collisions. Once a particular time is completed that has been determined as apriori the network will return to the set-up phase and enter a round of the CH election.

Even though the LEACH protocol will tend to prolong the lifetime of the network it still continues to have some problems. The election of the CH is made randomly to ensure that the optimal distribution and number of the CHs are not ensured. So the nodes that have a low level of residue energy are chosen to be the CH that can result in the nodes die first.

The CHs will be communicating with the BS within a single hop mode making the LEACH to be used in the large-scale WSNs for a range of SNs (Kaur et al., 2013).

3.3.2 Energy Efficient Hierarchical Clustering (EEHC)

It is a distributed, randomized clustering algorithm for WSNs. EEHC is based on two stages. Initial: In the initial stage, each node announces itself as a CH with probability p to the neighboring nodes within the communication range. These announcements are done by direct communication or by forwarding. These CHs are named as the volunteer CHs. The nodes which receives the announcement and is not itself a CH becomes the member of the cluster. The node which doesn't received the announcements within a time interval t that is calculated based on the duration for a packet to reach a node becomes a forced CH.Extended: Multi-level clustering is performed in this stage. CHs at the level-one transmit aggregated data to the level-two CHs. At the top level CHs transmit the aggregated data to the BS.

3.3.3 Hybrid Energy-Efficient Distributed Clustering (HEED)

The energy efficient clustering protocol for WSNs, with a focus on efficient clustering by proper selection of CHs based on the physical distance between nodes. The main objectives of HEED are to: Distribute energy consumption to prolong network lifetime; Minimize energy during the CH selection phase; Minimize the control overhead of the network (Saini & Singh 2014). The most important aspect of HEED is the method of CH selection. CHs are determined based on two important parameters:1) The residual energy of each node is used to probabilistically choose the initial set of CHs. This parameter is commonly used in many other clustering schemes. 2) Intra-cluster communication cost is used by nodes to determine the cluster to join. This is especially useful if a given node falls within the range of more than one CH. In HEED it is important to identify what the range of a node is in terms of its power levels as a given node will have multiple discrete transmission power levels. The power level used by a node for intra-cluster announcements and during clustering is referred to as cluster power level. Low cluster power levels promote an increase in spatial reuse while high cluster power levels are required for intercluster communication as they span two or more cluster areas. Therefore, when choosing a cluster, a node will communicate with the CH that yields the lowest intra-cluster communication cost.

3.3.4 Distributed Weight-based Energy-efficient Hierarchical Clustering protocol (DWEHC)

A distributed clustering algorithm similar to HEED. The main objective of DWEHC is to improve HEED by building balanced cluster sizes and optimize the intra-cluster topology using location awareness of the nodes. Both DWEHC and HEED share some similarities including no assumptions about network size and density, and considering residual energy in the process of CH election. Every node implements DWEHC individually and the algorithm ends after several iterations that are implemented in a distributed manner (Liu 2012).

3.3.5 Genetic Algorithm (GA)

The GA is that technique for that of a randomized search as well as an optimization that is applied to a varied range of the investigations. There is a basic operation flow for the GA which includes the creation of initial population, the fitness evaluation, crossover, mutation, selection and the updating of the optimal chromosomes and the checking of all the termination conditions. The GA starts by means of using a set of the possible solutions that are generated randomly known as the population. For each such individual solution within the population is called the chromosome or the individual. Each such chromosome has been represented as the array of the genes that can consist of the particular part of this solution. The actual values of the genes will be known as the alleles, and the length of the chromosomes within the population will have to be the same, and the fitness function has been provided with the assigning of fitness value for all the individuals (Zahmatkesh & Yaghmaee 2012).

This function has been based on the manner in which the individual which is close to its optimal solution. The higher the value of fitness, the closer it will be to the optimal solution, and the randomly chosen chromosomes are called the parents that can exchange the information within the process that is known as the crossover or the recombination. This will produce two of the randomly chosen chromosomes that are called parents. This will produce the two new chromosomes that are called the child or the offspring. In case both parents have been sharing a certain pattern for their chromosome and the same pattern that has to be randomly applied after this crossover process. The mutation will help in restoring the lost genetic values at the time the population that converges faster. The crossover processes and the mutation are completed and are converged faster. The processes of the crossover have occurred within the population and the chromosomes for the subsequent generation have been chosen (Bayrakli & Erdogan 2012).

The GA may be used effectively to search for all the optimal clusters and this can create the energy efficient clusters for the purpose of routing in the WSNs and for the purpose of evaluating the consumption of energy they make use of a radio model. Furthermore, an assumed fitness function using some fitness parameters like the direct distance from the sink, the transfer energy, the cluster energy and the transmissions. The proposed algorithm will maximize the fitness function having more energy efficient cluster based routing protocols.

The GAs are applied in solving various problems in engineering and use the GAs for designing the WSN that is a very successful method. The commonest use of the GA is that it can achieve an energy-aware network under some specific routing conditions and this at the same time can reduce the channel contention (Zhu & O'Connor 2013). These efforts are normally for energy efficiency, and additionally, the researchers have employed the GAs for the multiple Quality of Service (QoS) parameter based problem that determines the near-optimal multicast routes for the Mobile Ad hoc Network (the MANET).

In case of a GA-based methodology, there is an adaptive WSN design. The fitness function will incorporate seven parameters of design for its specific application, connectivity of network and consumption of energy for the optimization process that has many needs (like the status of its SNs, the selection process of the CH and the distance among the nodes) which have been considered for the designing of a dependable and energy aware WSN.

4. Results And Discussion

In this section, the LEACH EEHC, HEED, DWEHC and GA methods are used. Experiments are carried out using 100 to 600 number of nodes. The number of clusters formed, average end to end delay (sec), average packet loss rate (%) and lifetime computation as shown in tables 4.1 to 4.4.

Table 4.1 Number of Clusters Formed

Number of nodes	EEHC	HEED	DWEHC	LEACH	GA
100	50	60	30	10	11
200	45	35	25	15	16
300	66	46	36	26	29
400	74	64	54	34	33
500	42	40	30	32	35
600	49	45	40	39	39

Table 4.2 Average End to End Delay (sec)

Number of nodes	EEHC	HEED	DWEHC	LEACH	GA
100	0.00417	0.00357	0.00657	0.00757	0.00159
200	0.00316	0.00261	0.00611	0.00181	0.00157
300	0.02604	0.03604	0.06042	0.06041	0.0165
400	0.03632	0.04632	0.06322	0.06322	0.02551
500	0.07805	0.06805	0.08055	0.06805	0.05988
600	0.08473	0.07473	0.05647	0.06473	0.06066

Table 4.3 Average Packet Loss Rate (%)

Number of nodes	EEHC	HEED	DWEHC	LEACH	GA
100	61.07	71.70	11.07	11.07	8.77
200	77.64	67.46	17.64	17.64	13.75
300	88.19	81.91	18.19	18.19	13.26
400	93.01	83.11	23.01	23.01	20.88
500	81.99	79.99	31.99	31.99	26.9
600	83.89	63.68	43.89	43.89	30.73

Table 4.4 Lifetime Computation

Number of rounds	EEHC	HEED	DWEHC	LEACH	GA
0	60	70	80	100	100
100	50	75	78	100	100
200	78	67	61	87	94
300	44	59	65	74	89
400	21	29	36	41	75
500	20	27	30	24	52
600	15	18	19	2	22
700	10	13	15	0	7
800	8	7	4	0	0

5. Conclusion

Clustering is an extremely efficient technique for saving energy in the WSNs. WSN is based on the hierarchical cluster and hence the CHs will consume some more energy owing to the additional overload for the receiving and the aggregating of data from that of their member SNs and this transmits all the aggregated data to its BS. So the proper selection of the CH has a vital role to play in conserving

the energy of the SNs for the purpose of prolonging the WSNs and their lifetime. Here in this work, a LEACH, EEHC, HEED, DWEHC and the GA is considered. The LEACH is a popular clustering algorithm wherein the SNs will elect themselves to be the CH having a certain probability. But the main disadvantage of this algorithm will be that it may choose a CH having low energy that will be able to die quickly and thereby degrades the network performance. So there is a large number of algorithms that are developed for improving the LEACH. The work has proposed one more energy efficient CH algorithm of selection that has been based on the GA algorithm. GAs successfully handled many areas of applications and was able to solve a wide variety of difficult numerical optimization problems. GAs requires no gradient information and is much less likely to get trapped in local minima on multi-modal search spaces. Results show that the GA has higher number of clusters formed when compared with LEACH, EEHC, HEED, DWEHC method.

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