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A Survey of Advanced LEACH-based Protocols

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Abstract

In recent years, wireless sensor networks (WSNs) have been utilized widely. Clustering is one of the methods for applying these networks energy-efficiently. In this field, many protocols have been introduced. LEACH is one of the most important clustering protocols which has attracted the attention of researchers. Therefore, prior studies have endeavored to improve it through removing some of disadvantages. As the result, many protocols have been developed during the recent years. In this paper, less studied protocols are investigated and compared with regard to different criteria such as cluster count, homogeneity or heterogeneity level, multi-levels attributes, the role of cluster head cycle, inter-cluster and intra-cluster connectivity.

Keywords: *Wireless Sensor Network (WSN), low energy adaptive clustering hierarchy (LEACH), clustering*

1. Introduction

Wireless sensor networks (WSNs) are improving rapidly. Advancements in field of introduced approaches with low energy consumption result in emerging little sized, energy-efficient sensors that could gather environmental data [1, 2, and 3]. Processing these data provides information about events that occur around sensors and sensor users can take advantage of to make decisions. The capabilities of sensors has led into using a group of sensors to cover vast area known as sensor networks in order to collect data instead of using single sensors [4]. Due to network application, hundreds or thousands sensors might be applied in sensor networks. One of the major issues is designing energy-efficient sensors, thus, new methods tried to decrease energy consumption of the sensors in different ways. One of the most efficient approaches to reduce energy consumption is using clustering protocols. In these protocols, networks could be divided into smaller units with each unit having a head cluster. Cluster head is responsible for collecting the data for the area it is covering. Therefore, this method improves sensor network management and lowers the energy consumption that plays a clear role in the life cycle of the network. Numerous clustering algorithms and protocols are supposed so far. LEACH, is the primary, and most known proposed clustering protocol for WSNs. This protocol is the first dynamic clustering protocol that particularly, meets WSN needs and also uses static homogenous, sensor nodes that are distributed in LEACH randomly. WSN is still used as the basis of other advanced clustering protocols in WSNs. In general, this protocol is a hierarchical, probable, distributed and one-hop protocol that aims at fulfilling two prime purposes: extending the life cycle of WSN networks through distributing the energy consumption in network nodes by data accumulation and reducing the exchanged

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messages [5]. Due to the features of this protocol, it was attempted to review the methods that are developed based on WSN. This article is organized as follows: in section two, the LEACH protocol and its advantages and disadvantages are described. In section three, a few protocols which are developed based on LEACH protocol are reviewed and also the deficiencies of LEACH protocol are discussed and some solutions are provided. Finally, in Section 4, the reviewed protocols are compared based on their features.

2. The Advantages of LEACH

LEACH protocol was introduced by Heinzelman [1] in 2002. This protocol forms clusters based on the received signals and using distributed algorithms. Nodes make decisions without concentric control independently. In order to balance the energy consumption of each node, in every round, all groups have the opportunity to become the cluster head. In this protocol cluster head nodes are used as route finders (to the base station). All data processing, such as data accumulation and combination in each cluster are performed locally. LEACH protocol breaks down into rounds. Each round consists of a setup phase and a steady-state phase. In the setup phase, nodes organized themselves as clusters. Each node decides to become cluster head by P probability and broadcasts the decision. Each node selects a random T number (between 0 & 1). The node in current cycle round becomes cluster head if T number in equation is lower than the threshold in the formulae bellow.

$$T(i) = \begin{cases} \frac{\mathrm{p}}{1-\mathrm{p}*\left(\mathrm{r} \bmod \frac{1}{p}\right)} & if \quad i \in G \\ 0 & otherwise \end{cases} \tag{1}$$

where P is the demanded percentage of cluster head nodes in all sensors and r is the current round number, and G is the set of nodes that are not cluster head in the previous 1/p round. After all cluster heads are selected, a message is broadcasted to other nodes and non-cluster head nodes determine the cluster that they want join. Each node selects its cluster such that it communicates with its associated cluster head with lower energy consumption. Non-cluster head nodes, when receive the strongest signal from a cluster head, join it. After joining, each node sends a signal to inform its membership to the head cluster. After cluster formation, setup phase is finished. In the steady state phase, network performance is divided into time frames, so that in each frame, all nodes of a cluster send their data to the head cluster in a specific time interval. As time shear longevity of each node is stable, a time frame length depends on node numbers of clusters. Cluster head creates a time schedule (Time Division Multi Access) TDMA for its member nodes. This allows the member nodes to save more energy by turning off their receiving radiations during their communication round time schedule. After a predetermined time, this round ends and a new round starts which changes the cluster head role among the cluster nodes and balances the load.

Deficiencies and weaknesses of this protocol will be discussed in detail in following sections. However, some of its advantages include: 1) this is a random protocol; that is, in each round, almost a specific number of nodes selects themselves as cluster heads randomly and cluster heads are not assigned to particular nodes. 2) This is an adaptive protocol; that is, nodes that play cluster head role at current round couldn’t nominate for cluster head in the next round. Therefore, in each round, cluster head role nominates are determined based on the previous round. Thus, it is expected that after a specific number of rounds, all nodes might become cluster heads, but not necessarily every one of them. 3) This is a self-organized protocol; that is, nodes in this network are formed without any help from external factors or nodes in the network which is useful for the scalability of the network. 4) It is a local performance protocol; that is, data transmission of cluster nodes to cluster head and from cluster head to the base station is carried out through local control and there is no need to external help. 5) This protocol uses MAC protocol in which radio waves are turned off and, therefore, lower energy is consumed. 6) To reduce the data volume transmitted by the sensors, this protocol makes use of data combination mechanism before sending data to the base station.

3. Extended LEACH Algorithms

In this section, it is attempted to introduce LEACH-based algorithms and protocols and review their shortages and solutions that represented by each algorithms to solve these problems.

3-1. LEACH-Centralize (LEACH -C)

This protocol is introduced by the designers of LEACH [2] protocol. LEACH-C uses a clustering algorithm concentrated in the setup phase. Through distributing the cluster head in the whole network, this protocol might more efficient. In the setup phase, each node sends the data about its current position and energy level to the base station. In addition to forming appropriate clusters (*e.g.*, appropriate physical condition and approximately equal nodes) the base station needs to distribute the energy among all nodes equally. To achieve this, the base station calculates average energy level of each network node; nodes with energy levels lower than average rate could not be cluster heads in the next round. Through annealing algorithm, the base station uses other nodes for problem solving to find the optimal cluster head. This algorithm minimizes the energy consumed by non-cluster head nodes to transmit their data to cluster head. This is done through minimizing the total square roots of distances among all non-cluster head nodes and nearest cluster head. When cluster heads and witness clusters are generated, base station broadcasts a message to all sensor nodes in the network containing the cluster head node ID. If the ID of cluster head node is equal with the node ID, it is the cluster head node. Otherwise, the node receives its time slot in TDMA schedule to transmit the data and is turned off until its data transfers the time which is similar to the LEACH protocol.

3-2. Power-Efficient Gathering in Sensor Information Systems (PEGASIS)

In order to improve cluster formation efficacy in LEACH protocol, Lindsey *et al.*, [6] introduced the PEGASIS protocol. The key idea in PEGASIS is consuming lower energy linking each node to the nearest adjacent node which is carried out by formation of a chain of whole network nodes. This chain is formed by the base station processing using the Greedy algorithm. After the string is formed, each node sent data to the next node in the string. Next node combines the received data by its own data and sends this package to next node in the string. The leader in the string sends the final data to the base station. When the round is finished, a new leader is selected and a new round starts. To help the load distribution, the leader role is changed among all nodes. However, nodes that are located at remote places in the string could not become leader because data transmission in more far distances consumes more energy and eliminates the energy saved through cluster algorithm. In each round, just one node could transmit the data to the base station which saves more energy. Simulation results showed that PEGASIS perform better than LEACH for various sized networks. This is because there is no need to form cluster segments and the data amount sent to the base station is reduced compared to the LEACH protocol. The problem with PEGASIS is that during the leader selection for each round, the remnant energy is not taken into the account. Moreover, to create best kind of strings requires the whole network data such as node numbers and their positions. Meanwhile, the main disadvantage of PEGASIS is that it takes more time to send the final data to the base station. Another problem is that there is only one sensor for connecting to the base station which is a big barrier to the scalability of this protocol. Figure 1 shows the performance of the PEGASIS protocol. As the figure shows, C0 sensor sends the data to

C1; and C1 sensor combines the received with its data. C4 sensor sends the data to C3; C3 combines the received data with its own and sends it to C2. The C2 sensor combines both data and sends it to the base station.

C0→C1→C2← C3←C4

Base Station ↓

Figure 1. PEGASIS Protocol Performance Method [6]

3-3. Maximum Energy Cluster Head (MECH)

MECH protocol is developed by R. Sh. Chang *et al.*, [7]. MECH protocol, in general, addressed two issues in LEACH protocol: it modifies the cluster formation method and prevents imbalance node distribution in clusters; and uses hierarchy routing plan to prevent long distance direct connection of cluster heads and the base station in LEACH protocol. This protocol is composed of three stages: setup phase, steady state phase, and forward phase. Initially, each node broadcast HELLO message to its neighbor nodes. TTL of this message as time of data collection uses its neighbor nodes in one hop. This way, radio district is determined and each node registers its the number of neighbor nodes. In this protocol, there is a systematic parameter called CN which determines the maximum neighbors of a node. If the population of nodes reaches CN, the node broadcasts a signal to its neighbors in one hop distance. This message indicates “I am a cluster head”. All nodes that receive this message register it and turn on a back off timer. However, there are nodes which reach the CN limit, but never claim to be a cluster head because in that radio district there should be just one cluster head. After back off timer is expired, each node selects its cluster head based on the strongest received signal and send a message to that cluster head.

Steady state Phase: This stage is associated with the number of cluster members; To synchronize, each cluster head counts all its members and sends it to the base station and the base station calculates maximum accounted time slots and broadcasts it to all cluster heads. Afterwards, according to this, cluster heads determines TDMA and sends it to its members and they transmit the received data with the remaining energy to the cluster heads during the time slot. The node with maximum energy is registered in a table, and that node is be selected as the cluster head for the next round. Afterwards, in the forwarding phase, the data is forwarded to the base station. The forward phase includes three stages: in the first stage, the base station broadcasts a HELLO message containing hop-count (number of hops between cluster head and base station) and energy level in the rounds, which is formed initially by the respective amounts of zero and infinite. After a head cluster receives the message, if the energy level of the current cluster head is lower than the energy level in alternative message to that cluster head, hop-count is added to it. Non-cluster head nodes ignore the message. In the second stage: after the message is received by the cluster head, the cluster head records the message and forwards the HELLO message. In the third stage: if another cluster head receives the HELLO messages, it decides as follows:

Case1: hop_ count (old) < hop _ count (new), do nothing;

Case2: hop_ count (old) > hop _ count (new), replace the forwarding cluster-head;

Case3: hop_ count (old) = hop _ count (new), then If energy (old) ≤ energy (new) replace the forwarding cluster-head; Else do nothing;

While this protocol benefits from advantages such as load balance, lower energy consumption, and self-organizing, its main disadvantage is that this protocol uses more control messages than LEACH protocol to generate even distribution topology and also needs expensive hardware tools and equipment for its sensor nodes in its synchronization mechanisms.

3-4. Three-layered Routing Protocol for WSN based on LEACH Algorithm (TL-LEACH)

TL-LEACH protocol was first introduced by D.Zhixiang *et al.*, [8]. This protocol uses PEGASIS protocol concept to improve LEACH. That is, the LEACH protocol with some nodes as cluster heads to link the base station directly, uses the PEGASIS concept, prevents direct link between all cluster heads and the base station. On the other hand, the time lag in the PEGASIS protocol to transfer the data is solved through using the LEACH protocol and considering multiple cluster heads. Moreover, in this protocol there is no need for all nodes to be aware of their positions and also there is no need for multiple cluster heads. Therefore, through reducing the number of cluster heads that have direct links with the base station and consume extra energy, this new protocol increases the network's lifetime. The TL-LEACH protocol follows three phases: cluster head selection, cluster setup and data transition which is as same as the LEACH protocol. Cluster head selection consists of two secondary stages: The first section is selecting the cluster head at the first level and the second section is selecting the cluster head at the second level. Cluster head selection in first level similar to the LEACH protocol, is calculated with the optimized LEACH formula as follows:

$$T(n) = \begin{cases} (\mathrm{r}+1)\mathrm{mod}\frac{1}{p} * p & n \in G \\ 0 & otherwise \end{cases} \tag{2}$$

Where n is the factional part as $1/\mathrm{N}, 2/\mathrm{N}, \dots\dots, 1$. Each node selects a number randomly and N is the total number of the network nodes. When the number is smaller than the T (n) threshold, it is selected as the cluster head in the current round. After the cluster heads are selected in the first stage, the cluster heads that communicate with the base station are selected from the cluster heads of chosen in the first stage based on their energy consumption. Each cluster head in of the fist level broadcasts its energy through the CSMA protocol. In addition, their energy power consumption is compared and then decision made about which one of them has to be selected as cluster head of the second stage. In the cluster setup phase, the cluster head is selected, each cluster head selected in the stage 1 broadcasts a message containing useful information about cluster head and its ID. In lower layers, common nodes are located; Based on the most powerful signal received from the cluster heads, nodes decide to join a cluster head, and send a response back to the cluster head. Afterwards, each cluster head at level 1 registers its cluster members. Cluster setup phase at level 2 is the same as the cluster setup phase at level 1. However, the difference lies in the response messages forwarded from the cluster heads at level 1 to the cluster heads at level 2. This includes the ID of a head cluster at level joining the cluster. Receiving the message, cluster head at level 2 registers the number of all level 1 cluster heads and all other nodes which are member to a level 1 cluster head. In the data transmission phase, ordinary nodes send their data in the specified time slot to the level 1 cluster heads. And the level 1 cluster head send the combined data to the level 2 cluster heads. Finally, level 2 cluster heads combine the level 1 data with their data and forward it to the base station.

3-5. Time–Based cluster head selection (TB-LEACH)

Time-based cluster head selection protocol is introduced by Hu. Junping *et al.*, [9]. The main focus in this protocol is the modification of cluster heads, through the algorithm in LEACH protocol and optimizing the cluster segmentation process. To increase the network lifetime and cluster segmentation in even and integrated manner throughput the network, the number of cluster heads must be optimal. In the LEACH protocol, for a simple network it is shown that when cluster heads are 3 to 5, the system is more efficient. The number of clusters in this protocol is considered as 4. Cluster selection includes two phases: setup and steady state phases. The setup phase is similar to LEACH protocol; in the setup phase of the TB-LEACH protocol, cluster head competition does not rely on random numbers like LEACH. However, in this protocol each node builds a random time round. The shortest time nodes win the cluster head competition and in turn, produce fixed number of cluster heads. There is a counter here; when the counter reach a specified number, other cluster heads stop competiting.

3-6. Threshold –based Cluster Head Replacement (T-LEACH)

T-LEACH-protocol is developed by J. Hong *et al.*, [10]. In most clustering protocols as well as in LEACH protocol energy consumption and the role of changes made in cluster heads are ignored. Meanwhile, cluster head selection and unnecessary frequent substitution of cluster heads results in higher energy consumption in these sensors. In T-LEACH protocol, the number of cluster heads and its substitution by the remaining energy threshold is minimized. In other words, when current cluster heads keep their remaining energy in a level higher than the threshold, the cluster heads are never substituted even when their time slot comes. In general, the cluster head round time rotation is delayed until the energy level is becomes lower than the threshold limit. Therefore, the nodes are allowed to play the role of cluster head permanently. Given the threshold limit in the energy consumed in each normal node, and the energy consumed when a node is a cluster head is determined and calculated. Practical threshold limit is different for each node because each cluster head have different member nodes. This protocol performs clustering in two phases. The only difference with LEACH is the setup phase. Once a cluster and the cluster heads are generated, the protocol delays the second round of cluster formation until energy threshold limit reaches a specific level and afterwards cluster heads are replaced; that is, cluster formation is rebuilt.

3-7. Energy Efficient Heterogeneous Clustered Scheme (EEHC)

Kumar *et al.*, [11] introduced the energy efficient heterogeneous clustered model for wireless sensor networks (WSMs). In this protocol, the main purpose is to increase the lifetime and stability of the network through heterogeneous nodes. In this protocol, three kinds of nodes are used: normal nodes, advanced nodes, and super nodes. It is assumed that some nodes have higher energy resources than others. If we assume that m is part of the total network nodes n and mo is the percent of total m nodes with β is equipped with higher energy time than normal nodes. These nodes are called super nodes. Other nodes (*i.e.*, n ∗ m ∗ (1 _ mo)) with α energy source higher than normal nodes are called advanced nodes. The remaining nodes are normal nodes which are scattered evenly throughput network. This protocol involves two phases. In the setup phase all the levels are similar to LEACH protocol. The only difference is that in this protocol, three node types with 3 different levels of energy are used. Given the initial energy of the nodes to other nodes, a weighted probability is used to choose a cluster head. This probability must be equal with the initial energy of each node divided to the initial energy of normal nodes. Therefore, it was assumed that p_n is the weighted probability for being selected as a normal node and p_a is the weighted probability for being selected as an advanced node and p_s for being selected as a super node. Given the above possibilities, in this protocol, a threshold is defined for cluster head selection in both rounds. For normal nodes the threshold limit is as follows:

$$T(sn) = \begin{cases} \frac{p_n}{1-p_n*(r*mod\frac{1}{p_n})} & if\ s \in G' \\ 0 & otherwise \end{cases} \quad (3)$$

Where r is the current round count, G' the set of normal nodes that in $1/p_n$ rounds from the previous rounds are not selected as cluster heads. $T(sn)$ is the threshold limit in normal nodes, and this threshold limit guarantees that each normal node is selected as cluster head just once in $(1 + m * (\alpha + mo * \beta)) / p_{opt}$ rounds. p_{opt} determines the optimal number of cluster heads and average number of cluster heads in each round from rounds and its equal with $n * (1 \_ m) * p_n$.Threshold limit and nodes to be determined in each time are determined in the same way. Each node might decide to be the cluster head depending on its threshold limit and the number of cluster heads in that node. Therefore, we have the cluster heads of all 3 nodes that result in the consumption of energy compared to the initial consumption.

3-8. Density of Sensor – LEACH (DS –LEACH

This protocol is introduced by J. Bagherzadeh *et al.*, [12]. This protocol obtains the local density of sensor nodes in different routes and uses it in the following clustering process. DS-LEACH works based on the LEACH protocol. The main task is performed in the setup phase, because in this phase one node introduces itself as the cluster head. In DS-LEACH, node densities are used as measures to find cluster heads. One of the LEACH problems is that some sensor nodes do not participate in clustering because of long distances between the nodes and cluster heads. Therefore, none of these non-clustering sensor nodes send their data to the base station. In the DS-LEACH protocol, the issue mentioned above and areas with a few sensor nodes which are usually left without cluster heads in LEACH are considered and by the protocol tries to solve this problem through using the density factor. It is assumed that there are many rounds in the network and in each round, sensor nodes are divided to clusters. In setup phase, each i node calculates the cluster head possibility using the following equation:

$$p_i = \max\left(\frac{1}{M_i - (\mathrm{r} \bmod M_i)} - \frac{C_i}{r}\ ,0\right) \quad (4)$$

where, C_i indicate times that the node i is selected as cluster head. M_i is the node numbers in each cluster (or average times in clusters that i is selected as cluster head in previous rounds); r is the current round number, p_i is the i node probability, *i.e.*, cluster head in r round. Initially, M_i must be assumed a random number greater than zero (the initial clusters that are known as cluster head percentage). After several rounds, if i node is selected as the cluster head, the M_i value is updated based on the nodes of that cluster. P_i depends on r, C_i and M_i. If M_i is high, *i.e.*, i cluster has high intensity, the probability of becoming the cluster head reduces. If C_i is high, it means that the cluster i is frequently selected as the cluster head and, therefore, the possibility of that node for being selected as the cluster head is reduced. When the number of rounds r increase, P_i is increased too. After P_i is calculated, each node selects the random number x between 0 and 1 and compares x with P_i. If, P_i >x, then node i prevent itself from becoming the cluster head and waits to receive a message from another cluster head and join it. The main feature of this protocol is that in the setup phase, it identifies the location for sensor nodes accumulation. When some sensor nodes lose their energy and density of that areas sensor nodes is decreased, and probability of becoming cluster head increase in that area; as the result sensor nodes of that area consume less energy rate.

3-9. LEACH Sub Cluster Head (LEACH-Sub-CH) or Vice-LEACH (VLEACH)

VLEACH protocol is developed by M. B. Yassein [13] and the LEACH-Sub-CH protocol is designed by N. Mittal *et al.*, [14]. Both protocols follow the same rules. Therefore, here, we just study the LEACH-Sub-CH protocol. The main focus of this protocol is decreasing the energy consumption of WSNs. In this approach, each cluster is composed of: Cluster Head (CH), which functions as sending the data received from cluster members to the base station. Sub-CH is a node that becomes cluster head of a cluster when its previous cluster head was dead. Cluster nodes, gather data from environment and send it to cluster heads. In LEACH protocol, cluster heads always gather data from the member nodes and send it to the base station while the base station might be far from the cluster heads. Therefore, cluster heads that play significant role in gathering, sending and listening to the data, loose their energy sooner. When cluster head dies, the cluster function becomes useless. Since the data gathered by member nodes in a cluster are never forwarded to the base station, in the setup phase there is another node known as Sub-CH next to the cluster head; when a cluster head dies, it is replaced by Sub-CH. Therefore, in the steady state phase all the data will reach to the base station and there is no need to introduce a new cluster head when the previous head dies. This results in a decrease in the messages sent by cluster heads and, thus, the lifetime of the network. Figure 2 shows this clustering.

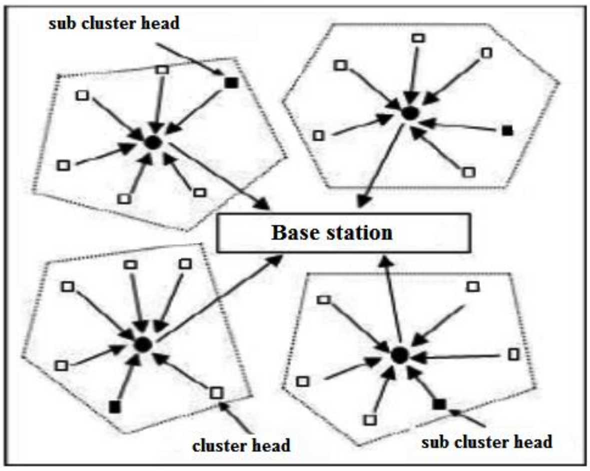

Figure 2. LEACH-Sub-CH Protocol Architecture [14]

3-10. LEACH Clustering Algorithm based on the Base Station Assistant

In the LEACH protocol, unspecified cluster head numbers leads into fluctuation in the number of cluster heads in some areas. Therefore, the network becomes asymmetric and the energy consumption in the network gets higher. Therefore, to solve the asymmetry distribution issue, a protocol is introduced by Li. Xunbo *et al.*, [15]. This is a two stage protocol which includes setup phase and steady state phase similar to the LEACH protocol. The only difference is that in the setup phase in this protocol, production rate of the threshold limit for cluster head is controlled and modified; if the cluster head generation in threshold limit in a network performs regularly, cluster head distribution in network could be controlled indirectly. In order to regulate cluster heads distribution in this protocol, it a function was used in which the distance parameters between nodes and the base station are addressed precisely. This function controls threshold limit value for the network nodes and evenly distributes in the threshold limit. Therefore, in the setup phase, when nodes select a random number between zero and 1, if the selected number was lower than threshold limit $T(n)$ in following equation, that node becomes the cluster head.

$$T(n) = \frac{\mathrm{p}}{1-p[r \bmod (1/p)]} \times f(r, d_{bs}) \quad (5)$$

In $f(r, d_{bs})$, f is the function of r parameters and d_{bs} parameters where, r is the current round number and d_{bs}, is the distance between the nodes and the base station. P is the optimal number of the cluster heads. Nodes are located differently to the base station.

Therefore, there are different values for d_{bs}. The $T(n)$ value is different too and equal with sinusoidal distribution. Then nodes in arcs with peak threshold limit that have more probability to become cluster head were located evenly. Figure 3 shows the node distribution among arcs. As the figure shows, nodes near to semi-circular arcs (have highest threshold limit) have the highest probability to become cluster heads. Regulator function value of threshold limit of nodes within the two arcs of circle is close to zero. Therefore, they have no chance to become cluster heads. Regulator function could be calculated using the initial probability of multiplication in regulator function value. In turn, threshold value in the whole network gets smaller because regulator function value is lower than 1. Therefore, cluster heads are lower than optimal theoretical value. To avoid this problem, the optimal number of cluster heads before applying the regulator function, and also cluster heads are calculated after regulators function application. The network cluster heads are determined accordingly. In turn, all nodes in the network have equal chances to become cluster head in one round.

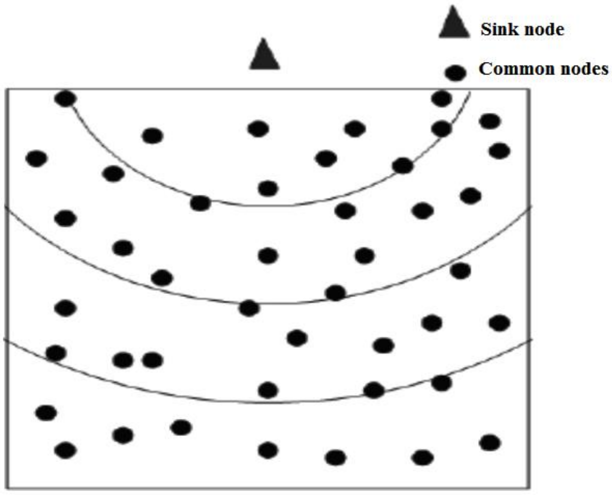

Figure 3. Distribution of the Nodes with the Greatest Thresholds [14]

3-11. Advanced LEACH (A-LEACH)

A-LEACH protocol is developed by Abdellah *et al.*, [16]. This protocol is an extension of the stable election protocol (SEP). SEP protocol is an advanced form of LEACH protocol in which the main idea is using heterogeneous sensor nodes in WSNs. In the A-LEACH protocol the emphasis is on increasing the existence time before the death of the first node (which is known as the stable region) and decreasing the deteriorate probability of sensor nodes using heterogeneous parameters specifications. This protocol includes two stages: the setup phase and the steady state phase. However, both rounds start with each other at the same time using a synchronizer clock. Some of applied nodes are nodes that have higher energy than others. If the number of all nodes are shown by n, and m be a part of n, with α time more energy than other sensor nodes, they are called CAG. All nodes are distributed evenly. In the setup phase, all nodes are like LEACH protocols and decide about being cluster heads. All CAG nodes become gateway nodes, unless they are selected as cluster heads. A node that decides to be the cluster heads broadcast a message to other nodes. Joining to the cluster is carried out based on receiving the strongest signal by nodes. This node acts as the same as LEACH protocol. That the only difference is that, when cluster heads receive all the data from their members, and combine them in the steady state phase, the combined data are forwarded to the base station based on the cluster head identity. If the cluster head is a normal node (which is selected from normal nodes), it will identify the nearest CAG and select it as the gateway node to orientation and routing of data to the base station. If cluster heads are CAG nodes (which are selected from CAG nodes), they send the data to the base station directly. In this protocol when all normal nodes are dead, then CAG groups could send their data to the base station and increase the data received by the base station. Figure 4 shows a typical A-LEACH clustering type.

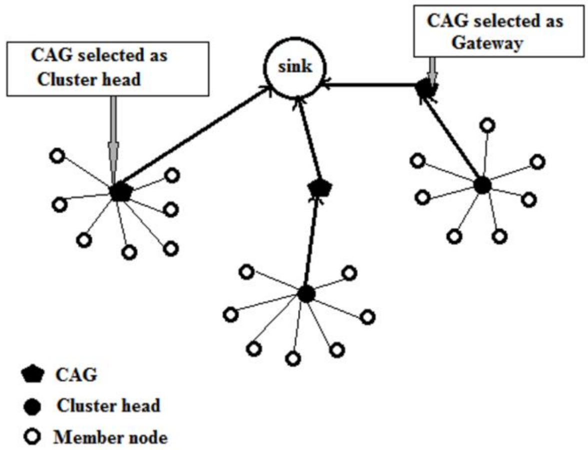

Figure 4. The A-LEACH Network Model [16]

3-12. Energy Efficient Clustering Algorithm for Maximizing the Lifetime of WSNs

Min *et al.*, [17] developed an algorithm that, it is a clustering analysis model with optimal one-hop which determines the angle of clustering and formulates these two parameters using minimization of energy consumption in inter cluster and intra cluster communication. In addition, it uses a mechanism in which every cluster head works permanently and cluster head role is never changed until cluster head performance time reaches a significant value. This time is calculated based on one-hop and determines the cluster angle. In this approach in the setup phase all nodes are divided into stable clusters with optimal parameters. As Figure 5 shows, it is assumed that n, is the sensor node in separate spaces v, with clustering angle θ, and nodes are distributed evenly. v, is the segments in m loop ($v_1, v_2, \ldots, v_m$.). Each loop is one cluster and the distance between two loops is one hop which is written as $d_1, d_2, \ldots, d_m$, $and\ d_i\ (1 \leq i \leq m)$. Cluster close to the base station are smaller than those far from the base station. Different cluster sizes ensure that cluster heads close to the base station have sufficient energy to transmit and combine the data which is received by the base station from distant cluster heads. Therefore, different cluster sizes create balance in energy consumption in inter-clusters. However, to decrease the energy consumption in intra-cluster and frequent processing of cluster updates, current cluster heads mechanism are used as local control center. Therefore, to the two parameters of cluster angle and optimal one-hop are optimized in the setup phase of clusters. The base stations must obtain information about the position and ID of the close cluster heads. A message contains its position and depending on the one-hop parameter, broadcasts a message to the close nodes. According to the response received, the base station determines which nodes must act as the first cluster heads. After cluster head is determined, cluster heads broadcast messages and determine the topography of lower layers nodes. Here, members of each cluster must recognize their cluster head, this is done by the message that cluster head broadcast to its members. Lower layer cluster heads become members of the upper layer cluster heads that act as the base station. In the steady state phase, this approach acts as the LEACH protocol, the only difference is that it is assumed that all nodes are simultaneous and advanced nodes of upper layers clusters are fewer than lower layer clusters. Therefore, time slots for each cluster is different and lower layer clusters heads act as normal clusters for the upper layer clusters. As the result, time slot of lower layer clusters must be half the time of upper layer cluster time slots.

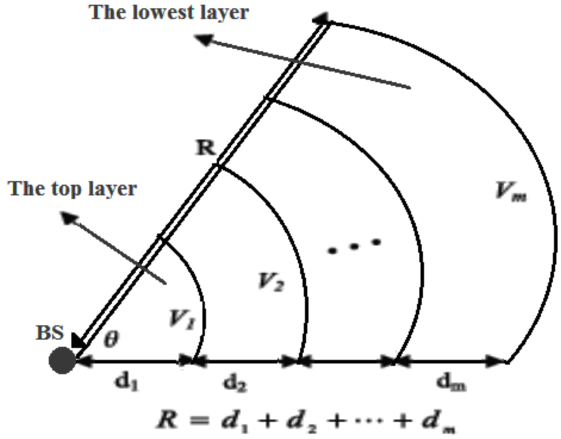

Figure 5. Sketch Map of Clustering Model [17]

3-13. LEACH with Sliding Window and Dynamic Number of Node (LEACH-SWDN)

LEACH-SWDN protocol is developed by Wang *et al.*, [18]. In this protocol, cluster heads are chosen the remaining energy level of the nodes dynamically. In this method a sliding window is used in the setup phase to create balance in the cluster head selection probability using two parameters of nodes initial energy and average energy of nodes that never been cluster heads and maintain cluster heads in predictive range. In fact, in this approach the problem in LEACH protocol is solved where there was no guarantee about the number of cluster heads during its lifetime. This approach uses live nodes instead of all nodes (alive or dead). This protocol selects a number randomly in the setup phase. However, this number is not assigned in clear distance between 0 and 1 like LEACH protocol but its larger and dynamic and due to network performance which changes dynamically. In fact, this is the sliding window of this protocol that is shown as $[0\,,\mathrm{E}_{\mathrm{average-nch}}/\mathrm{E}_{\mathrm{i-max}}]$. $\mathrm{E}_{\mathrm{average-nch}}$, this is the average of nodes that is never selected as a cluster head before that was calculated by the base station. $\mathrm{E}_{\mathrm{i-max}}$ is the initial energy of nodes. In the steady state phase the performance is like LEACH protocol, which is break down to some frames based on the number of this cluster nodes which is divided to some slots. Each node forwards a pocket in its especial slot to its related cluster heads. Nodes which never have been cluster heads, in the current round forward a pocket about their remaining energy in the last slot to their cluster heads. Cluster heads transmit a package that is concentrated in the end of the last frame of that cluster to the base station and puts other frames in normal packages and transmit them to the base station. Then the base station calculates the average energy $E_{average-nch}$ based on the data received in the current round and before the start of a new round, together with other alive nodes, broadcasts it throughput the network. By receiving these data nodes update useful values in the sliding window and the new round starts through selecting a number randomly from the sliding window. Each node selects a random number, if this random number is lower than threshold limit, $p_i(t)$ in following equation, this node is selected as the cluster head.

$$p_i(t) = \begin{cases} \frac{k}{N-K(r \bmod N/K)} \frac{E_{i-current}}{E_{i-max}} & C_i(t) = 1, \\ 0 & C_i(t) = 0. \end{cases} \quad (6)$$

where, N, is the total nodes, k is the total cluster heads (here c% indicate total live nodes). r is the number of current round, and $E_{i-current}$ is the current energy of the node i.
In the following section, Table 1 compares the algorithms discussed in this section and Table 2 classifies these algorithms based on the taxonomy of attributes discussed.

3-14. ASLPR (Application-Specific Low Power Routing)

Recently, evolutionary algorithms have attracted attentions from researchers to develop clustering protocols in wireless sensor networks [19-27]. The aim of the evolutionary-based approaches reported in [19-25] is to dynamically cluster the sensor nodes in the setup phase in such a way that some criteria (*e.g.*, energy consumption, clustering distances, *etc.*,) to be optimized. For N nodes, there are totally $2^N - 1$ different solutions, where in the every solution, each node can be selected as a cluster head or not. Although the evolutionary-based clustering approaches outperform other clustering protocols in prolonging network lifetime, they have a common drawback. Since an evolutionary algorithm should be run in the setup phase in the each round, these protocols increase delay and overhead.

In order to overcome the mentioned drawback, LEACH-LPR [26] and ASLPR [27] have been introduced. Since the iteratively-based evolutionary algorithm in both LEACH-LPR and ASLPR protocols is performed offline before the operation of the network, there is no need to perform an evolutionary algorithm in the each round, and consequently, it does not generate extra overhead and delay to select CHs.

LEACH-LPR [26] is an adaptive distributed clustering algorithm based on the LEACH architecture, which considers the distance of nodes to the sink, the residual energy of nodes, and the neighborhood density to select appropriate CHs. In this approach, genetic algorithm is performed to optimize the LEACH-LPR protocol, in order to prolong the network lifetime. Also, ASLPR is a centralized evolutionary-based routing protocol, in which, a hybrid evolutionary algorithm based on genetic algorithm and simulated annealing is utilized to optimize the controllable parameters of the ASLPR protocol.

ASLPR (Application-Specific Low Power Routing) [27] is a hybrid evolutionary-based clustering protocol which takes into account some criteria from the current situation of sensor nodes in the network to elect optimal cluster heads. The criteria include the distance from sensors to the base station, the remained energy of sensors, distance of nodes from other cluster heads, and history of cluster heads. The ASLPR can optimally balance the distribution of sensor nodes over the network. As the ASLPR is complex with seven controllable parameters, a hybrid algorithm based on genetic algorithm and simulated annealing has been used to optimize its parameters. The main advantage is that ASLPR can adaptively tune its parameters in order to match the application specifications. On the other hand, the ASLPR protocol can prolong the defined lifetime scheme (*e.g.*, FND, HND, *etc.*), based on the application definitions.

Table 1. Comparison of Presented Clustering Algorithm based on LEACH

Criterion / Protocols	Classification	Node mobility	Self-organization	location awareness	Balanced clustering	Multi-level	Cluster or chain stability	Failure recovery	Added factor to LEACH	Homogeneous	CH or leader rotation
LEACH [1]	Hierarchical	Limited	Yes	No	Ok	Yes	Moderate	Yes	---	Yes	Yes
LEACH-C [2]	Hierarchical	Limited	No	Yes	Very good	No	High	Yes	Using clustering centralize and almost constant regardless of the number of members to the cluster by the BS	Yes	Yes
PEGASIS [6]	chain	Limited	No	Yes	Very good	Yes	High	Yes	Chooses the shortest path for selecting the neighbor node as head cluster, using BS data	Yes	Yes/No
MECH [7]	Hierarchical	Limited	Yes	Yes	Very good	Yes	Moderate	Yes	Considering equal number of members for clusters and using hierarchical for communicating with BS	Yes	Yes

TL-LEACH [8]	Hierarc hical	Limited	Yes	No	ok	Yes	Moderat e	Yes	Using PEGASIS idea and reducing number of cluster heads which have relations with BS	Yes	Yes
TB-LEACH [9]	Hierarc hical	Limited	Yes	No	Very good	No	High	Yes	Considering a fixed number of clusters and using a random time for choosing the cluster head instead of a random number in setup phase.	Yes	Yes
T-LEACH [10]	Hierarc hical	Limited	Yes	No	ok	No	Moderat e	Yes	Delaying cluster head replace considering nodes remaining energy	Yes	Yes
EE HC [11]	Hierarc hical	Limited	Yes	Yes	Ok	No	Moderat e	Yes	Using heterogeneous nodes (two types of nodes equipped with more energy than normal nodes called super and advanced)	No	Yes
DS-LEACH [12]	Hierarc hical	Limited	Yes	No	Good	No	Moderat e	Yes	using sensor density for symmetrical distribution of cluster head	Yes	Yes
V-LEACH [13 or Sub-LEACH [14]	Hierarc hical	Limited	Yes	No	Ok	No	Moderat e	Yes	Using a replaced node as cluster head and preventing the cluster-forming stage from initiating when the server is dead	Yes	Yes/No
[15]	Hierarc hical	Limited	Yes	Yes	Good	No	Moderat e	Yes	Using a function with nodes distance from BS for homogenous distribution of clusters	Yes	Yes
A-LEACH [16]	Hierarc hical	Limited	Yes	Yes	Ok	No/ yes	Moderat e	Yes/ No	Using heterogeneous nodes (a node equipped with more energy than (normal nodes called CAG	No	Yes
[17]	Hierarc hical	Limited	No	Yes	Very good	Yes	High	Yes	Considering the optimal angle and distance for inter-cluster relations and continuous operation of cluster heads	Yes	Yes
LEACH-SWDN [18]	Hierarc hical	Limited	Yes	No	Good	No	High	Yes	Considering live nodes instead of all nodes (dead) and using the remaining energy for determining the new and dynamic threshold for choosing the new cluster head	Yes	Yes
ASLPR [27]	Hierarc hical	Limited	Yes	No	Very good	Yes	Moderat e	Yes	Energy nodes and their distance to the base station and the distance between each other's heads with checks	Yes	**Yes**

Table 2. Classification of Presented Algorithm based on Clustering Attributes

Clustering Protocol	**Cluster properties**				**Cluster head capabilities**			**Clustering process**		
	Cluster count	**Intra-cluster topology**	**Inter-cluster connectivity**	**stability**	**Mobility**	**Node type**	**Role**	**Methodology**	**Objective of node grouping**	**CH selection**
LEACH [1]	Variable	Fixed (1-hop)	Direct link	Provisioned	stationary	Sensor	Aggregation& relaying	Distributed	Save energy	Random
LEACH-C [2]	Variable	Fixed (1-hop)	Direct link	Provisioned	stationary	Sensor	Aggregation& relaying	Centralized	Load balancing	Pre-assigned
MECH [7]	Variable	Fixed (1-hop)	Direct link (Multi-hop)	Provisioned	stationary	Sensor	Aggregation& relaying	Distributed	Save energy& Load balancing	choose maximum energy node in current round by CH current
TL-LEACH [8]	Variable	Fixed (1-hop)	Direct link (Multi-hop)	Provisioned	stationary	Sensor	Aggregation& relaying	Distributed	Save energy& Decrease in amount of data using two phase combination	Prob/random / Maximum energy(for choose level2 CH)
TB-LEACH [9]	Fixed	Fixed (1-hop)	Direct link	Assumed d	stationary	Sensor	Aggregation& relaying	Distributed	Save energy& Load balancing	Prob/random
T-LEACH [10]	Variable	Fixed (1-hop)	Direct link	Provisioned	stationary	Sensor	Aggregation& relaying	Distributed	Save energy	remaining energy
EE HC [11]	Variable	Fixed (1-hop)	Direct link	Provisioned	stationary	Resour ce rich-sensor	Aggregation& relaying	Distributed	Save energy	Prob/random
DS-LEACH [12]	Variable	Fixed (1-hop)	Direct link	Provisioned	stationary	Sensor	Aggregation& relaying	Distributed	Load balancing & increase in data delivery to the BS	Prob/random /density sensor
VLEACH [13] or LEACH-Sub-CH [14]	Variable	Fixed (1-hop)	Direct link	Provisioned	stationary	Sensor	relaying	Distributed	Save energy& increase in data delivery to the BS	Random/ Pre-assigned

[15]	Fixed	Fixed (1-hop)	Direct link	Provisioned	stationary	Sensor	Aggregation& relaying	Distributed	Save energy& Load balancing	Prob/random /dbs
A-LEACH [16]	Variable	Fixed (1-hop)	Direct link (Multi-hop)	Assumed	stationary	Resource rich-sensor	Aggregation& relaying	Distributed	increase Stable region &fault tolerance	Prob/random
[17]	Preset	Fixed (1-hop)	Direct link (Multi-hop)	Assumed	stationary	Sensor	Aggregation& relaying	Centralized	Connectivity &save energy increase in data delivery to the BS	Pre-assigned
LEACH-SWDN [18]	Variable	Fixed (1-hop)	Direct link	Provisioned	stationary	Sensor	Aggregation& relaying	Distributed	save energy& increase lifetime& variability and expectation number of the cluster head	Prob/random / remaining energy
ASLPR [27]	Variable	Fixed (1-hop)	Direct link	Provisioned	stationary	Sensor	Aggregation& relaying	Centralized	Save energy& Good distribution of cluster heads	**Energy / Distance to the main station / the distance between the cluster heads**

4. Conclusion

In recent years, more attentions is paid to WSNs and these networks were used in many applications. Node grouping in clusters is the best way to develop, maintain, protect and improve the efficacy of WSN. In addition, most attentions are paid to clustering algorithms and approaches and one of the most important algorithms is LEACH protocol. Numerous protocols are introduced to improve the LEACH protocol. We review some of these protocols briefly. Cluster features and clustering process and cluster head potentialities of these protocols were classified [4]. Finally, we study them with regard to features like configuration, multi-level, break down retrieve capability *etc*.

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