Hierarchical Cluster-Based Routing Protocols for Wireless Sensor Networks – A Survey

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Abstract

Hierarchical cluster-based routing protocols are considered as one of the most efficient routing protocols in wireless sensor networks (WSN) due to its higher energy efficiency, network scalability, and lower data retransmission. In cluster-based routing protocols the network is divided into clusters each with a cluster head (CH) that is used for data aggregation and transmission, and other non CH nodes are used for data sensing. The most important issue with clustering is how to select CH, and manage clusters. For this reason several cluster-based routing protocols have been proposed. In this paper we conduct a comprehensive list of the most recent hierarchical cluster-based routing protocols and discuss how these protocols reduce energy consuming and improve network life time. We classify the protocols according to node capabilities into homogeneous and heterogeneous protocols. While the former achieves uniform energy consumption, the later achieves lower hardware cost. Another level of classification is applied on the listed protocols based on the distance between the CH and the base station. The protocols are classified into single hop and multi hop. We then compare the protocols based on issues face each protocol and how to be overcome and improved by other proposed protocols. Finally we conclude with possible future research.

Keywords: *Wireless Sensor Networks; Routing Protocols; Homogeneous; Heterogeneous; Single-Hop; Multi-Hop; Clustering; Energy Consumption.*

1. Introduction

Wireless Sensor Networks (WSN) [1] is considered as one of the most important technology emerged due the rapid evolving of Micro-Electro-Mechanical Systems (MEMS). It is a set of wireless, low size, low energy and un-rechargeable battery, low computational power, low storage, and low cost devices called sensor nodes that sense the environment and communicate with each other to gather information through wireless links. These sensed data is forwarded to a base station either directly or via multi hop relaying.

The unique characteristics of WSN in terms of limited energy and computation constraints, limited transmission range, no public identification, and the denser level of node deployment [2] make it distinguishable from traditional wireless networks and useful for variety of applications.

Since it could be deployed in harsh environment, WSN are used in environmental monitoring such as hazard or disaster monitoring, military application such as battlefield monitoring or object protection, health care applications, home automation, and moreover in human everyday-life [2]. Due to the complex nature of WSN and in order to prolong the lifetime of the sensors, efficient routing algorithms must be employed for data gathering [3]. There are two approaches for data gathering: Flat and Hierarchical approaches [4]. In a flat network, the base station flood a query to all nodes in the network and only the nodes that matches the query, will reply through multi hop path via its first hop neighbors. The main disadvantage of this network is the duplication of the transmitted sensed data specially when getting closer to the base station. Therefore, the nodes that are closer to the base station die faster which leads to partitioning the network.

To accommodate the disadvantage of flat networks, hierarchical networks have been proposed to reduce the number of the transmitted messages by involving only special nodes for data aggregation and transmission, and other nodes for data sensing. This approach improves not only energy efficiency but also scalability and balances traffic load in a network. Many hierarchical based routing protocols have been proposed and could be classified into four classes: chain based routing protocols, tree based routing protocols, cluster based routing protocols, and hybrid routing protocols.

In this paper we consider clustered based routing protocols because clustering increases scalability of the network, balances energy consumption among the nodes in the network, and reduces the amount of data that is actually transmitted to the base station due to the aggregation process [5].

In cluster based protocols, the network is divided into groups called clusters each has a cluster head (CH) node that has the responsibility of gathering sensed data from non-cluster head nodes within the cluster and transmitting the aggregated data towards the base station. The main problem with these protocols is how to select the CH and how to manage the clusters [6].

Data transmission can be classified into single-hop or multi-hop networks depending on the size of network and the number of hops between sensor nodes and the base station [7]. In a single-hop mode, all sensor nodes transmit their sensed data directly to the base station or sink without using intermediate nodes; but in a multi-hop network, some sensors deliver their data to the sink by assistance of intermediate nodes. Also the transmission of sensed data can be done from sensor nodes to the cluster head (intra-cluster) and then from cluster heads to the base station or sink (inter-cluster). These two phases may be performed either through direct transmission (single-hop) or via one or more intermediate nodes (multi-hop) [5].

In general, a single-hop mode makes network architecture simpler to implement and easier to control. It is energy efficient and suitable for applications in small sensing areas with sparsely deployed sensor nodes. However, this requires long-range wireless communication, so the furthest nodes from the sink will consume a lot of energy compared with those are closer to the sink. Also, the overall traffic load in the network may increase rapidly with the increase of the network size, which would cause more collisions, and delivery latency. Figure 1 illustrates the main architecture of single-hop clustering network.

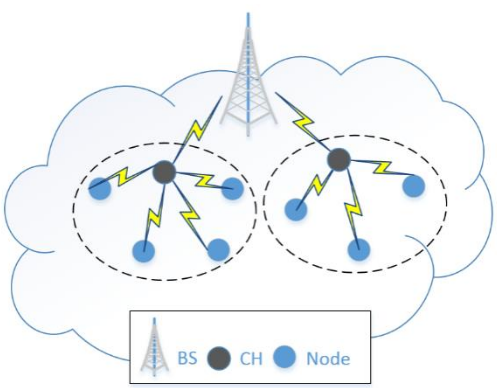

Fig. 1. Single-hop clustering network

In a multi-hop WSN, sensor nodes communicate with each other using short-range wireless communication. Each node in the network plays dual role of routing and forward data along a multi-hop communication links. Moreover, data aggregation can be performed at an intermediate node to eliminate data redundancy, which can reduce the total amount of traffic in the network and thus improve the energy efficiency of the network in order to maximize the lifetime. Another reason for using multi-hop routing is to extend the range of a network. The general architecture of multi-hop clustering network is shown in Figure 2.

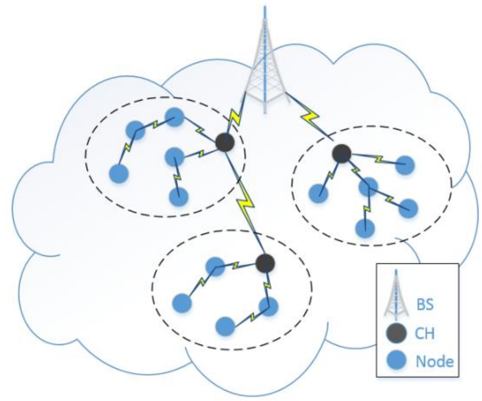

Fig. 2. Multi-hop clustering network

Multi-hop networks have a wide range of applications that are suitable for traffic distribution in short-distance and dense areas. However, multi-hop routing presents significant overhead for topology management and medium access control [8].

In terms of nodes' capability, cluster sensor network is classified into homogeneous [9] and heterogeneous [10] sensor networks. In homogeneous sensor networks all nodes are equipped with the same capabilities in terms of computation, storage, communication, and energy power. All nodes in turn consume the energy at equal rates. Most of the WSN protocols are designed for homogeneous sensors.

However, in the real world many applications require that sensors have different capabilities in terms of sensing and communication to expand network lifetime. This leads to the definition of heterogeneous sensor networks where not all the sensors have the same capabilities. There is a few of expensive sensors that are equipped with more powerful and less resource constrained devices and responsible for processing and data forwarding to the sink, while the rest of inexpensive sensors are responsible for sensing and gathering environmental information. Heterogeneous networks are more attractive for several reasons. First of all the energy consumption during data transmission is decreased. Hence, the network life time is extended. Moreover, the number of hops between normal nodes and the sink is fewer in node heterogeneity than node homogeneity which implies to higher reliability. Finally, the fewer hops mean less latency.

In this paper, we present and classify recent cluster based routing protocols based on the number of hops between a sensor node and the base station, and according to the

sensor nodes capabilities in terms of homogeneity and heterogeneity.
The next section we discuss single and multi-hop homogeneous cluster based routing protocols respectively, while section 3 we present single and multi-hop heterogeneous cluster based routing protocols. Section 4 compares and summarizes the advantages and the disadvantages of the classified routing protocols. Finally we draw a conclusion in section 5.

2. Homogeneous Networks

In this section we present and investigate in details homogeneous cluster-based protocols classified into single-hop and multi-hop networks depending on the size of network and the number of hops between sensor nodes and the base station. Nodes in this network have the same capabilities in terms of computation, storage, communication, and energy power.

2.1 Homogeneous Single-hop protocols

LEACH

Low Energy Adaptive Clustering Hierarchy (LEACH) [8] is the first clustering scheme. It is suitable for constant monitoring and periodic data reporting applications. The operation of LEACH is divided into two phases: the Setup phase, and the Steady State phase.
During the setup phase, LEACH divides the network into clusters each of which consists of cluster head (CH), and cluster members. These CHs are not selected in a static manner, instead they are randomly selected each round. The non CH sensor nodes join the cluster with the nearest CH. i.e. the CH with the largest signal.
The CHs in LEACH are elected according to the following probability:

$$T(n) = \begin{cases} \frac{p}{1-p(r \bmod (1/p))}, & n \in G \\ 0, & otherwise \end{cases} \quad (1)$$

Where $T(n)$ is a threshold that will be compared with a random number between 0 and 1. The random number is generated in each node, if it is less than $T(n)$, the node becomes a CH for the current round. P is the desired percentage of CHs, r is the current round, and G is the set of nodes that were not selected as CHs
The random selection of CHs will balance the energy consumption among the nodes in the network, because static CHs will die quickly due consuming their energy, while randomized selection of CHs in each round will distribute the CHs' role to other nodes in the network. However, good amount of energy is wasted during the CH selection phase. Another disadvantage of LEACH is that some nodes may join a CH so that the distance between the CH and the sink is even further than the distance between the node itself and the sink. Moreover, some nodes may die faster due being selected as CH several times.
During the steady state phase data will be transmitted from the cluster members to the cluster head using Time Division Multiple Access (TDMA) to regulate the channel access. After the CH gathers the information from its members, it sends the data to the sink directly. This may consume a large amount of energy especially if the CH is located far away from the sink.

LEACH_C

In LEACH Centralized protocol (LEACH_C) [6], the base station starts a centralized algorithm to choose the CHs according to their location information. This improves LEACH by forming better clusters, where it achieves balanced clusters partition in network. It improves the performance of LEACH by 20% to 40% in terms of the number of the data gathering rounds. However, since GPS receiver should be activated at the beginning of each round during the setup phase to get the node's location makes LEACH-C not robust.
The protocol has the same steady state phase as LEACH. However, during the setup phase of LEACH_C every node sends a message containing the current location and the energy level information to the base station. Since finding optimal CHs is considered NP-hard problem, simulated annealing algorithm is used to find the CHs. After finding the CHs, the base station broadcasts a message to all nodes to inform them about the CHs ID.
In [11], a performance comparison between LEACH and LEACH_C regarding to sink location is conducted, and they found that there is no optimal routing protocol suitable for any scenarios.

LEACH-F

LEACH-F proposed in [6] is an efficient clustering technique based on LEACH protocol with clusters that are formed only once and then become fixed.
In LEACH-F protocol, the cluster head role rotates among the nodes within the cluster. The rotation schedule of the future CH in the cluster is coordinated by the sink. In this way, the energy consumption is balanced between the sensors and the next CH is selected based on the status of each node.
The advantage that stands behind the fixed clusters avoids the setup overhead at the beginning of each round. This way does not allow any new nodes to be added to the cluster.
LEACH-F is the same as LEACH and LEACH-C couldn't solve the problem of fixed round time. Therefore, energy and information is wasted due to CH's death before completing the round for energy limitation. This problem

can be minimized by introducing a relationship between round time and current energy of CHs [12].

CLUDDA

Clustered Diffusion with Dynamic Data Aggregation (CLUDDA) [13] is a data aggregation based protocol that uses in-network processing to eliminate redundant transmission. It alleviates the flooding problem with Direct Diffusion (DD) [14] by combining it with clustering.
Unlike DD, only CHs and gateway nodes are involved to disseminate the interest messages, while the rest of nodes remain silent.
CLUDDA allows nodes to serve unfamiliar queries that were not defined before network deployment. The interest message initiated by the sink contains all the required components, and the operations to perform these components. This allows nodes (CHs, gateways, or regular node that can serve a query) to gather individual components of data and process them which results in data reduction. The reduced data will in turn be transmitted back to the sink.
CLUDDA also achieves dynamic data aggregation points, since the location of the sink which initiates the interest can be changed and in turn new CHs and gateways that are closer to the sink will perform data aggregation. This improves the system performance through even distribution of energy consumption.

sLEACH

Solar aware LEACH (sLEACH) [15], improves network lifetime through solar power. Some nodes are solar powered and are preferable to be chosen as CHs. Voigt et. al. extended both LEACH-C and LEACH by sLEACH.
In solar aware LEACH-C, each node transmits its location, residual energy, and its solar status to the base station. Nodes with higher energy are selected as CH and those are solar-driven nodes, since they normally maximize the residual energy. However, if the time when energy is gained (*i.e*. during *sunDuration*) is small, sLEACH will not perform well. The solution is to apply CH handover, where new CHs are chosen during the steady state phase. If the CH is running on a battery and received a flag from a node, this node may become the new CH.
In solar aware LEACH, to choose solar powered nodes as CHs some modifications applied on eq. (1). First of all solar powered nodes should have higher probability to become CHs. Also, theses solar powered nodes should be able to become CH again during the next ($1 /p$) round.

LEACH-ET

Energy Threshold (ET) [16] algorithm is an algorithm that calculates when to rotate rounds in LEACH algorithm. ET fits in LEACH, TEEN, and APTEEN. It assumes un-continuous data transmission, where nodes not always have data to send.
Rotating set up phase is important to distribute the heavy load of CH roles. However, it is energy consuming since control messages will be transmitted. Therefore, LEACH-ET aimed to save energy by reducing the times of round rotation and use this saved energy in steady state phase. This will prolong the lifetime of the network.
ET is a threshold that triggers set up phase when any CHs' energy level drop below it. ET is calculated as $n.P.E_{ch}$, where n is number of bits transmitted by each node, P is the probability of retransmission in every round, and E_{ch} is the energy dissipation rate of the CH per bit. The base station calculates and broadcasts the ET at the beginning of the network.
LEACH-ET outperforms LEACH in terms of data transmission and network's lifetime especially with low value of P. However, it causes extra overhead due to heavy-loaded CHs.

E-LEACH

Energy LEACH (E-LEACH) [17] protocol like LEACH, has two phases and the first phase is divided into rounds. However, it improves the cluster head selection procedure. E-LEACH depends on the residual energy of nodes to decide whether to turn these nodes into CHs or not in the next round. Nodes with more residual energy turn into CHs, and other nodes with less residual energy become members to a cluster.
The protocol shows same residual energy as LEACH at the beginning, but it is enhanced gradually after certain period of time. Moreover, the network life time in E-LEACH survives longer than LEACH.

RRCH

The Round-Robin Cluster Header protocol proposed in [18] uses a single set-up process to achieve high energy efficiency in wireless sensor networks.
The RRCH approach is like LEACH-F, it relies on the rotation sequence for selecting a CH instead of random rotation used in LEACH. The only difference between them is that the coordinated node in RRCH is CH and the sink or BS in LEACH-F.
In the RRCH, the CH node is replaced in each round according to the schedule based on an internal procedure within a sensor node without need to send or receive any additional information, which minimizes energy consumptions. Furthermore, abnormal sensor nodes are eliminated when the CH is changed by broadcasting a fault-tolerant message.

TB-LEACH

Time-based Cluster-head selection algorithm for LEACH (TB-LEACH) [19] is a protocol that only changes the way of selecting CHs. It aims to select a constant number of CHs autonomously without any centralized algorithms, or global information. TB-LEACH outperforms LEACH by about 20% to 30% in terms of network lifetime.
In TB-LEACH instead of using a random number for electing CHs, a random time interval is used. The node with the shortest time interval is elected to become a CH. First of all a counter is set to obtain a constant number of CHs, then every node produces a random timer at the beginning of each round during the setup phase. When the timer expires, and if the number of the received CHs advertisement messages is less than the counter, the node announce itself a CH and broadcast its status using non-persistent CSMA MAC protocol. Otherwise, it cannot become a CH.
On the other hand, TB-LEACH doesn't perform well in large scenarios. Because all nodes should be located in the range of the CH advertisement broadcasting message of all CHs, so the counter could work precisely.

MELEACH-L

The More Energy-efficient LEACH for Large-scale WSN protocol (MELEACH-L) [20] solves two problems facing WSN: the channel assignment between neighbors within the same cluster, and the cooperation between CHs during calculating data.
During the CH Selection Phase, each node sets up a timer (*Ti*). When the timer expires the node becomes a CH and broadcast an advertisement message. Other nodes that timer does not expire yet, and received the advertisement message drop the competition for CH role. This timer is a function of both residual energy of a node and the CH Selection Phase duration (δ).

$$T_i = \left[\alpha \frac{E_{start} - E_{residual\ i}}{E_{start}} + (1-\alpha) random(0,1).\right].\delta \quad (2)$$

As shown in eq. (2) where α is a constant value, the timer will expire earlier for nodes with higher energy level at higher probability, so nodes with lower energy level and close to the higher ones will have less chance to become CH. Therefore, equal size of WSN parts will be dominated by CHs, so the load will be balanced among the CHs.

V-LEACH

The new Version LEACH (V-LEACH) protocol proposed in [21] improves the original LEACH protocol by selecting backup-CH that takes over the role of the CH in case it dies. When a CH die, the cluster becomes useless because all data gathered by sensors in the cluster will never reach the sink. So in addition to elect CH, the vice-CH should be chosen. By doing this, cluster nodes data will always reach the BS; no need to elect a new CH each time the CH dies, and this will extend the life time of wireless network.

pLEACH

In [22], the partition-based LEACH (pLEACH) algorithm is proposed. It improves LEACH and LEACH-C algorithms, in which it partitions the whole network area into an optimal number of sectors, and then selects a head for each sector with highest residual energy based on centralized clustering approach.
In pLEACH, the BS or sink is located in the center of a network to be allowed for each node sends its location and its residual energy to the sink.
pLEACH protocol presents network as a circular field where the sink marks every node in the sector with the sequence number according to its central angle. When the amount of transmitted data in a sector exceeds other sectors, the sink rotates the partition circle of a given angle for the next round to balance the wasted energy among sensor nodes in the WSNs.

WST-LEACH

In Weighted Spanning Tree for LEACH (WST-LEACH) [23], the selection of CHs depends on three weighted parameters that optimize the transmission path which in turn reduce power dissipation that results in increasing network lifetime.
The protocol is similar to LEACH in its operation, but modifications are applied on the probability of the threshold formula *T(n).* These modifications aim to increase the probability of selecting nodes with more residual energy, less number of neighbors, and closer to the base stations, to become CHs.

$$T(n) = \frac{p}{1 - p * (r \bmod (\frac{1}{p}))} * \left\{ w_1 * \frac{S(n).E}{E_0} + w_2 * \frac{S(n).Nb}{p * N} + w_3 * \frac{1}{S(n).ToBs} \right. \quad (3)$$

The algorithm also considers different weights for the previous parameters. Eq. (3) shows the modification of WST-LEACH on LEACH. Where *S (n).E* is the residual energy of node n; N is number of nodes in the network*;* *S(n).Nb* is the number of neighbor of node n within a radius *R*; *S (n).ToBs* is the distance between node *n* and the BS; and w_1,w_2,w_3 are coefficients respectively.
The appropriate selection of the weights is crucial, where the average chance of the nodes to become CH or not should be balanced.

EBC

In an Energy Balanced Clustering (EBC) algorithm [24], the re-clustering decisions are based on the traffic load processed by the CH in particular round instead of time scheduling, and this ensures that new CH selecting is done only when it is really required. Furthermore, it saves the energy resources spent during unnecessary re-clustering stages.

In EBC, each node sends information about its residual energy with sensed data to the CH. When the amount of received data reaches to a predefined threshold, the new CH for the next round is selected by current CH based on the energy-case of cluster's nodes. In this way, it reduces the energy consumption and delay due to sending or receiving control messages to select new CH.

EBC protocol balances energy and increases the overall life time of the wireless sensor networks.

LEACH-SC

LEACH Selective Cluster (LEACH-SC) [25], outperforms LEACH in terms of energy consumption and network lifetime by using location information.

One main problem that may occur in LEACH is that a node could join a cluster so that the distance between the CH and the sink is further than the distance between the node itself and the sink.

In LEACH-SC, after CHs are selected, each will send an advertisement message to declare about its ID as a CH and its location information. The non CHs node in turn will join the cluster where its CH is closest to the middle-point between the node itself and the sink. That is, only the way of selecting a cluster is changed in order to optimize the communication cost, and prolong system lifetime.

2.2 Homogeneous Multi-hop protocols

M-LEACH

Multi-hop LEACH protocol (M-LEACH) proposed in [26] improves LEACH protocol by allowing sensor nodes intra and inter-clusters to use multi-hop communication in order to increase the energy efficiency of wireless network.

In M-LEACH, the intermediate CHs act as relay stations to solve the problem of earlier versions of LEACH in which each node will go down rapidly due to consuming a lot of its energy during direct or single-hop data transmission between CH and the far sink [27]. It selects an optimal path between the CH and sink through other CHs to transmit data gathered from sensor nodes.

M-LEACH assumes that all nodes are homogeneous in term of radius for in-cluster communication and the CHs that near to the sink node will bear more load of communication for transmitting the data from further CHs. These nodes are hot spots, and will be down faster than other nodes [28].

M-LEACH protocol is similar to LEACH. It only modifies communication mode from single hop to multi-hop between CHs and sink. Furthermore, M-LEACH is more efficient in case of large network size and LEACH is suitable when network area is small. In addition, both M-LEACH and LEACH protocols are limited scalability.

TL-LEACH

Two level LEACH proposed in [29] extends one level hierarchy of LEACH by building a two level of clustering. In LEACH, the CH sends the gathered data from sensor nodes to the sink directly in one hop. However, TL-LEACH utilizes two levels of cluster heads: the top-level CH receives collected data by assistant of secondary CH which is located near the cluster nodes, and passes it directly to the sink.

In TL-LEACH, the clusters are built based on minimum distance between sensor nodes and its corresponding CH.

Multi-level hierarchy used in TL-LEACH protocol reduces the energy consumption due distributing the energy load among the sensors in the dense sensor networks.

LEACH-L

In [30], an improved multi-hop routing protocol called LEACH-L is proposed. It switches one-hop LEACH protocol to multi-hop transmission way according to the distance between CHs and BS or sink. If CH is closed to the BS, single-hop strategy is adopted; otherwise the next hop toward the BS is selected based on its residual energy and distance to BS.

In LEACH-L, two metrics are defined to decide between single-hop and multi-hop transmission from CHs to the BS: the restriction distance as the shortest efficient distance for data transmission and Max-distance as the longest distance of direct transmission.

The results of experiments show that LEACH-L protocol can balance network load, and reduce energy consumption of the sensors in different areas in addition to prolong the lifetime of WSNs.

MS-LEACH

MS-LEACH proposed in [31] combines between multi-hop and single-hop Transmission modes to reduce energy consumption and prolong the lifetime of WSNs.

A critical value of the cluster area size is selected based on characteristics of both modes. If the area size of cluster is bigger than the critical value, multi-hop transmissions are adopted in the cluster for transmitting data to the sink. Otherwise single-hop transmissions are adopted.

3. Heterogeneous Networks

In this section we present and investigate in details heterogeneous cluster-based protocols classified into single-hop and multi-hop networks.

Sensor nodes in this network have different capabilities in terms of sensing and communication. There is a few of expensive sensors that are equipped with more powerful and less resource constrained devices and responsible for processing and data forwarding to the sink, while the rest of inexpensive sensors are responsible for sensing and gathering environmental information. This makes heterogeneous networks more attractive as they can extend network lifetime.

3.1 Heterogeneous single-hop protocols

EECHE

Energy-Efficient Cluster Head Election Protocol for Heterogeneous Wireless Sensor Networks [32] is a heterogeneous protocol that is based on three types of sensor networks. Each type is equipped with different energy resources, and the election of the CH is weighted based on the initial energy of a node. The simulation results in [32] showed that EECHE outperforms LEACH and SEP in terms of throughput and network lifetime.
EECHE improved the network lifetime using three level heterogeneous nodes, namely type-1, type-2, and type-3, where type2 and 3 nodes have to become CHs more often than type1 nodes. The idea is to assign a weight to the optimal probability P_{opt}. The weighed probabilities for type-1, type-2 and type-3 nodes are respectively:

$$P_1 = 1/N_e \quad (4)$$

$$P_2 = \left(\frac{1}{N_e}\right).(1+\alpha) \quad (5)$$

$$P_3 = \left(\frac{1}{N_e}\right).(1+\beta) \quad (6)$$

Where N_e is the new epoch of the heterogeneous network, α and β are the additional energy factor for type-2, and type-3 nodes respectively. Thus three different threshold equations were defined for each type to elect CH for each round by replacing P_{opt} with the weighted probabilities.
EECHE was developed for small sized wireless networks and it is based on single hop delivery from CHs to base station.

NEAP

The Novel Energy Adaptive protocol for Heterogeneous Wireless Sensor Networks (NEAP) [33] is based on LEACH and optimizes sensor nodes for the characteristics of heterogeneous WSN. However, the reliability of the network relies on the reliability of CH nodes.
The CHs are selected randomly and periodically according to a threshold based on the following equation:

$$T(n) = \frac{p}{1-p*(r \bmod (\frac{1}{p}))} * \left\{\frac{current\ energy}{initial\ energy} + \left[r_s div \frac{1}{p}\right] * \left[1 - \frac{current\ energy}{initial\ energy}\right]\right\} \quad (7)$$

Where r_s is the number of consecutive rounds in which the node did not become a CH. When $r_s = 1/p$ the threshold is computed without considering the remaining energy. Thus, the possibility of node n to become CH will be increased. When a node becomes a CH r_s will equal to zero. This ensures the transmission of data to the base station as long as the node is alive.
During cluster formation, the non CH nodes join a cluster based on a confidence value. The confidence value depends on: CH remaining energy, the distance between the CH and the nodes, and the number of nodes already joined the cluster. The node joins a CH which can support it with its remaining energy.
NEAP is developed for monitoring environment remotely, and it is assumed that all sensor nodes have enough power to reach the base station.

3.2 Heterogeneous Multi-hop protocols

SEP

SEP: A Stable Election Protocol [34] for clustered heterogeneous wireless sensor networks is developed to prolong the time interval before the first node dies. In SEP two levels of nodes are included: the advanced and normal nodes according to their initial energy.
Each node could become a CH according to the remaining energy and based on weighted election probabilities as the following:

$$P_{nrm} = \frac{P_{opt}}{1+\alpha.m} \quad (8)$$

$$P_{adv} = \frac{P_{opt}}{1+\alpha.m}.(1+\alpha) \quad (9)$$

Where P_{opt} is the optimal probability, $m$the fraction of the advanced nodes,α is the additional energy factor between advanced and normal nodes. Thus the CH election thresholds for the normal and advanced nodes are, respectively:

$$T(s_{nmm}) = \begin{cases} \frac{P_{nrm}}{1-P_{nrm}.(r \bmod \frac{1}{P_{nrm}})} & if\, s_{nrm} \in G' \\ 0 & otherwise \end{cases} \quad (10)$$

$$T(s_{adv}) = \begin{cases} \frac{P_{adv}}{1-P_{adv}.(r \bmod \frac{1}{P_{adv}})} & if\, s_{adv} \in G'' \\ 0 & otherwise \end{cases} \quad (11)$$

Where, G' is the set of normal nodes and G'' is the set of the advanced nodes.
SEP does not require global knowledge of energy at every election round. It works with large- and small-scale networks, and does not require prior distribution of the sensor nodes. SEP is scalable since there is no need for position knowledge.

HEED

HEED (Hybrid Energy-Efficient Distributed Clustering) proposed in [35] operates in a multi-hop inter-cluster wireless sensor networks. It improves LEACH protocol by selecting periodically CHs based on combination of residual energy of each node and node's neighbor degree in order to achieve power balancing and increase the network scalability and lifetime.
HEED takes into account the residual-energy of each node and a node that has the highest energy will be selected as CH. It also depends on the node proximity to its neighbors
In the HEED protocol, the clustering process terminates in a constant number of iterations, which achieves fairly regular CHs distribution across the network and reduces control overhead between sensor nodes.
HEED improves the network lifetime over LEACH. In LEACH the CH is selected randomly which may lead to rapid death of certain node. However, in HEED the CHs are selected with minimum communication cost which prolongs the nod's life time. In addition, the energy spent in clustering process is less in HEED compared to LEACH.

EEUC

In [36], the novel energy-efficient clustering approach for wireless sensor networks was proposed. It is used to avoid the hot spots problem due to heavy relay traffic on CHs those are closer to the BS or sink.
The EEUC idea depends on the relationship between the node's radius and distance between clusters and the sink. Thus the CH's radius should be decreased as long as its distance to the sink decreases.
The EEUC protocol partitions the sensor nodes into unequal size clusters to balance the energy consumption among CHs and it extends the life time of WSNs. Clusters closer to the sink have smaller sizes than others to preserve some of its CH's energy for inter-cluster multi-hop communication. However, EEUC elects CH every round, and it is difficult to control nodes due to differences in their positions. Moreover, it depends on the residual energy of node and this is not enough in case of heterogeneous network [37].

LEACH-HPR

LEACH-HPR [38] like LEACH, selects CH for each cluster. However, it considers heterogeneous WSN environment, where some nodes are equipped with additional energy resources. The nodes are divided into three types: type A, type B, and type C. Each type has different energy and percentage in the nodes set.
During set up phase each node is given a timer based on the node's residual energy. The higher the residual energy, the less the timer period is. When the timer expires the node will broadcast an advertisement message to announce itself as a CH. Therefore, nodes with higher residual energy become CHs, while other nodes with lower residual energy will become non CHs.
Each non CH node will join the appropriate CH according to the CH residual energy, and the distance between non-CH node itself with the CH.
In each round, every non CH node sends a message to its CH that contains its residual energy, so that the CH selects the top stronger nodes as assistant node to balance the energy consumption. LEACH-HPR also considers the problem of consuming lots of energy in LEACH due to the long distance communication. Therefore, LEACH-HPR uses multi hop communication and it selects intermediate nodes based on their residual energy. The minimum spanning tree is included to construct an inter-cluster routing.

DEUC

Distance and Energy based Uneven Clustering (DEUC) [28], is a multi-hop protocol. Unlike M-LEACH it tries to alleviate the hotspot problem for the nodes that are closer to the base station. It uses the same EEUC method to select CH. However, it does not consider the linear relation between the radius of the CH, and the distance with its next hop.
The authors in [28] concluded that the larger the cluster radius, the less related data. Therefore, it considers the distance from the sink node and the remaining energy of the sensor nodes to select CHs.
The selected candidate CHs are grouped by their radius and for each group the candidate CHs with largest energy will be selected as CHs. Simulation results showed that DEUC performs better than EEUC.

4. Comparative Study

In this section, we compare between routing protocols covered in this survey. Table 1 summarizes the classification of the hierarchical cluster-based routing protocols by stating its strength points and limitations.
It is obvious that there are wide number of researches were conducted for homogeneous networks where all nodes consume energy at same level, while there are few researches were developed for some heterogeneous networks where some nodes are supported with more capabilities and are assigned with more responsibilities such as data gathering and forwarding. Hence the consumed energy level is not equal among all nodes.
The main advantage of homogeneous over heterogeneous protocols is the formulation of approximately balanced clusters partition in network, while heterogeneous

overcomes homogeneous protocols in terms of increasing reliability, lifetime, and decreasing network latency.
Since real world applications may require different capability-supported sensors to develop network reliability and prolong network lifetime, researches should be oriented towards heterogeneous networks.
In the homogeneous WSNs, most of proposed single-hop protocols are based on LEACH protocol and have sought to overcome the drawbacks that it suffers from, such as wasting energy during CH-selection phase, unbalanced clusters, and consuming a large amount of energy if the CHs are located far away of the sink.
Many of protocols that have been suggested to improve LEACH protocol suffer from the same problems in addition to an extra overhead of forming clusters and then selecting CHs.
On the other hand, multi-hop routing protocols were suggested to improve LEACH protocol by reducing the energy consumption due to long-distance direct transmission. However, many of these specified protocols suffer from hotspots, delay, overhead, in addition to limited scalability.
Single-hop heterogeneous protocols achieve more reliability and less delay compared to multi-hop heterogeneous protocols. This can be explored by the number of hops required to reach the sink. Fewer hops mean higher reliability and less latency.
In general, single-hop heterogeneous protocols prolong network life time e.g. (EECHE compared to SEP and NEAP compared to HEED). However, they may consume large amount of energy if CHs are located far away of the sink. Moreover, single-hop heterogeneous protocols suffer from scalability compared to multi-hop heterogeneous protocols.
On the other hand, the main advantage of multi-hop heterogeneous protocols is increasing scalability. Moreover, some protocols are developed to alleviate the hotspot problem.
The down side of these protocols is the extra overhead that is required for performing a cluster, or constructing a route towards the sink.

Table 1. Summary of cluster-based routing protocols

Type		protocols	Advantage	disadvantage
Homogeneous	Single-hop	**LEACH**	- Avoid battery depletion and balance the energy consumption among the nodes	- Wasted energy during CH selection phase. - Consume a large amount of energy if the CH is located far away from the sink. - No guarantee of good CHs distribution.
		LEACH-C	- Forming better balanced clusters	- Wasted energy to achieve global information - Not robust - Relatively high overhead.
		LEACH-F	- Balance the energy consumption between sensors. - Avoid the setup overhead	- Fixed round time. - Wasted energy and information due to CH's death before completing the round for energy limitation.
		CLUDDA	- Eliminate redundant transmission. - Avoid flooding problem. - Achieves dynamic data aggregation point	- Increases delay time and require large memory storage.
		sLEACH	- Improves network life time by solar power. - Maximize the residual energy. - Is used for both centralized and distributed CH selection algorithm.	- It does not perform well if the time of recharging energy is small.
		LEACH-ET	- Save energy by reducing the time of round rotation	- Consume a lot of energy due to transmitting a control messages.

				- Not applicable for continuous monitoring
		E-LEACH	- Save the residual energy of nodes	- Suffers from wasted energy due to fixed time round.
		RRCH	- Single setup process. - Minimize energy consumption.	- Causes extra overhead
		TB-LEACH	- Increase the life time of network.	- Weak in large scenarios
		MELEACH-L	- Assign channels between neighbors within the same cluster. - Cooperate between CHs during calculating data. - Equal size of WSN parts - Load balancing	- Increases setup phase - Extra overhead
		V-LEACH	- No need to elect a new CH each time the CH dies.	- Increases setup phase - Reserves a node in each round
		pLEACH	- balance the wasted energy among sensor	- Increases setup phase - Extra overhead during setup
		WST-LEACH	- Optimize transmission path - Reduce power dissipation by increasing the probability of selecting nodes with more residual energy, less number of neighbors and closer to the sink.	- Variance in number of CHs in each round. - Extra overhead. - Increases setup phase. - The appropriate selection of the weights is crucial
		EBC	- Save the energy resources spent during unnecessary re-clustering stages	- Causes an extra overhead to overloaded CHs
		LEACH-SC	- Eliminate the main problem of LEACH. i.e. no selection for CH that are far away from the sink. - Increase scalability	- Extra overhead. - No guaranty of good CH distribution.
	Multi-hop	**M-LEACH**	- Suitable for large-size network	- Suffers from hotspots. - Limited scalability.
	Multi-hop	**TL-LEACH**	- Reduce the energy consumption due to distributing the energy load among the sensors in the dense networks	- It is not suitable for densely deployed network. - Increases delay time. - Requires knowledge about network topology in advance.
	Multi-hop	**LEACH-L**	- Balance network load and reduce energy consumption.	- Extra overhead. - Suffers from hotspots
	Multi-hop	**MS-LEACH**	- Reduce the energy consumption by combining between single-hop and multi-hop transmission modes.	- Limited scalability - Extra overhead
Heterogeneous	**Single-hop**	**EECHE**	- Outperforms LEACH and SEP in terms of throughput and lifetime of network. - Less latency	- Consume a large amount of energy if the CH is located far away from the sink. - Limited scalability
Heterogeneous	**Single-hop**	**NEAP**	- Increases the possibility of non CH nodes to become CH. - Increase reliability - Improves the energy consumption	- Limited scalability - Possibility of selecting CH far away from the sink

			compared to LEACH and HEED	
	Multi-hop	**SEP**	- No need to collect information about node's energy in each round. - Work with small and large-scale network. It doesn't require prior distribution of the sensor nodes.	- It doesn't use the residual energy of higher level nodes efficiently. - No guarantee of efficient deployment of nodes. - Cannot be applied to multi-level networks.
		HEED	- Balance power among nodes. - Increase the scalability of network - Reduce control overhead - Fairly CHs distribution	- Limited scalability. - Causes a delay
		EEUC	- Avoids the hot spots problem through uneven clusters. - balance the energy consumption among CHs	- difficult to control nodes due to differences in their positions - depends on the residual energy of node - The clusters are not balanced
		LEACH-HPR	- CH selects the top stronger nodes as assistant node to balance the energy consumption. - It selects intermediate nodes based on their residual energy. - Uses the minimum spanning tree to construct an inter-cluster routing.	- Extra overhead. - The energy efficiency is moderate - The clusters are not balanced
		DEUC	- Alleviate the hotspot problem. - Performs better than EEUC in terms of life time	- Extra over head - The clusters are not balanced

5. Conclusion and Future Scope

Hierarchical cluster-based routing protocols are considered as one of the most efficient routing protocols in wireless sensor networks (WSN) due to its higher energy efficiency, network scalability, and lower data retransmission.
In this paper, we have examined recent proposed clustering protocols in WSNs and classified the schemes according to homogeneous, heterogeneous, single- and multi-hop categories.
The design issues for such protocols are how to form clusters and select CHs in order to reduce the energy consumption due to transmission redundant messages to the sink. The factors affecting cluster formation and CHs communication are open future research issues. Furthermore, QoS requirements such as delay, fault tolerance, and network lifetime play a crucial role in designing an enhanced mechanism for clustering schemes.
Many of the current researches focus on the homogeneous wireless sensor networks while there are few research that seeks the heterogeneous-type which it more suitable for real life applications.
It was observed that most of the current routing protocols assume that sensor nodes and sink are static. However, there are some situations where sinks as well as the sensor nodes need to be mobile.
Finally, we summarize all routing protocols covered in this survey by stating their strengths and limitations.

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