



## Review

# A systematic review on clustering and routing techniques based upon LEACH protocol for wireless sensor networks

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## ABSTRACT

In recent years, Wireless Sensor Networks (WSNs) have emerged as a new powerful technology used in many applications such as military operations, surveillance system, Intelligent Transport Systems (ITS) etc. These networks consist of many Sensor Nodes (SNs), which are not only used for monitoring but also capturing the required data from the environment. Most of the research proposals on WSNs have been developed keeping in view of minimization of energy during the process of extracting the essential data from the environment where SNs are deployed. The primary reason for this is the fact that the SNs are operated on battery which discharges quickly after each operation. It has been found in literature that clustering is the most common technique used for energy aware routing in WSNs. The most popular protocol for clustering in WSNs is Low Energy Adaptive Clustering Hierarchy (LEACH) which is based on adaptive clustering technique. This paper provides the taxonomy of various clustering and routing techniques in WSNs based upon metrics such as power management, energy management, network lifetime, optimal cluster head selection, multihop data transmission etc. A comprehensive discussion is provided in the text highlighting the relative advantages and disadvantages of many of the prominent proposals in this category which helps the designers to select a particular proposal based upon its merits over the others.

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## 1. Introduction

Wireless Sensor Networks (WSNs) are being used in wide range of potential applications such as environment monitoring, military operations, target tracking and surveillance system, vehicle motion control, earthquake detection, patient monitoring systems, pollution control system etc. These networks consist of SNs which are capable of monitoring and processing the data from a particular geographical location and send the same to remote location which is called as Base Station (BS).

WSNs typically consist of small, inexpensive, resource constrained devices that communicate among each other using a multihop wireless communication. Each node of WSN is called as a SN which contains one sensor, embedded processors, limited memory, low-power radio, and is normally operated with battery. Each SN is responsible for sensing a desired event locally and for relaying a remote event sensed by other SNs so that the event is reported to the destination through BS. As SNs have limited energy so applications and protocols for WSNs should be carefully designed for optimized consumption of energy for prolonging the network lifetime. Figure 1 shows the generalized view of WSNs, which consists of a BS, Cluster Heads (CHs) and SNs deployed in a geographical region (Cook and Das, 2004).

Clustering has been widely used in WSNs for designing various energy efficient protocols in WSNs. One of the most common protocols used in this category is Low Energy Adaptive Clustering Hierarchy (LEACH) (Heinzelman et al., 2000). LEACH is a self-organizing, adaptive clustering protocol which uses equalized energy load distribution among the SNs in the WSN. The operation of LEACH is divided into rounds and each round is divided into two phases namely as: setup and steady-state phase. Steady-state phase is always long compared to the set-up phase to minimize the overhead. In LEACH protocol, the SNs organize themselves into local clusters, with one node acting as the leader and known as cluster head (CH) and rest of the nodes act as ordinary nodes. To prolong the lifetime of the network, LEACH includes randomized rotation of the high-energy CH and performs local data fusion to transmit the amount of data being sent from the CHs to the BS. If BS is far away from the network then the energy of CHs will be affected as only CHs are directly communicating with the BS. Set of clusters will be different for different time interval and the decision to become a CH depends on the amount of energy left at the SN. Figure 2 describes the various units in LEACH protocol consisting of transmitter and receiver.

It also shows various parameters of transmitter and receiver as defined by (Heinzelman et al., 2000) which are defined below.

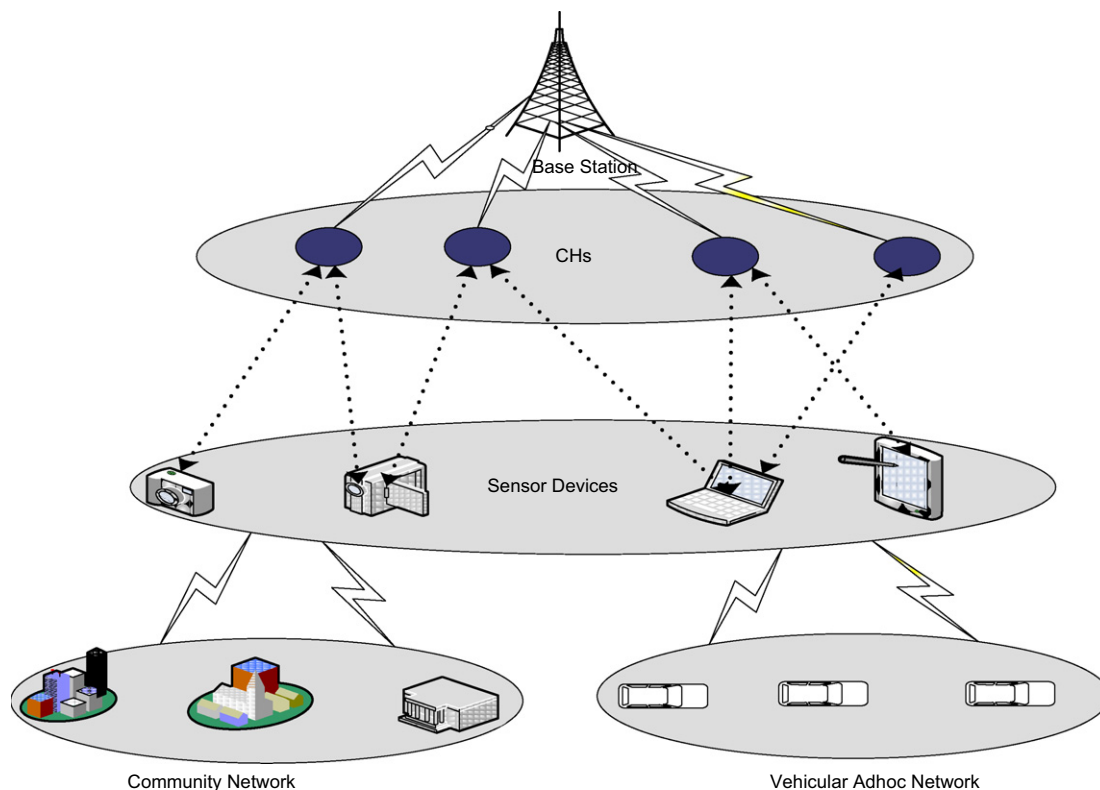


Fig. 1. Generalized view of WSN.

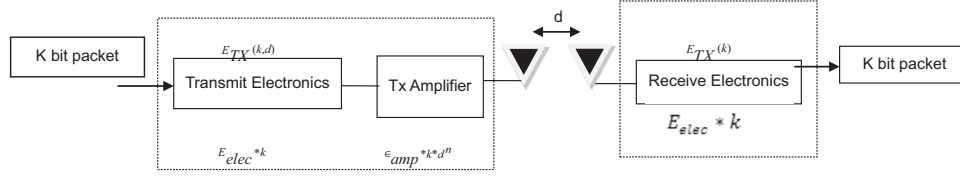


Fig. 2. Radio Model of LEACH Protocol.

Table 1

Parameters used in LEACH.

| Operation                                    | Energy dissipated         |
|--|---------------------------|
| Transmitter electronics<br>( $E_{TX-elec}$ ) | 50 nJ/bit                 |
| Receiver electronics<br>( $E_{RX-elec}$ )    | 100 pJ/bit/m <sup>2</sup> |
| ( $E_{TX-elec} = E_{RX-elec} = E_{elec}$ )   |                           |
| Transmit amplifier $\epsilon_{amp}$          |                           |

Transmitting radio equations are defined as follows (Heinzelman et al., 2000):

$$E_{TX}(k,d) = E_{TX-elec}(k) + E_{TX-amp}(k,d)$$

$$E_{TX}(k,d) = E_{elec} \times k + \epsilon_{amp} \times k \times d^2 \quad (1)$$

Receiving radio equations are

$$E_{RX}(k) = E_{RX-elec}(k)$$

$$E_{RX}(k) = E_{elec} \times k \quad (2)$$

$E_{elec}$  is the radio energy dissipation for transmission and reception and  $\epsilon_{amp}$  is the amplification factor used for the transmission of  $k$  bit message to a distance  $d$ .

For cluster formation, each SN decides whether or not to become a CH for the current round. This decision is based on the percentage of CHs for the network and the number of times the SN has been a CH so far. In this process, every SN has to select a random number between 0 and 1. If the number is less than a threshold  $T(n)$ , the SN becomes a CH for the current round. The threshold is set as follows (Heinzelman et al., 2000):

$$T(n) = \begin{cases} p - p \left( r \bmod \frac{1}{p} \right), & n \in G \\ 0, & \text{otherwise} \end{cases} \quad (3)$$

where  $P$  is the desired percentage of CHs (e.g.,  $P=0.05$ ),  $r$  is the current round, and  $G$  is the set of SNs that have not been CHs in the last  $1/P$  rounds. During round 0, every SN has a probability  $P$  of becoming a CH. The SNs that are CHs in round 0 cannot be CHs for the next  $1/P$  rounds. Thus the probability that the remaining SNs are CHs must be increased, since there are less SNs that are eligible to become CHs. Using this threshold, each SN will be a CH at some point within  $1/P$  rounds. Table 1 shows the various parameters used in LEACH protocol (Heinzelman, 2000).

Each round of the LEACH protocol is defined by the set-up and steady phases. In set-up phase, CH for the current round broadcasts an advertisement message to the rest of the SNs. The SNs must keep their receivers on and based on the received signal strength of the advertisement, every non-CH node decides to which cluster it belongs for this round. If ties occur then a random CH is selected. In steady phase, the energy of all Cluster Members (CMs) can be reduced using sleep mode activation and now data transmission can begin. Once the CH has all the data from the CMs, the CH aggregates and fuses the data to the BS. After a certain time, which is determined a priori, the next round begins with each SN determining if it should be a CH for this round. Figure 3 shows the steps used in the protocol.

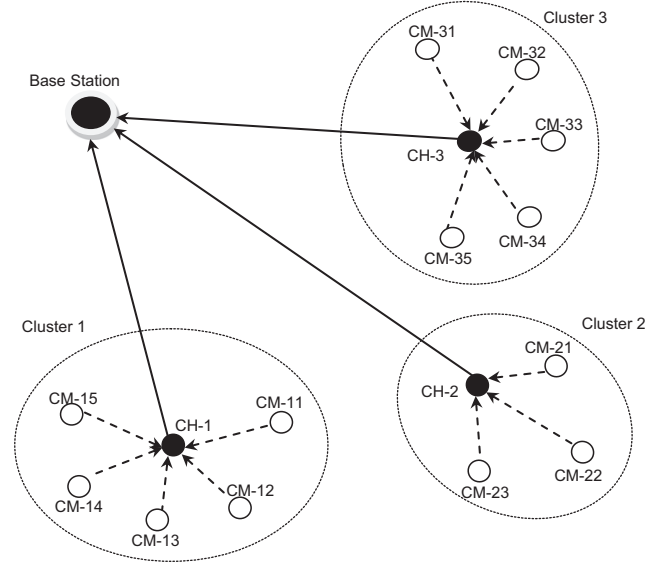


Fig. 3. Cluster based model.

Apart from many potential applications of WSNs, there are many constraints such as deployment strategy, optimal energy consumption, computation and storage, scalability, security, fault tolerance, reliability, Quality of Service (QoS), adaptability and bandwidth utilization. Many proposals in the literature are reported based upon the above defined parameters. Keeping in view of the above issues, this paper provides a detailed description of various existing LEACH based routing and clustering protocols which are used to solve many of the above defined issued in WSNs.

Rest of the paper is organized as follows. Section 2 provides the taxonomy of different clustering based routing protocols depending upon various parameters. Section 3 provides the comparison of all LEACH based clustering protocols with respect to various parameters. Section 4 provides the open issues in this area and finally Section 5 concludes the article.

## 2. Taxonomy of clustering based protocols

There are several parameters based upon which LEACH protocol has been modified and accordingly various variants of LEACH protocol exist in the literature. Figure 4 describes various parameters based upon which various categories of LEACH based protocols have been developed. The purpose of this paper is to provide the detailed description of all those modified LEACH based protocols according to the categorization shown in Fig. 4.

### 2.1. Selection of cluster head (CH)

To decrease the complexity of any operation and to preserve the energy of SNs, clustering of SNs has been widely used in the literature. But for any clustering based routing technique, the most important task is to select the CH based upon the parameters defined below. This section illustrates how CHs have been

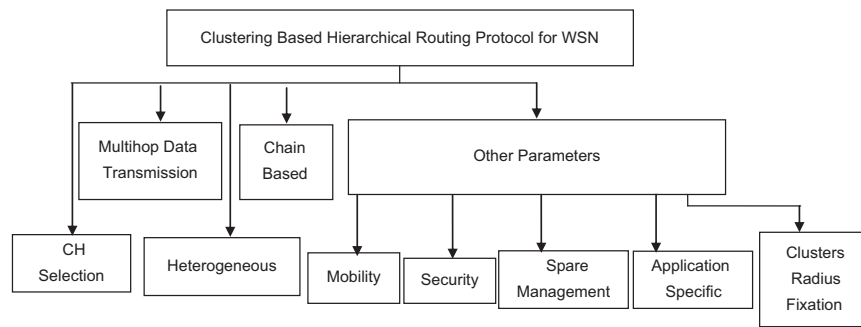


Fig. 4. Categorization of LEACH Related Routing Protocols for WSNs.

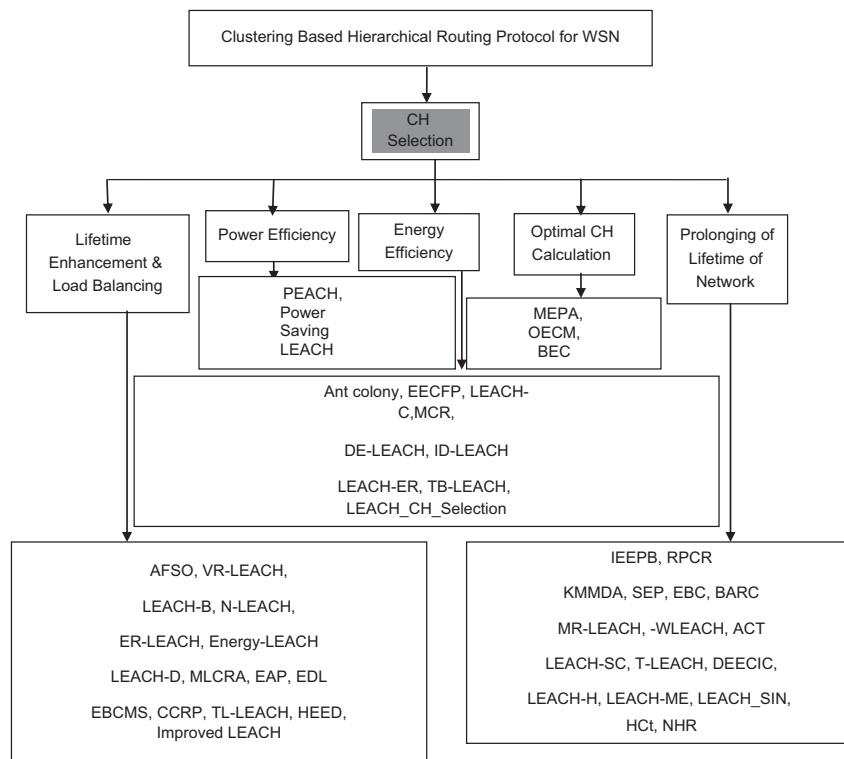


Fig. 5. Categorization of Cluster Head election for cluster based routing protocols.

used in various issues in WSNs. The issues and their associated protocols are discussed in detail in Fig. 5.

#### 2.1.1. Lifetime enhancement and load balancing

SNs are always energy limited because they are operated on battery and it is difficult to recharge the battery of SNs because of their random deployment. Therefore life of a SN can be increased by load balancing technique. There are several protocols based on this issue and all of these protocols are discussed as below:

Song et al. (2010) have proposed a hierarchical routing protocol based on Artificial Fish Swarm Optimization (AFSO). Main aim of this protocol was to enhance the lifetime of the network and achieve the goal of load balancing using fish behaviors such as praying, and swarming. The authors proposed a random and parallel search algorithm in which steady state phase is similar to LEACH but for the data transmission, CHs of AFSO have used multihop transmission. The algorithm contains variables and functions to represent different moves in the network.

Peng and Li (2010) have proposed Variable Round-LEACH (VR-LEACH) which is based upon CH selection. In this protocol, CH is selected according to the situation of SN. Life time of the network is enhanced by using VR-LEACH. In the initial step, nodes having energy less than the average are selected and only those nodes are allowed to participate in the CH selection which has energy greater than average energy. Each round of selection is divided into frames with each frame is divided into time slot depending upon number of members in the cluster. Tong and Tang (2010) have proposed Balanced LEACH (LEACH-B). It removes the problems of fluctuation of the number of CHs and considered the residual energy of SNs as the parameter for CH selection. Moreover, it has been found that the number of CH is constant and near optimal per round. In this scheme, in the first round CH is selected based upon the LEACH protocol and in the second round node residual energy is considered for CH selection. Zhao and Jiang (2010) have proposed N-LEACH protocol to improve the election process of CH. N-LEACH take the advantage of residual energy of SNs. The CH used the distance from the BS to construct spanning tree to avoid many CHs to communicate

directly with the BS. It also selects the root node from the CHs to collect data and to send the same to the BS which reduces the large number of communication between CHs and BS and effectively decreases the energy consumption. Figure 5 describes various routing protocols in this category.

Al-Refai et al. (2011) proposed Efficient Routing-LEACH (ER-LEACH). In this protocol, authors have focused on the data, as the interest of BS is to get the data from environment. Therefore data can be aggregated by SNs rather than sending to the BS. In this proposal, authors have removed some of the problems in the classical LEACH based protocol, which are listed as follows:

- During the setup phase of LEACH, the selection of the CH was random.
- CH dies faster because of heavy load and again new CH election was required.
- Direct communication between CHs and BS.

Based on the above problems, authors have designed ER-LEACH protocol that enhances the lifetime of WSNs through load balancing using following steps:

- By enhancing the selection of the CH during setup phase.
- By using an alternative CH to take the role of the CH in case that the underlying CH dies.
- By using zone routing protocol for load balancing of WSNs.
- By performing well especially when the mobility is very high.

Xiangning and Song (2007) have proposed two modified protocols of LEACH as Energy-LEACH and Multihop-LEACH. Energy-LEACH protocol improves the way of selection of CH. In this method, the nodes having higher residual energy are considered for selection of CH in the very next round. To improve the communication among the CH and sink, multihop LEACH protocol has been proposed. The results obtained show considerable improvements in the proposed scheme compared to the earlier schemes of its category.

Liu et al. (2010) have proposed LEACH-Density Distribution of Node (LEACH-D) protocol. This protocol has focused on energy load balancing by making an adjustment in the threshold function defined by the fixed radius of region of deployment of SNs. Major component used in the threshold is the connectivity density which takes the density of distribution of SN into consideration. The CH decides its cluster radius according to their distance from the BS and the degree of connectivity. Non-cluster head node selects to join a cluster according to the energy of CH and the distance from the CH. Finally CH uses a multi-hop steady-state transmitting data to the BS. It was observed that LEACH-D reduces the entire network energy consumption.

Liu et al. (2010) have proposed Multi Layer Clustering Routing Algorithm (MLCRA). This protocol was application oriented and suited for Wireless Vehicular Sensor Networks (WVSNs). Authors of MLCRA give a brief discussion on single hop and multihop communication but unable to recommend that which one is best suited because of several parameters introduced in this proposal. Therefore MLCRA uses the combination of both single and multihop. The proposed protocol has multilayered structure with the consideration that the SNs farthest from the BS will use multihop communication and the nearest SNs to the BS can communicate directly in a single hop. The formation of layer is based upon the selection of the distance between two SNs such that there is a guaranteed communication between different layers. In this manner, the consumption of energy reduces as the communication distance decreases, which enhance the life of SNs. Also the proposed scheme removes the hot spot problem in WSNs. MLCRA performs better in terms of balancing the energy consumption in the network and to enhance the network lifetime.

Liu et al. (2009) have proposed Energy Aware Routing Protocol (EAP) for long-lived SNs. The scheme was proposed by the authors keeping in view of the issues of balancing the energy for SNs energy according to the needs of applications. It manages a good performance in terms of lifetime of SNs by minimizing energy consumption and load distribution for communications among the SNs. Each SN maintains a neighborhood table that contains the ID, status and residual energy of neighboring nodes. It also introduces a new clustering parameter for CH election which can handle the heterogeneous energy capacities of the nodes intelligently. EAP clusters the SNs into groups and builds routing tree among CHs for energy saving. Hou et al. (2009) have proposed Energy and Distance LEACH (EDL) by taking residual energy and distance of SNs as the key parameters. The proposed scheme performs CHs distribution in actual limited regions more uniformly and thus avoiding unnecessary energy loss which is due to the short distance between CHs. In data transmission stage, single hop communication mode is used among either CM nodes or CH and sink node. The proposed protocol is suitable for both homogeneous and heterogeneous networks.

Ding et al. (2009) have proposed the Energy-Balanced Clustering algorithm with Master/Slave method (EBCMS). In EBCMS algorithm, one master CH and two slave CHs are selected in each cluster. It selects the nodes with more residual energy as master CHs and others as slave CHs. It works in many phases same as LEACH protocol. In the initial phase, a random number is generated and based upon some predefined threshold each node broadcast its own id and its residual energy. After finite interval of time, if the residual energy of this node is greater than predefined threshold then it declares itself as CH otherwise the other nodes satisfying the criteria are selected for CH. EBCMS selects those nodes for data forwarding which have minimum energy consumption. EBCMS perform better for Half Node Alive (HNA) in comparison to LEACH and have balanced energy consumption for prolonging the network lifetime.

Bian et al. (2008) have proposed the Cluster-Chain Routing Protocol (CCRP) which adopts a more balanced CH selection algorithm and an improved data transmission mechanism from the CHs to the BS. For CH selection, CCRP have used residual energy and number of the neighbors. The data transmission is improved by constructing a chain among all the CHs. Network lifetime is prolonged as the load distribution of energy is evenly distributed. The threshold chosen for the node to act as CH is multiplied by the remaining energy of the nodes and the modified formula for LEACH in this proposal is described as follows:

$$T(n) = \begin{cases} \left\{ \frac{p}{1-p \left( r \bmod \frac{1}{p} \right)} \left( \frac{E_c}{E_m} \right) \right\}, & n \in G \\ 0, & \text{otherwise} \end{cases}$$

Moreover, for CH election, numbers of members within the transmission range are counted. Each CH has  $1/(p-1)$  neighbors and more the number of neighbors, lesser the consumption of energy of the nodes in the network. The proposed scheme outperforms the LEACH protocol in terms of energy consumption when 1, 50 and 100% nodes die in the network.

Loscri et al. (2005) have proposed Two Level Hierarchy LEACH (TL-LEACH). TL-LEACH uses random rotation of primary and secondary CHs. Two level hierarchy permits to distribute the energy load among the SNs in the network especially when the density of network is higher. TL-LEACH uses localized coordination to enable scalability and robustness. The proposed scheme consists of following four phases: advertisement phase, cluster setup phase, schedule creation, and data transmission. In the first phase each node decides if it wants to be at primary CH or at secondary CH or simple node. The proposed scheme is different from LEACH because each secondary CH decides to which primary



CH it belongs, then each secondary CH sends a message to advertise its primary CH and each simple node will decide whether it will be its secondary CH and informs it through the reverse message. In this scheme, clusters are created such that each node can transmit in respect to the TDMA schedule by its primary CH. In this way, TL-LEACH delivers more data packets than the original LEACH protocol.

Younis and Fahmy (2004) have proposed Hybrid Energy-Efficient Distributed Clustering (HEED) which is a distributed clustering approach for long-lived ad hoc sensor networks. HEED protocol periodically selects CH according to the node residual energy and node degree. With appropriate bounds on node density, intra-cluster and inter-cluster transmission ranges, HEED can have asymptotically almost surely (a.a.s.) guarantee connectivity of clustered networks. Assumptions made by the authors are quasi-stationary where nodes are location-unaware and have equal significance. HEED can be used to design several types of sensor network protocols that require scalability, prolonged network lifetime, fault tolerance, and load balancing. The designed algorithm completes in  $O(1)$  time. By selecting appropriate bound on node density and transmission range, HEED proves guaranteed coverage of nodes in WSNs. The authors assume that within the cell of area  $c \times c$ , the network is guaranteed to be connected if  $R_t = (1 + c\sqrt{5})$  and cell side range should be  $\leq (R_c/\sqrt{2})$ , where  $R_c$  is the cluster range and  $R_t$  is the transmission range. The authors also proved that two CHs communicate if  $R_t \geq 6R_c$ . Observations show that HEED was effective in prolonging the network lifetime and supporting scalable data aggregation.

Xiaoping et al. (2010) have focused on the election of CH for LEACH. For the enhancement of lifetime of the network, authors have proposed the use of current energy for CH election and multihop routing. If the current energy of the nodes is larger than the average energy then it is selected as a CH and after  $1/(p-1)$  rounds the same node will become CH again if  $R < (p)/(1-p(\text{rmod}(1/p)))$ , where  $R$  is the randomly generated number.

### 2.1.2. Power efficient

Yi et al. (2007) have proposed Power-Efficient and Adaptive Clustering Hierarchy Protocol (PEACH) for WSNs. PEACH forms the clusters without additional overhead and supports adaptive multi-level clustering. Important feature of PEACH was that it can be used for both location-unaware and location-aware WSNs. The main idea is to construct adaptive clustering using two sets of nodes as follows:

In the first set,  $\text{NodeSet}(N_i, N_j)$  consists of nodes with center as  $N_i$  and radius equal to the distance between  $N_i$  and  $N_j$ . In the second set, following equation is used:

$$\text{ClusterSet}(N_i, N_j) = \text{NodeSet}(N_i, N_j) \cap \text{NodeSet}(N_j, N_i)$$

where  $\text{NodeSet}(N_i, N_j)$  consists of all the nodes which overhear the transmission from  $N_i$  to  $N_j$  and  $\text{ClusterSet}(N_i, N_j)$  is the set of all those nodes which are overheard in a cluster.

Moreover, if the location of the SNs cannot be detected then the location unaware version of the PEACH can be used. On the other hand, if nodes support GPS facility then location aware PEACH can be used which support the localization mechanisms. As each node knows the information about the other nodes so global transmission is possible which reduces the energy consumption of the nodes in the network. The transmission schedule of each node is distributed in the initial phase and the maximum transmission range of the nodes removes the collision problem during the transmission. The node which is at the maximum distance from the sink starts the process of transmission.

The performance of the PEACH is evaluated with respect to various parameters such as number of nodes alive, residual energy, algorithm complexity, intra and inter cluster communication

overhead after several rounds of various operations. The results obtained show that PEACH minimizes energy consumption of each SN and extends the network lifetime, compared with the existing clustering protocols such as LEACH, HEED, and PEGASIS.

Liao and Yang (2012) have proposed a grid-based architecture. Their algorithm works on power management system for saving energy by using the concept of sleep node. In this scheme, authors use the concept of grid in which two SNs will always remain the active mode and rest are in the sleep mode to save the energy. They have assumed the network can be partitioned into 2-dimensional grid and constructed a scheduling matrix (active or sleep) in which snake like power scheduling is proposed by the following equations:

$$T_{ij} = \begin{cases} (i-1) \times n + j, & i = 2i+1 \\ (i \times n + 1) - j, & i = 2i \end{cases}$$

Here  $N$  are the total sensor nodes and  $m$  and  $n$  are rows and columns with  $N = m + n$ . The above equations described the slot during which some of the nodes will remain active and others will remain in the sleep mode. The nodes along the horizontal or vertical rows are selected in the sequential manner for sleep or active mode in a particular time slot as defined above. Authors calculate the cost of storage and query as  $\sqrt{g}$  and  $2\sqrt{g}$  where  $\sqrt{g}$  is used to estimate the cost of sending and retrieving a message between two nodes in the network.

### 2.1.3. Energy efficiency

Liao et al. (2008) have proposed an ant colony algorithm for data aggregation in WSNs. This algorithm works on sending the data from different SNs to the BS through the tree with the help of ant colony optimization. Several protocols under this category are shown in Fig. 5 which are discussed as follows.

Allirani and Suganthi (2009) have proposed an Energy Efficient Cluster Formation Protocol (EECFP) which provides energy efficiency and clustering to increase the lifetime of the network. The cluster formation algorithm allows each node to make independent decisions so as to generate efficient clusters at the end. The proposed scheme has used different cycles namely as first and consecutive cycles in which five nodes which has maximum residual energy are selected as candidate for transfer the data to BS. This process continues till all the nodes in the network die. The results obtained show that EECFP utilizes minimum energy and latency for cluster formation which reduces the overhead of the protocol. Also it achieves low energy dissipation and latency without sacrificing the quality of the application.

Heinzelman et al. (2002) have proposed Centralized-LEACH (LEACH-C). The purpose of LEACH-C protocol was to combine the energy-efficient clustering and routing for application-specific data aggregation to increase the network lifetime and to decrease the data access latency. The proposed scheme includes a new distributed cluster formation technique which enables self-organization of large numbers of SNs.

Authors have divided the proposed scheme into different phases as CH election, Cluster formation, Steady phase etc. In CH election each node elects itself as CH at beginning of time  $t$  with probability as  $P$ . If the expected number of CH for this round are assumed to be  $n$  such that  $N$  are the total number of nodes in the network then  $\sum_{i=1}^N P_i \times 1 = n$ .

Authors have formulated a mathematical formula to estimate that a node becomes a CH after finite number of iterations as follows:

$$P_i(t) = \begin{cases} \left\{ \frac{n}{N - n(k \bmod \frac{N}{n})} \right\}, & f(t) = 1 \\ 0, & f(t) = 0 \end{cases}$$

$f(t)$  is used to estimate if the node has been a CH in the most recent rounds ( $f(t) = 1$ ) or not ( $f(t) = 0$ ). Using the above equation, after  $n/N$  rounds each node is expected to become CH.

So from the above equation, the nodes which have not become CH in the recent rounds and have more residual energy than the other nodes will become CH in the subsequent rounds. Authors have also differentiated the cases when all the nodes have equal initial energy and have data to send to the nodes which have higher residual energy and send only when some event occurs. After this phase, each CH broadcast the message using CSMA with its ID so that non-CH nodes join the CH. Finally in the steady state phase each non-CH nodes send the frames to CH during their time slot depending upon the number of nodes in the cluster. The performance of the proposed scheme is evaluated using the metrics such as remaining energy, total amount of data received at the BS, and number of nodes alive after finite number of rounds. The results obtained show that the proposed scheme have better performance than the other well known schemes of its category.

Kumar et al. (2011) have proposed energy efficient Multihop Communication Routing (MCR) protocol. MCR provides load balancing, lifetime enhancement, stability and energy efficiency for the given WSNs. MCR utilize the concept of both single hop as well as multihop. CHs are selected on the basis of certain weighted probability. Normal nodes communicate with the CH using a single hop communication and CH communicates with the BS using the multihop communication. Authors have introduced the concept of advanced and super advanced nodes along with the normal nodes so that the resulting network becomes a heterogeneous network. The advanced nodes are those nodes which are having  $\alpha$  times more energy than the normal nodes and  $m_0$  are those nodes which are having  $\beta$  times more energy than the normal nodes. The rest of the  $n(1-m)$  nodes are treated as normal nodes. If  $E_0$  is the initial energy of the nodes then energy of the super and advanced nodes is  $E_0(1+\beta)$  and  $E_0(1+\alpha)$  respectively.

The total energy of the network can be written as follows:

$$E = nE_0(1 + m(\alpha - m_0(\alpha - \beta)))$$

The weighted probability of nodes to become CH can be written as follows:

$$P_{normal} = \frac{P_{opt}}{1 + m(\alpha - m_0(\alpha - \beta))}$$

$$P_{advanced} = \frac{P_{opt}}{1 + m(\alpha - m_0(\alpha - \beta))} (1 + \alpha)$$

$$P_{Super\_Advanced} = \frac{P_{opt}}{1 + m(\alpha - m_0(\alpha - \beta))} (1 + \beta)$$

Using the above equations, authors have derived an expression of threshold for normal, advanced and super advanced nodes. The other phases of the proposed scheme were cluster formation, route selection and data transmission. The performance of the proposed MCR was found to be better than M-LEACH and MEECHCP with respect to the metrics such as number of nodes alive, number of CHs and average number of message transmitted into the network.

Li et al. (2010) have proposed an improved LEACH routing algorithm based on the differential evolution algorithm (DE\_LEACH). It uses the simple and fast search features of the DE algorithm to optimize multiple objectives for the selection process of CHs to improve energy efficiency and stability. Important feature of DE\_LEACH was to prevent blind nodes. The proposed algorithm works in the phases namely as coding, initial swarm formation, variation, cross over and selection process. The solution vector is represented as  $X = (x_1, x_2, \dots, x_n)$ . In the initial phase swarm is created based upon the ID's of the nodes as

$ID_1 < ID_2 < \dots < ID_n$ . A common binomial cross over is selected to add variety in the solution by generating random integer between  $[0,1]$ . Based upon these values the objective function is defined as follows:

$$Objective = \frac{1}{n} \sum_{j=1}^n (\alpha E_j + \beta \bar{E}_j), \alpha + \beta = 1$$

where  $E_j$  is the energy of the  $j$ th node and  $\bar{E}_j$  is the average energy of node except  $j$ .

Based upon the above, an optimized CH selection algorithm is presented by the authors.

The performance of the proposed DE\_LEACH algorithm was better than the other existing algorithms with respect to various parameters such as energy consumption, number of nodes alive and energy consumed.

Torkzaban et al. (2009) have proposed a new routing algorithm which is based on ID and called as Identification Based LEACH (ID-LEACH). This protocol assigns a unique ID with binary number to each SN. By using this ID, BS can send data to the special node on a single path for unicast or geocast transfer. The evaluations show that ID-LEACH has high energy efficiency and can improve the network lifetime. Using the identification of the nodes, a tree structure is constructed in which a binary number is assigned to each SN with two parameters as distance and degree. Each node sends its distance and degree to its father in the hierarchical structure. This information is sent to BS using the CH in which case BS multiply the maximum distance and degree. Each node saves its degree and distance. The performance of the proposed scheme was found better than the other existing schemes.

Guo et al. (2010) have proposed LEACH-Ensuring Reliable Data Delivery (LEACH-ER) protocol which is based upon the election of CH with the objective of energy efficiency and data reliability. This protocol has worked on the concept that the major energy consumption in WSNs is due to packet reception. The energy consumption for computation is relatively small and can be ignored. LEACH-ER assumed that BS maintains a list of CHs based on the energy and there is no problem of energy at the BS so it can be used for the selection of CHs. The proposed method decreases the number of packet reception between CH and CMs within cluster, which reduce energy consumption of the network and prolong the lifetime of the network. Higher data reliability is achieved by introducing differentiated services method for data transmission. Authors have introduced a format for the list of sink nodes as follows:

| Pointer | ID | Energy level (ENG) | FLAG |
|---------|----|--------------------|------|
|---------|----|--------------------|------|

Where pointer points to the next node in the network, ID indicates the identification of the nodes in the network, ENG specifies the energy level of the nodes in the network and FLAG specifies whether the node will act as CH in the current round or not. According to the values of ENG field and change of CH within the cluster, the BS determines the selection and maintenance of the CH in the network.

Junping et al. (2008) have presented a Time-based Cluster-Head Selection Algorithm for LEACH (TB-LEACH). In TB-LEACH protocol, the selection of the CH is not dependent on the random number generated but on the time interval. Selection of CH is done based upon the shortest time interval. A random timer is used to form constant number of clusters which do not require any global information. In the beginning, each node produces a random timer. Before the expiry of the time interval, if the number is less than the advertisement message, node broadcast its CH status by using the non persistent CSMA MAC protocol otherwise it will not become CH in near future. Results obtained show that the TB-LEACH provides better energy efficiency and the longer network lifetime than LEACH.

Handy et al. (2002) have modified LEACH protocol with respect to the criterion for selection of a CH (LEACH\_CH\_Selection). Only local information has been used for the selection of CH. Each SN determines whether it can become CH or not based upon three important metrics as First Node Dies (FND), HNA, and Last Node Dies (LND). Authors have modified the threshold level (thr) of the nodes to become a CH in deterministic manner as:

$$thr = \frac{p}{1 - p \left( r \bmod \frac{1}{p} \right)} \frac{E_{current}}{E_{init}},$$

where  $E_{current}$  is the current energy of the nodes,  $E_{init}$  is the initial energy of the nodes,  $p$  is the CH probability and  $r$  is the number of rounds. The simulation results obtained show that the threshold defined for CH reduces the energy consumption by 30% for FND and 20% for HNA. But as the threshold is set up to low value after finite number of steps network may be jammed, so to overcome this problem the threshold defined above can be modified as follows:

$$thr = \frac{p}{1 - p \left( r \bmod \frac{1}{p} \right)} \frac{E_{current}}{E_{init}} + \left( r_s \bmod \frac{1}{p} \right) \left( 1 - \frac{E_{current}}{E_{init}} \right)$$

where  $r_s$  are the number of consecutive rounds in which node does not become CH. Simulation results show that the proposed scheme is better than the existing schemes of its category.

#### 2.1.4. Optimal CH calculation

In this section, we will describe the various proposals for optimal CHs calculation. Ngo et al. (2007) have proposed the Message Passing algorithm (MEPA) which is an energy-efficient distributed clustering protocol using simple and local message-passing rules. MEPA combines both node residual energy and network topology features to elect a near-optimal set of CHs. The authors have introduced the concept of normalized residual energy of the node which is the ratio of the node residual energy and the sum of residual energy of the neighboring nodes and defined as follows:

$$p_i = \frac{re_j}{\sum_{j \in N(i)} re_j}$$

where  $re_j$  is the residual energy of the node  $j$  and  $N(i)$  is the set of neighboring nodes of  $i$  and  $p_i$  is the normalized preference of node  $i$ . The request message sent from node  $i$  to select node  $j$  as its CH can be formulated as:

$$request_i(j) = p_i(j) - \max(p_i(j') + res_i(j')),$$

where  $j'$  is the neighboring CH.

Similarly, response message from CH to node can be formulated as follows:

$$response_i(j) = \min \left( 0, req_i(j) + \sum_{j' \in N(j) \setminus i} \max(0, req_i(j')) \right)$$

The CH for a particular node  $i$  can be decided by the following:

$$CH_i = \arg \max(res_i(j) + p_i(j))$$

The performance of MEPA was found better than HEED with respect to the parameters such as nodes alive and residual energy in the network.

Yang et al. (2010) proposed an Optimal Energy Consumption Model (OECM) in which optimal number of CHs are affected by number of SNs, radius of the network and other parameters like packet length, circuit energy dissipation etc. The proposed scheme is different from the LEACH protocol in which numbers of clusters are same if numbers of nodes are constant. If  $n$  is the number of SNs,  $k$  is the number of rounds of CHs and  $E_i$  is the total energy consumed in each cluster in each round then the total

energy consumed in each round can be formulated as follows:

$$E_{total} = E_1 + mE_2 + \beta mE_3$$

where  $m$  is the data collection time when nodes are in the working stage,  $\beta$  is the ratio of cluster maintenance time to the data collection time.  $E_1$ ,  $E_2$  and  $E_3$  are described as the energy consumed in the clustering, working and maintenance phase. Using this model, authors have derived a relationship between optimal number of CHs and their dependence on various other factors such as number of rounds  $n$ , radius and energy disseminated for the circuitry.

Wang et al. (2010) have proposed Based Energy Clustering (BEC) protocol. BEC provides the optimal number of CHs in a network. The proposed BEC protocol was different from the existing LEACH protocol in the method of selection of CH and criteria for selection of CHs.

The number of CHs and threshold are determined as follows in the proposed BEC protocol

$$n = \frac{\sqrt{27} \times M}{2 \times r^2 \times \pi^2}$$

where  $M$  is the area of monitoring,  $r$  is the radius of the nodes and  $n$  is the number of CHs.

$$thr = \frac{E_i n}{E_{total}}$$

where  $E_i$  is the residual energy of the nodes and  $thr$  is the threshold used for the nodes to act as a CH and  $E_{total}$  is the total energy of the nodes. The performance of the proposed BEC was found better than LEACH.

#### 2.1.5. Prolonging of lifetime of network

If the energy consumption of SNs gets reduced then the life of individual SN would also be increased which results an increase in the overall lifetime of WSNs. Following are the key protocols of this category:

Sen et al. (2011) have proposed Improved Energy-Efficient PEGASIS-Based Protocol (IEEPB). The main aim of the IEEPB was to improve the deficiencies of PEGASIS and Energy Efficient PEGASIS-Based Protocol (EEPB). IEEPB used a different method to build the chain which simplifies the chain construction process and avoids the formation of Long Link (LL). Operation of this protocol is divided in several phases starting with the chain construction phase. In chain construction phase, it initializes all network parameters and then tries to find the distance between SNs and BS as follows:

$$D_{BS} = \frac{D_{to\_BS}^4}{D_{avg}^4}$$

where  $D_{avg}$  is the average distance between SN and BS, and  $D_{to\_BS}$  is the distance to the BS.

BS broadcast a hello message to all SNs. SNs those are farthest from the BS are having weak signal strength and called as the node 1. These nodes are responsible for starting the chain and having the information about the distance between themselves and other nodes which have not joined the chain. Those nodes are called as node 2 which are waiting to join the chain. Node 2 works as the end node and repeat the same steps performed by node 1. In this way, a more reliable chain is completed.

The energy portion is calculated as follows:

$$E_p = \frac{E_{init}}{E_i},$$

where  $E_{init}$  is the initial energy of the node and  $E_i$  is the residual energy of the node for round  $n$ . The combined weight  $W_i$  for each



node can be computed as follows:

$$W_i = w_1 E_p + w_2 D_{BS}, \text{ where } w_1 + w_2 = 1$$

In the second step, IEEPB selects the head using weighting method as defined above which considers both the residual energy of SNs and the distance from the BS. IEEPB selects the new head according to the combined weight in each round. It calculates the distance parameter using multiple model and energy portion using residual energy of SNs and finally both the factors are combined with their respective weights. The performance of IEEPB was found better than EEPB protocol.

Duan et al. (2009) have proposed Regional Partitioned Clustering Routing Algorithm (RPCR). The proposed scheme uses two steps namely as initialization and partitioning. Based upon this concept, authors have proposed an energy efficient regional partitioned clustering routing algorithm. With the help of timing mechanism, the SN nearest to the region center is selected as the CH and other non-CH nodes in the region become the CMs. Each CH node maintains a CM list and when a round is finished, it selects the CM with the highest energy as the new CH for the next round. The clusters are distributed evenly in the network and the numbers of clusters are nearly uniform, which effectively improve the performance of the network. Authors have given a mathematical formula for optimum number of CHs within a distance which are calculated as follows.

Let  $N$  nodes are distributed in a region of  $2a \times 2a$  with BS at the center. Number of nodes in every cluster is  $N/(k-1)$ , where  $k$  is the number of regions. Then the distance from CH to BS is computed as  $D(d_{CH}^2) = (2a^2/3k)$ . Average square distance from nodes using the fading model to BS is:  $D(d_{BS}^2) = (d^2/2)$ . In the free space model the distance between member node and CH is less than  $d$  and ratio can be defined as  $R = (\pi d^2/4a^2)$ .

The average quartic distance between other nodes to BS is computed as follows:

$$R = \frac{\pi d^2}{4a^2} = \frac{1}{4a^2 - \pi d^2} \left( \frac{112a^6}{45} - \frac{\pi d^2}{3} \right)$$

Authors have derived a formula for optimal number of CH in a region which is as follows:

$$\left[ \frac{3RE(d_{BS}^2)}{2a^2N} - \frac{3(E_{elec} + E_{BF})}{2\epsilon f a^2N} + \frac{3\epsilon(1-R)E(d_{BS}^4)}{2\epsilon f a^2N} \right]$$

where  $E_{BF}$  is the energy consumed when a bit data is beam formed and  $\epsilon f$  is the small quantity called as transmitter amplifier parameter and  $E_{elec}$  is the energy consumed in running the transmitter or receiver circuitry. The above equation gives the optimal number of CHs in the partitioned regions of the network.

Peng and Edwards (2010) have proposed K-Means Minimum Mean Distance Algorithm (KMMDA) for WSNs. It minimizes the energy consumption by selecting the CHs based on the minimum mean distance between SNs. Important features of KMMDA are energy saving, optimal CH selection and increase in the overall lifetime of the network. There are always five CHs during each round in the network. Following are the phases of the CH election in the proposed algorithm: advertisement, cluster setup, transmission scheduling and data transmission phase. The performance of KMMDA was found better than LEACH with respect to the metrics such as overall network lifetime, number of dead and alive nodes, and energy consumption.

Smaragdakis et al. (2004) have proposed Stable Election Protocol (SEP) which is based upon the heterogeneity of SNs. SEP computes the weighted election probabilities of each SN to become CH according to the remaining energy of each SN. Features of SEP were that it does not require any global knowledge of energy at every election round. Further SEP is dynamic so

it does not assume any prior distribution of the different levels of energy in SNs. Finally SEP is scalable as it does not require any knowledge of the exact position of each node in the field of deployment of nodes. SEP used the radio energy model same as of LEACH protocol (Wendi Rabiner et al., 2000) but proposed new modified equations for energy consumption as follows.

Energy used in the CH during a particular round is given by

$$E = L.E_{elect} \left( \frac{n}{k} - 1 \right) + L.E_{DA} \frac{n}{k} + L.E_{elect} + L\epsilon f_s d_{BS}^2$$

where  $k$  is the number of clusters,  $E_{elect}$  is the energy consumed per bit to run the transmitter or receiver circuitry,  $E_{DA}$  is the processing cost per bit,  $d_{BS}$  is the distance between CH and BS,  $L$  is the length of the message to be sent, and  $\epsilon f_s$  is the variable dependent upon the transmitter amplifier.

Total energy used in the network is computed as

$$E_{tot} = L \left( 2nE_{elect} + nE_{DA} + \epsilon f_s \left( kd_{BS}^2 + n \frac{A^2}{2\pi k} \right) \right)$$

where  $A$  is the area under consideration and  $n$  is the total number of nodes in the network.

By differentiating the above equation and then equating to zero, we can get the optimal number of CHs as

$$k_{opt} = \frac{2}{0.765} \sqrt{\frac{n}{2\pi}}$$

Hence the optimal probability of a node to become CH is computed as

$$P_{opt} = \frac{k_{opt}}{n}$$

The performance of the proposed SEP was found better than LEACH with respect to the metrics such as energy conservation and overall throughput of the network.

Lan et al. (2009) have proposed Energy Balanced Clustering (EBC) routing protocol. Major contribution of EBC was to use the signal intensity to control the distance between SNs which are in the same cluster. The nodes with more remaining energy are selected as the CH. The proposed scheme consists of CH election and CMs enrollment. After the initialization process, each SN broadcast its ID and residual energy to all the nodes in the network. Only one node is allowed to broadcast in a particular time interval to avoid collisions. Every node compares its residual energy with the other nodes in the network and if the residual energy of a particular node is large than the other nodes then it is elected as CH. The node broadcast its current status to all the other nodes in its vicinity and those nodes join the CH which has highest signal strength among all CHs. Once the decision about the selection of CH is done then the communication among the nodes proceeds in which each node is allowed to transmit in its own schedule. The information retrieved by the CH is filtered and sent to the BS for further processing.

Watfa et al. (2009) have proposed Battery Aware Reliable Clustering (BARC) protocol. This protocol uses trust factor and battery recovery scheme for the selection of CH which makes the network more reliable. In the proposed scheme, each node maintains three parameters belief, disbelief and uncertainty such that  $B + D + U = 1$ , where  $B$  is the belief,  $D$  is the disbelief and  $U$  is the uncertainty. An opinion value is computed based upon the events of the neighboring nodes as

$$B = \frac{p}{p+n+2}, \quad D = \frac{n}{p+n+2}, \quad U = \frac{2}{p+n+2}$$

where  $p$  and  $n$  are positive and negative events of the nodes about the other nodes of the network. If the message transmission between the nodes is successful then the trust value is increased by one else it is decreased by one. Each node decides its belief to

be part of a particular CH if the value of belief is greater than 0.5. On the other hand if disbelief is larger than 0.5 then it will not choose the particular node as its CH. Lastly if the uncertainty is larger than 0.5 then it will ask its neighbors to provide the information about the trust of the other nodes in the network. The performance of the proposed scheme was found better than the LEACH protocol with respect to the metrics such as % of nodes alive, load balancing, and lifetime of the network.

Farooq et al. (2010) have proposed Multi-hop Routing with Low Energy Adaptive Clustering Hierarchy (MR-LEACH) protocol. It partitions the network into different layers of clusters. MR-LEACH introduced the concept of equal clustering, i.e., any node in the given layer will reach the BS in equal number of hops. Major contributions of MR-LEACH were to reduce the average distance of each CH from its upper level CH so that in reaching the BS, the energy consumption is distributed among different CHs which results in longer network lifetime. Selection of CHs at second and other subsequent levels is made by the BS so that the computational cost at SNs level can be reduced.

It works in the following three phases: cluster formation at the lowest level, cluster discovery at different levels by BS and scheduling. In the cluster formation at the lowest level, each node broadcast the HELLO message to its neighboring nodes within the transmission range. Each node maintains the table about the node ID, residual energy and current status. If a particular node has highest residual energy than all its neighboring nodes then it will elect itself as CH. In the second phase, BS locates the CH using the broadcast message. BS broadcasts its id to all the CHs which are one hop away from it and in reply the CHs also send their id and layer on which they are operating. After CH formation, a TDMA schedule is performed for sending the data to CH to BS. The performance of the proposed MR-LEACH was found better than LEACH with respect to the metrics such as energy consumption and network lifetime.

Abdulsalam and Kamel (2010) have proposed the Weighted Low Energy Adaptive Hierarchy (W-LEACH) algorithm for data streams of WSNs. The most important feature of W-LEACH was that it can handle non-uniform as well as uniform networks, without affecting the network lifetime. In W-LEACH protocol, CHs are selected on the basis of sensor weights. Sensor weights are based on the sensor densities and their remaining energy. Density of SNs can be defined as the number of alive sensors in a particular region to the total number of alive sensors in the network. Weight and density for each sensor can be formulated based upon the following:

- More the density, more is the weight.
- More the residual energy, more is the weight.
- If no sensor node are found within the range then density is set to 1.
- If all the sensors are located within the transmission range then density is set to  $n$ .

The weight function that satisfies the above condition can be defined as follows:

$$W_i = \begin{cases} re_i(d_i, d_i) > d_{thr} \\ d_i, \text{ else} \end{cases}$$

where  $d_i = (1 + n(r))/(n)$ ,  $n(r)$  is the number of SNs in region  $r$ .  $d_{thr}$  is the threshold defined for the SNs in a very low density area.

In the starting phase, all the SNs are assumed to have equal energy. In each round, the densities of the sensors are calculated and respective weights are computed with maximum number of  $p\%$  of  $n$  sensors with high weights are selected to be CHs.

Sensors whose density is less than the predefined threshold are selected to send the data to CH than the sensors which have more density in the network otherwise they will wait till the beginning

of the next round for data transmission to respective CHs. The performance of the proposed scheme is evaluated based upon the parameters such as network lifetime, first and last node dies, and remaining energy. The results obtained show that W-LEACH is better than LEACH with respect to the parameters such as first node dies, last node dies, average lifetime for sensors, network remaining energy, and number of nodes alive in network.

Lai et al. (2012) have proposed Arranging Cluster Sizes and Transmission Ranges (ACT) for WSNs. Objective of ACT protocol was to reduce the size of clusters near the BS because CHs closer to the BS need to relay more data. Further it allows every CH to consume same amount of energy so that the CHs near the BS do not exhaust their power quickly. The proposed scheme uses the multihop communication to reduce the energy dissipation of CHs which are farthest from the BS whereas the CHs around the BS undertake larger relaying loads and exhaust their energy more quickly. In ACT protocol the network topology and energy consumption are used to calculate a cluster radius to balance the energy dissipation of each CH while prolonging the network lifetime.

ACT consists of the cluster formation phase, data forwarding phase and cluster maintenance phases. In cluster formation phase, BS divides the network topology into  $i$  levels and then radius of each cluster is computed as follows:

$$E_{Tx}(k, d) = k(E_{elect} + \epsilon_{amp}d^2)$$

where  $k$  bits of data to be transmitted at distance  $d$ ,  $E_{Tx}$  is the transmission energy of the nodes,  $\epsilon_{amp}$  is the energy consumed by the transceiver for transmission of one-bit of data through amplifier, and  $E_{elect}$  is the energy used in the SN (Wendi Rabiner et al., 2000).

Total energy consumed at the  $K$  the level is

$$E_k = (r_k^2 \pi d_n) [E_{elect} + \epsilon_{amp}(r_k + r_{k-1})^2]$$

where  $r$  is the transmission range of and  $d_n$  is the density of the sensor nodes in a region (Fig. 6).

In the second phase, cluster set up phase is executed in which the elected CH broadcasts a CH message that contains the information about the current energy level, the distance between the CH and BS, and the sensor node's ID. After this CH-to-CH routing path information is computed using the following equations:

$$N_i = \begin{cases} [N - (2i - 1)] \times r_1 & \text{if } N \text{ is odd} \\ 2[(i - (\frac{N}{2} + 1))]r_1 & \end{cases}$$

$$N_i = \begin{cases} [N - (2i - 1)]r_1 & \text{if } N \text{ is even} \\ 2[(i - \frac{N}{2}) - 1]r_1 & \end{cases}$$

where  $N_i$  is the vertical distance of node  $i$ , i.e., center of node  $i$  and BS,  $N$  is the number of nodes and  $r_1, r_2, \dots, r_n$  are the first, second,  $n$ th level cluster radius respectively.

In the next step, inter and intra-cluster data forwarding approach is applied for transferring of data to the BS. Finally cluster

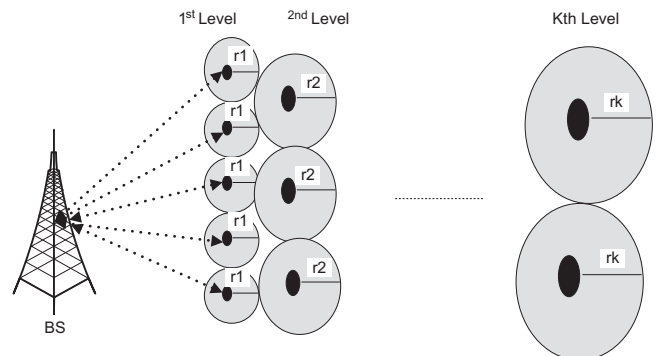


Fig. 6. Different levels of CH arrangement in ACT protocol (Lai et al., 2012).

maintenance phase is evaluated by varying different parameters such as direction of rotation of CH etc.

It was observed in the proposed scheme that ACT can efficiently reduce the energy consumption of CHs around the BS and increased the lifetime of the network of the network by more than 15%–20% in comparison to LEACH and Multi-hop routing with Low Energy Adaptive Clustering Hierarchy (MR-LEACH).

Jun et al. (2011) have proposed LEACH-Selective Cluster (LEACH-SC) protocol. This protocol was the modified version of LEACH in terms of distance based clustering. Distance based CH selection criterion was used in this protocol. In LEACH-SC, a particular SN can select CH, which is closest to the center point between that particular SN and the BS. The main focus of LEACH-SC was to decrease the communication cost of SNs and to increase the energy of the system. Following assumptions were made for LEACH-SC protocol:

- BS is located near to the WSN field.
- All SNs are position aware by any means.

Based upon the above assumptions, the operations of LEACH-SC are as described below

- Election of CH is same as that of LEACH.
- Elected CHs transmit their ID and local position to the Nearest CHs (NCHs).
- Based upon communication range, NCH records the information transmitted by CH.
- NCH find the respective CH which is nearest to the middle point distance between NCH and BS.
- NCH will join with that CH and now become the CM for respective CH.

Distance is calculated from node to sink, CH to sink and from node to CH. The performance of the proposed LEACH-SC was found better than the LEACH with respect to the energy consumption and system lifetime.

Hong et al. (2009) have proposed Threshold-LEACH (T-LEACH) which is a threshold-based CH replacement scheme for clustering in WSNs. Most of the earlier protocols do not have considered the energy-efficient duration of CHs replacement. It was found that frequent CH selection and replacement may unnecessarily dissipate limited battery power of the entire WSNs. T-LEACH utilizes the concept of threshold of residual energy for replacement of CH. The member nodes communicate with the CH which sends the data to BS after aggregating the same. As the number of CHs is less therefore direct communication between CHs and BS is also less energy consumption which results an increase in the life time of WSNs. The performance of T-LEACH was found better than LEACH with respect to the network lifetime and energy conservation.

Liu et al. (2012) have proposed Distributed Energy-Efficient Clustering with Improved Coverage (DEECIC). The main focus of the proposal was to save energy consumption of the clusters and to overcome the node failure. In this proposal, clustering is performed with the least number of CHs to cover the whole network and assigning a unique ID to each SN based on the local information. This protocol works on the residual energy and distribution of SNs and does not require any synchronization or geographical information of the nodes. The protocol consists of cluster formation and CH migration phases. In the cluster formation phase, each node broadcast its degree message randomly between the time interval  $T_{\max}$  and  $T_{\max+k}$  where  $k$  is the delay.  $k = \alpha e^{1/d}$ , where  $\alpha$  is a constant and  $d$  is the degree of the nodes in the network.

The node waits for the message to be received from the other nodes till the time expires. If no message is received from the other nodes and node degree is larger than its own then it will declare itself as CH. The node with larger node degree among its neighbors

is more likely to become CH. Once the node is elected as CH then it will start sending the messages to its neighbors.

In the cluster head migration phase, each 2-hop nodes ( $H2$ ) transmit the data to 1-hop ( $H1$ ) nodes which transmit the same to CH. So the energy consumption during this process can be computed as follows:

$$E_{H2} = lE_{elect} + l \in f_s + D^2(H2, H1)$$

$$E_{H1} = (lE_{elect}C(H1) + lE_{DA}C(H2) + 1)$$

where  $D$  is the distance between 2-hop and 1-hop neighbors and rest of the parameters are same as that of LEACH. The performance of the proposed DEECIC was found better than the other existing schemes of its category.

Wang et al. (2009) have proposed Hybrid Cluster Head Selection LEACH (LEACH-H) protocol. In the first round of this protocol, the BS selects a CH set through Simulated Annealing Algorithm and then for next rounds the CHs select new CHs in their own cluster. This will solve the problem that the CHs are unevenly distributed in LEACH, and also maintain the characteristics of distribution. The energy consumption of the network is cut down and the life of WSN is extended in LEACH-H.

If  $C$  represent the current CH set and  $C'$  represent the new CH set then the probability of selection of CH can be defined as follows:

$$P = \begin{cases} e^{-\frac{f(C')-f(C)}{\alpha_k}}, & f(C') \geq f(C) \\ 1, & f(C') \leq f(C) \end{cases}$$

where  $f(C)$  is defined as follows:

$$f(C) = \sum_{i=1}^n \text{mind}^2(i, C)$$

where  $d(i, C)$  is the distance between  $i$  and  $C$ ,  $\alpha_k$  is a control parameter.  $f(C')$  is the energy consumption of the network whose CH set is  $C'$ . The second phase is the reconstruction phase in which the node which has participated in election of CH should be closer to the CH in the current round. The performance of the LEACH-H was better than LEACH.

Kumar et al. (2009) have proposed LEACH-Mobile-Enhanced Protocol (LEACH-ME). The Cluster based protocols like LEACH are best suited for routing in WSNs. But in mobility centric environments, some improvements are required in LEACH. In mobility centric areas, all the SNs are moving; therefore it is better to elect a SN as CH which is having less mobility related to its neighbors. Authors have modified LEACH-M protocol based on the mobility metric for CH election. This provides high success rate in data transfer between the CH and the BS even though nodes are moving.

Authors have introduced the concept of mobility factor based upon the transition count. Transition counts are the number of times nodes move from one cluster to another. If the node moves such that its speed and angular position from the current state cannot be predictable, its remoteness value changes. The relative mobility is measured in terms of remoteness of a node as follows:

$$M(t) = \frac{1}{N-1} \sum_{j=0}^{N-1} |d_{ij}(t)|$$

where  $d_{ij}$  is the distance between the nodes and each node communicates with CH using the given TDMA schedule and  $N$  is the number of nodes in the network. The performance of LEACH-ME was found better than the LEACH with respect to the energy consumption.

Xunbo et al. (2010) have proposed LEACH\_Sin protocol. Authors found the problem of the asymmetrical distribution of the CHs in LEACH. For the selection of CH two parameters are used: one is relative distance from the BS and the second one is running round

number as the adjustment function. By doing this the distribution of CH is symmetrical and the parameter FND has the improvement of 14%. All the SNs in the network have equal chances to be the CH to balance the energy consumption.

Alizadeh and Ali (2010) have proposed a Hierarchical Clustering (HC) method for energy conservation. In the proposed technique, first the network divides the SNs to small size clusters and determines a CH for each group of nodes in the network. Multi-level clustering is also used in which the first level CHs are selected by giving the fitness value based on the residual energy, distance from the BS and random number assigned from 0 to 1. Then CMs of first level clusters move into the sleep mode and now all CHs of first level become the SNs and select the CH for second level by same concept as used in first level. Re-clustering is required when first level nodes residual energy reaches to 5% of its initial energy.

Authors have computed the optimal probability of the nodes to become the CH as follows:

$$p = \left[ \frac{1}{3c} + \frac{3\sqrt{2}}{3c(2+27c^2+3\sqrt{3c}\sqrt{27c^2+4})^{1/3}} + \frac{(2+27c^2+3\sqrt{3c}\sqrt{27c^2+4})^{1/3}}{3c} \frac{1}{3\sqrt{2}} \right]$$

where  $c = 3.069\sqrt{\lambda}$ ,  $\lambda$  is the arrival rate.

Hosseinalipour et al. (2010) have proposed New Hierarchical Routing (NHR) for LEACH protocol's CH selection process with the consideration of remaining energy and distance of other nodes.

Authors have computed the average distance from each other in the same cluster as follows:

$$D = \sum_{i=1}^n d_i / n,$$

where  $(\sum_{i=1}^n d_i)$  is the sum of distance of the nodes from each other within the same cluster. The probability of becoming the CH is computed as follows:

$$P = E_{rem} / D,$$

where  $E_{rem}$  is the remaining energy of the nodes in the network.

The results obtained shows that life time of the network is better in the proposed scheme in comparison to LEACH and SEP.

## 2.2. Multihop data transmission

For any cluster based routing protocol, formation of cluster is the part of setup phase. Once the cluster is formed then next step is the election of CH because CH is responsible for the data communication from CMs to BS. Location of BS plays an important role for the data transmission between CHs and the BS. If BS is located far away from the area of interest then the distance of BS from CHs will also be more and also as the distance is increased the transmission cost is also increased and the corresponding CH will die soon. This is the situation of single hop data transmission, so the interesting remedy of the situation is multihop data transmission between CHs and BS. Multihop transmission can use parallel transmission to reduce the delay and improve energy consumption. This section discuss various issues with respect to multihop data transmission in WSNs. Figures 7 and 8 describes various multihop routing protocols with respect to various metrics in this category.

### 2.2.1. Reliability

Multihop data transmission plays an important role to increase the reliability of transmission as it reduces the occurrence of delay during data transmission. In this section, we will discuss several cluster based routing protocols which are suitable for reliable data communications and are described as follows.

Guo et al. (2010) have proposed LEACH-Ensuring the Reliable Data Delivery (LEACH-ER). The proposed scheme decreases the number of packet reception between CH and CMs within cluster, which reduce energy consumption of the network and prolong the lifetime of the network also. Higher data reliability is achieved

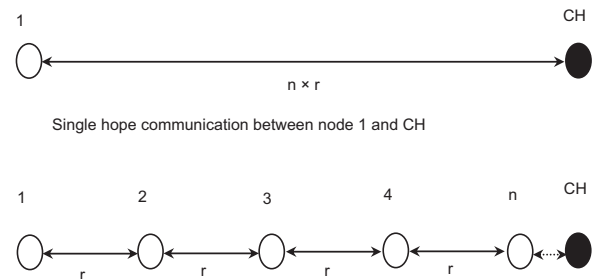


Fig. 8. Multihop communication between node 1 and CH.

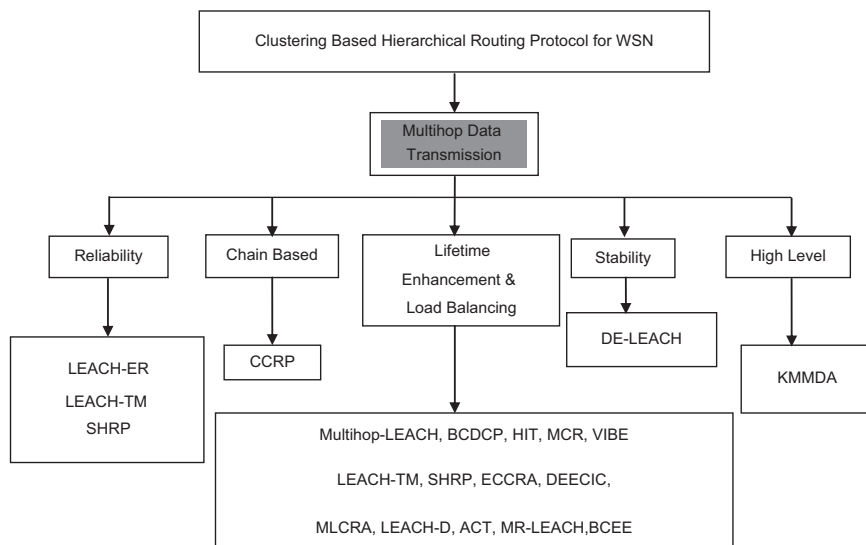


Fig. 7. Categorization of multihop data transmission for cluster based routing protocols.



by introducing differentiated services method for data transmission as discussed above.

Weichao et al. (2009) have proposed LEACH-Trust Transmission Mechanism (LEACH-TM). The authors have designed LEACH-TM protocol by using the concept of Trust designs in which CH establishes multi-path with the other CHs which are acting as routers. LEACH-TM has active trust transmission mechanism. Consideration of remaining energy, hop count and node trust make the algorithm more reliable for the data transmission through CHs to BS.

Authors have defined a new function which is used to select the nodes for CH election as follows:

$$E^{th} = E^{init}[1 - \theta^{n-r}],$$

where  $E^{init}$  is the initial energy of the nodes and  $E^{th}$  is the energy threshold for the nodes to become CH and  $0 < \theta < 1$  is the energy attenuation. Once the node is elected as a CH it broadcast the message to all the other nodes with its ID and remaining energy and finds the nearest CH by measuring the distance based upon the received signal strength as follows:

$$L = \mu \sqrt{\frac{1}{\pi j}} N$$

where  $\mu$  is an adjustment factor,  $N$  is the length of the side of the square area and  $j$  is the number of CHs.

Then the number of CHs which are close to the node can be computed as follows:

$$N^{CH} = w_1 \frac{E_{remaining}}{E_{init}} + w_2 \frac{T_{node}}{\sum T_{node}} + C_{ch}$$

where  $w_1, w_2 \in [0,1]$  are weight factors and  $E_{init}$  is the initial energy of the nodes,  $C_{ch}$  is the count that how many times a node is elected as CH,  $\sum T_{node}$  is the sum of the trust of all the nodes in the network. Based upon the trust computation as above, a multipath route establishment algorithm is proposed by the authors. The performance of the proposed algorithm was found better than LEACH with respect to energy consumption and number of nodes alive in the network.

Villalba et al. (2009) have proposed Simple Hierarchical Routing Protocol (SHRP). The main objective of SHARP was to prolong the network lifetime. It has considered three different metrics: battery availability, number of hops and link quality. The algorithm includes a load-balance technique so that the traffic is distributed among the possible routes. The SHRP protocol is concerned with topology maintenance which is related to the reliability of data delivery. It makes use of metrics like local battery availability and link quality between neighboring nodes in selecting the best route to the BS. Important advantage of the SHRP protocol is that it does not include those neighboring nodes in the routing table that have the Received Signal Strength Indicator (RSSI) values below a minimum threshold. SHRP uses metrics such as link quality indicator (LQI) and RSSI both in selecting the best route. The performance of SHRP was found better with respect to the metrics such as energy consumption and network lifetime.

### 2.2.2. Chain based data transmission

Bian et al. (2008) have proposed Cluster-Chain Routing Protocol (CCRP) which adopts a more balanced CH selection algorithm and an improved data transmission mechanism from the CHs to the BS as discussed in previous section.

### 2.2.3. Lifetime enhancement and load balancing

SNs are always having limited energy because they are powered with battery and it is difficult to recharge the battery of SNs because of their random deployment. Therefore life of SNs can be increased

by load balancing mechanism by use of Multihop data transmission between CHs and BS. In single hop data transmission, the distance between CH and BS is more so CH exhausts soon and die. But in multihop data transmission, distance is short therefore transmission cost is very low which results an increase in the life time of network. There are several protocol based on LEACH but they have used different algorithm for this category.

Xiangning and Song (2007) have proposed two modified protocols of LEACH as Energy-LEACH and Multihop-LEACH. Multihop-LEACH protocol improves communication mode from single hop to multi-hop between CH and BS as discussed above.

Muruganathan et al. (2005) have proposed a centralized routing protocol called as Base-Station Controlled Dynamic Clustering Protocol (BCDCP). The main aim of this protocol is to enhance the lifetime of the network. This protocol works in two modes as sensing and cluster head mode. In this protocol, BS plays an important role like formation of cluster, randomized CH selection, TDMA schedule creation and CH-to-CH routing path identification. SNs sense the assigned task and transmit the same to the CH in sensing mode while data gathering, fusion and transmission to the BS through CHs is performed in cluster head mode. SNs those are having energy greater than the average energy of the network are eligible for selection as CHs and clusters are formed by the BS using iterative cluster splitting algorithm. BCDCP distributes the energy dissipation evenly among all SNs to improve network lifetime and average energy savings. BCDCP reduces overall energy consumption and improves network lifetime over other protocols of its category.

Culpepper et al. (2004) have proposed Hybrid Indirect Transmission (HIT). HIT is based on a hybrid architecture that consists of one or more clusters, each of which is based on multiple, multihop indirect transmissions. In HIT protocol CMs transmit the data to the respective CH using multihop transmission.

Energy equations without fusion for single hop and multihop communication are as follows:

Equation for single hop communication is

$$(E_{elec}k + \varepsilon_{amp}k(nr)^2) + n(E_{elec}k)$$

Equation for multihop communication is

$$n(E_{elec}k + \varepsilon_{amp}kr^2) + n(E_{elec}k)$$

The operation of HIT protocol can be defined in the following phases:

*Cluster-Head Election Phase*—One or more CHs are elected in this phase.

*Cluster-Head Advertisement Phase*—In this phase, CHs broadcast their status to the network after election from the CH election phase.

*Cluster Setup Phase*—In this phase, CH and CMs relationship is formed.

*Blocking Set Computation Phase*—SN computes its blocking set here.

*Route Setup Phase*—CMs form multi-hop routes to the respective CH.

*TDMA Schedule Creation Phase*—In this phase, TDMA schedule is computed to allow for parallel transmissions.

*Data Transmission Phase*—It is like a steady-state phase of LEACH protocol where sensed data is sent to the BS.

HIT minimizes energy consumption and network delay by using the parallel transmissions among multiple clusters and within a cluster. This protocol uses the concept of chain used for intra-cluster communication and also it is fault tolerant towards the repairing of chain if required. Based on the performance metrics network longevity, network delay, average energy dissipation and

product of average delay with average energy dissipation it was found that HIT has reduced both energy consumption and network delay with three other existing protocols such as LEACH, PEGASIS and Direct Transmission. It also maintains longer network life compared to these three existing protocols.

Kumar et al. (2011) have proposed energy efficient multihop communication routing (MCR) that utilize the concept of both single hop as well as multihop as discussed above.

Papadopoulos et al. (2012) have proposed Virtual Infrastructure Based Energy-efficient (VIBE) routing. The objective of VIBE was to prolong the network lifetime by reducing the average energy utilized for each communication.

Weichao et al. (2009) have proposed LEACH-Trust Transmission Mechanism (LEACH-TM) as discussed above. Villalba et al. (2009) have proposed Simple Hierarchical Routing Protocol (SHRP) as discussed above.

Jin a et al. (2008) have proposed the Energy-Efficient Coverage and Connectivity Preserving Routing Algorithm (ECCRA). This protocol was developed to cover the specified circular shaped area with  $N$  SNs and then provide the guarantee of network connectivity based on the lower bound network connectivity probability. Authors assume that the SNs are distributed in a circle-shaped region uniformly. For the coverage of network, authors (Jin a et al., 2008) give the expected coverage of a node, when nodes with sensing range  $r_s$  are distributed uniformly in a circular shaped region including the borders effect

$$E[C] = \frac{1}{R^2} \left\{ \pi r_s^2 (R - r_s)^2 + 2 \int_{R-r_s}^R [r_s^2 (\beta - \sin \beta \cos \beta) + R^2 (\alpha - \sin \alpha \cos \alpha)] x dx \right\}$$

where  $R$  is the radius of circular shaped network region,  $E[C]$  is the expected coverage of the sensor node

$$\cos \beta = \frac{x^2 + r_s^2 + R^2}{2xr_s} \text{ and } \cos \alpha = \frac{x^2 - r_s^2 + R^2}{2xR}$$

Based on the expected coverage of the SN expected coverage ratio by  $N$  nodes is also provided in ECCRA which is

$$E[C_r^N] = 1 - \left( 1 - \frac{E[C]}{\pi R^2} \right)^2$$

Further for the network connectivity the lower bound of the network connectivity probability given by Jin is

$$P(C_p^N) > (1 - e^{-N r_t^2 / R^2})^w (1 - e^{-N [R^2 (\alpha - \sin \alpha) + \beta r_t^2] / \pi R^2})^{N-w}$$

where  $r_t$  is the radio range of the SN

$$w = N \left( 1 - \frac{r_t}{R} \right)^2, \cos \alpha = 1 - \frac{r_t}{2R^2} \text{ and } \cos \beta = \frac{r_t}{2R}$$

Similar to LEACH protocol it also has two phases for its operation. In the set-up phase, the CMs in any subset are formed to satisfy the connected, partial coverage requirement. In addition to this the minimal hop count routing path is also constructed by each SN. Then in the data transmission phase, each subset is scheduled periodically to reduce and balance the energy consumption of SNs. Based on algorithm delay, number of active nodes, network coverage ratio, packet delivery ratio and data transmission latency performance metrics, it is found that ECCRA is energy-efficient routing algorithm and achieves the required network coverage and sensor connectivity simultaneously.

Liu et al. (2012) have proposed Distributed Energy-Efficient Clustering with Improved Coverage (DEECIC). Objective of protocol was based on energy consumption of the clusters and the impact of node failures on coverage with different densities. Few other protocols such as the Multi Layer Clustering Routing Algorithm (MLCRA) (Liu et al., 2010), LEACH-Density of Distribution of Node (LEACH-D) (Liu et al., 2010), Arranging Cluster Sizes and Transmission Ranges (ACT) (Lai et al., 2012) and Multi-hop

Routing with Low Energy Adaptive Clustering Hierarchy (MR-LEACH) (Farooq et al., 2010) are also the part of this category.

Xiaoping et al. (2010) have proposed a mechanism for the election of CH for LEACH. For the enhancement of lifetime of the network, authors have used current energy for CH election and also used multihop routing as discussed above.

Cui and Liu (2009) have proposed Balanced Clustering Energy-Efficient (BCEE) hierarchical routing protocol. The main aim of BCEE protocol is to have load balancing and to enhance the life time of the network by reducing energy consumption. It operates in two phases: Cluster is formed in first phase, where RSSI and K-Means Clustering Strategy (KMDC) algorithms are used. RSSI is used for location identification of SNs. Route establishment is done in second phase and Ant Colony Optimization (ACO) algorithm is used for the same with optimal or sub-optimal power consumption between CHs and BS. The purpose of ACO algorithm was to have an effective multihop data transmission method to achieve reliable communications. Simulations show that 15% energy efficiency improvement is achieved by BCEE in comparison to LEACH.

#### 2.2.4. Stability

Li et al. (2010) have proposed an improved LEACH routing algorithm called as Differential Evolution-LEACH (DE-LEACH) which is based upon the differential evolution algorithm and provide stability as discussed above.

#### 2.2.5. High level data transmission

Peng and Edwards (2010) have proposed K-Means Minimum Mean Distance Algorithm (KMMDA) for WSNs. For the calculation of HNA it was found that KMMDA performs better in compared to LEACH as discussed above.

### 2.3. Heterogeneous networks

Most of the clustered protocols are supported by the homogeneous networks. Few protocols avoid this assumption that all SNs have equal energy. They have considered that some of the SNs having energy greater than the remaining one and this can enhance the lifetime of the network. In this section, we will describe the clustered protocols which support heterogeneity of the nodes. Figure 9 describes various routing protocols which are used for heterogeneous WSNs.

Derogarian et al. (2011) have proposed Source Routing for Minimum Cost Forwarding (SRMCF) protocol. It was focused on source based routing and minimum cost forwarding methods for heterogeneous WSNs. SRMCF contains neither routing tables nor network topology information at SN level but assume that it is essentially required at BS. The routing table on BS is formed in the network setup phase and updated after any change in network topology reported by SNs. Packets are always generated from the BS and it includes header and payload, where header includes pointer, offset and path three segments. Pointer determines the current position in the routing path and its value will be decremented by one when moves to the other node. Offset shows the length of path and is useful for the destination only. Path includes the ID of SNs those are present in the route. Two separate algorithms are developed for the route, one is from BS to SNs and second one is from SNs to BS. In both the situations, packets always follow the optimal communication path with minimum cost and header is different for both communication situations.

Liu et al. (2009) have proposed Energy Aware Routing Protocol (EAP) as discussed above. Senouci et al. (2012) have proposed Enhanced Hybrid Energy Efficient Distributed (EHEED) clustering

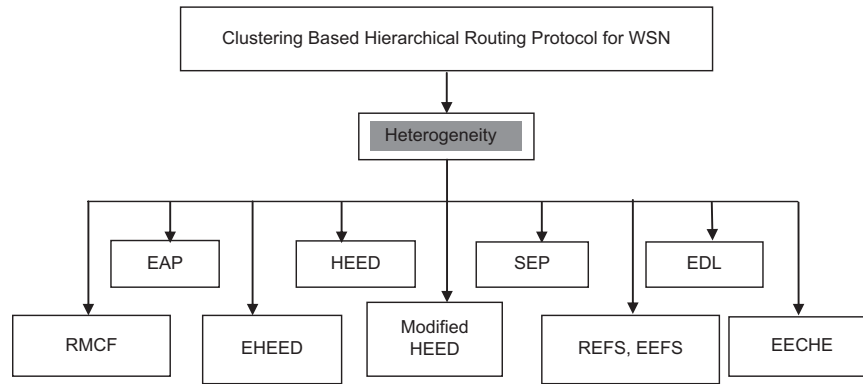


Fig. 9. Categorization of heterogeneous networks.

protocol. The objective of EHEED was to provide the good spatial-temporal distribution of lifetime.

Lin and Tsai (2006) have modified HEED protocol in terms of internetwork connectivity. According to HEED protocol (Younis and Fahmy 2004) two CHs communicate if  $R_t \geq 6R_c$ , where  $R_c$  is the cluster range and  $R_t$  is the transmission range. Lin suggested better and sufficient connectivity condition that two CHs communicate if  $R_t \approx 2.75R_c$ .

Younis and Fahmy (2004) have proposed a distributed clustering approach for long-lived ad hoc sensor networks called as Hybrid Energy-Efficient Distributed clustering (HEED). Assumptions made by the authors were quasi-stationary networks where nodes are location-unaware and have equal significance. Smaragdakis et al. (2004) have proposed Stable Election Protocol (SEP) as discussed above.

Shih et al. (2009) have proposed two schemes namely Remaining Energy First Scheme (REFS) and Energy Efficient First Scheme (EEFS). According to REFS, every SN considers its remaining energy and neighbors' decisions to enable its sensing units as well as to ensure every target being covered by the sensing attributes. While in EEFS, every SN have considered its sensing capabilities and remaining energy for making a better decision to turn on its sensing units. REFS and EEFS can prolong the network lifetime effectively.

Hou et al. (2009) have proposed Energy and Distance LEACH (EDL) by taking residual energy and distance of SNs as the key parameters as discussed above.

Kumar et al. (2009) have proposed Energy Efficient Cluster Head Election (EECHE) protocol used for heterogeneous WSNs. Authors have assumed that all the SNs are uniformly distributed and few SNs have extra energy. Authors used type-3 and type-2 nodes along with the type-1 nodes. The type-2 nodes are those nodes which are having  $\alpha$  times more energy than the type-1 nodes and type-3 nodes which are having  $\beta$  times more energy than the type-1 nodes.  $E_0$  is the initial energy of the type-1 nodes then energies of the type-3 and type-2 nodes are  $E_0(1+\beta)$  and  $E_0(1+\alpha)$  respectively.

The total initial energy of the network can be written as follows:

$$E = nE_0(1+mQ),$$

where  $Q = (\alpha - p(\alpha - \beta))$ ,  $m$  = number of type-2 nodes and  $p$  = number of type-3 nodes.

The weighted probability of nodes to become CH can be written as follows:

$$P_1 = \frac{P_{opt}}{1+mQ}$$

$$P_2 = \frac{P_{opt}}{1+mQ}(1+\alpha)$$

$$P_3 = \frac{P_{opt}}{1+mQ}(1+\beta)$$

Using the above equations, authors have derived an expression for threshold for type-1, type-2 and type-3 nodes. The performance of the proposed EECHE was found to be better than LEACH and SEP with respect to the metric number of nodes alive. It is found that EECHE extends the network lifetime and stability to prolong the time interval of FND.

#### 2.4. Chain based routing protocols

This category mainly focused on the construction of chain among the nodes for data transmission. Major advantages of chain based protocols are that they are having very good energy savings as one SN communicates with its two neighbors for making the chain for data fusion. Major problem with such type of protocols is of delay. Few algorithms are taking the advantage of LEACH and PEGASIS simultaneously and worked with the new metrics called as energy\_delay. In addition to this, three very important metrics FND, HNA and LNA are also discussed. These metrics are very useful for the calculation of lifetime of any network. In this session, we will describe different type of chain based routing protocols as shown in Fig. 10.

Samia and Refaay (2002) have proposed Chain-Chain Based Routing Protocol (CCBRP). Authors have focused on energy conservation of the SNs and the data delivery time from SNs to the BS and found that LEACH protocol consumes non negligible energy for periodical CH voting. Further PEGASIS has faced the challenge of long delay for data transmission. Chain-Cluster based Mixed routing (CCM) is the hybrid of LEACH and PEGASIS, but the major drawback of this protocol was that the consumption of energy increases as network size increases. CCBRP divides the WSN into chains and used the same algorithm as used in PEGASIS (Lindsey and Raghavendra, 2002a) and execute in two phases. In first phase SNs of every chain transmit data to the respective CHs in parallel and in the second phase, all CHs form a chain and select a head node randomly. Then all CHs send their data to the selected head node. Authors Samia and Refaay (2002) used energy  $\times$  delay, optimal number of chains and energy efficiency as the performance metrics and based on this they found that the proposed scheme achieves both minimum energy consumption and minimum delay.

Sen et al. (2011) have proposed Improved Energy-Efficient PEGASIS-Based Protocol (IEEPB) to improve the deficiencies of PEGASIS and Energy Efficient PEGASIS-Based Protocol (EEPB) as discussed above.

Lindsey and Raghavendra (2002a) have proposed Power-Efficient Gathering in Sensor Information Systems (PEGASIS). The proposed scheme was based upon the formation of optimal chain where each node communicates with a closest neighbor only. Chain is constructed based on the travelling sales man algorithm. The important features of PEGASIS were the reduction

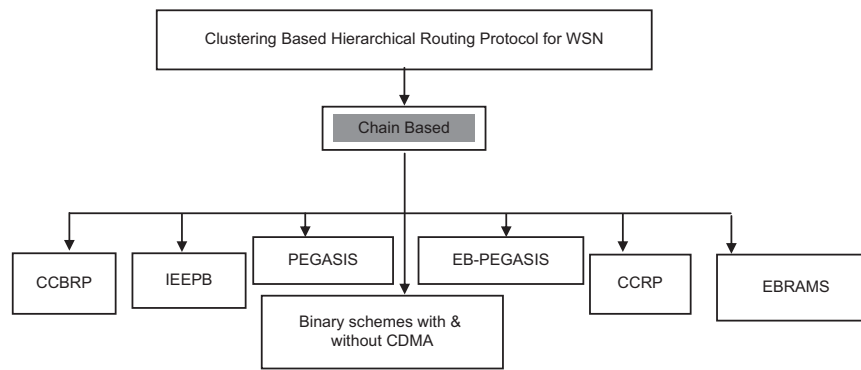


Fig. 10. Categorization of chain based routing protocols.

of amount of energy spent per round, eliminating the overhead of dynamic cluster formation, minimizing the distance between CH and SN, limiting the number of transmissions and receptions among all nodes. Nodes take turns to transmit the fused data to the BS to balance the energy depletion in the network and preserves robustness of SNs as nodes die at random locations. Major drawback of this protocol is timing delay in comparison to LEACH while as for as lifetime concern as the energy level doubles the number of rounds are also doubled for almost all cases like  $50 \times 50$ ,  $100 \times 100$  and  $200 \times 200$  network area.

Lindsey et al. (2002b) have proposed PEGASIS protocol which is, chain based, that minimizes the energy consumption in the network. In PEGASIS, each SN communicates only with the close neighbors and takes turns in transmitting to the BS, thus reducing the amount of energy spent per round. Nodes take turns to transmit the fused data to the BS to balance the energy depletion in the network and preserve the robustness of the SNs. The other protocols not only focused to reduce the energy but also consider delay for data gathering in WSNs. These are chain-based binary scheme for sensor networks with CDMA nodes and chain-based 3-level scheme for sensor networks with non-CDMA nodes. Out of these two schemes, binary scheme performs better than direct PEGASIS and LEACH. It performs better than LEACH by a factor of about 8 and about 10 times better than PEGASIS and more than 100 times better when compared to the direct scheme. The chain-based 3-level scheme with non-CDMA outperforms PEGASIS by a factor of 4 and is better than direct by a factor of 60.

Yueyang et al. (2006) have proposed EB-PEGASIS. This protocol is the advanced version of PEGASIS and it uses distance threshold due to which the lifetime of the network enhanced and achieve energy balancing. The PEGASIS was a chain-based algorithm in which sensors use the greedy algorithm to form a data chain but the problem of using greedy algorithm can result in communication distance between two sensors that are being too long. Therefore these sensors consume much more energy in transmitting data and die more early. EB-PEGASIS uses distance threshold to avoid the problem of long chain. Equation of average distance used in EB-PEGASIS is:  $d_{aver} = (\sum_{p=1}^h d_p) / (n)$  and distance threshold is  $d_{comp} = \alpha d_{aver}$ , where  $h$  is the hope number of formed chain,  $d_p$  is the distance of every segment of formed chain. Performance of EB-PEGASIS is evaluated on the different values of  $\alpha$  and it is found that distance threshold decreases by decreasing the value of  $\alpha$ . Optimum results of EB-PEGASIS was found when  $\alpha = 1$  and the performance of EB-PEGASIS is similar to PEGASIS when  $\alpha = 10$ . Therefore lifetime of network can be enhanced if  $\alpha < 10$ .

Bian et al. (2008) have proposed Cluster-Chain Routing Protocol (CCRCP) which adopts a more balanced CH selection algorithm and an improved data transmission mechanism from the CHs to the BS. Further the data transmission was improved by constructing a chain among all the CHs as discussed above.

Guan et al. (2012) have proposed Energy Balanced Routing Algorithm Based on Mobile BS (EBRAMS) for WSNs. This protocol is focused on minimization of energy dissipation and latency. It defines the collecting rows (CR) by the distance of concentric circular rings and the paralleling column (PC) by the difference of transmitting coordinates (TCs) of clusters. Similar to LEACH it also operates into two phases: clustering phase is used by the mobile BS to form the cluster further it use the greedy algorithm to construct the chain. Data transmission phase is used to transfer the data from SNs to mobile sink. In this phase parallel communication is used to decrease the delay and rotation of collecting row is utilized based on residual energy, transmit the data to the mobile sink. Based on transmission delay it is found that the performance of EBRAMS is better than PEGASIS and LEACH.

## 2.5. Other parameters based protocols

Figure 11 some of the other parameters based upon which selection of CH is made. The parameters and their associated protocols are described as below.

### 2.5.1. Mobility

Papadopoulos et al. (2012) have proposed Virtual Infrastructure Based Energy-efficient (VIBE) routing as discussed above.

Mobility based clustering protocol (MBC) (Deng et al., 2011) have been proposed which is well suited when SNs are mobile. In MBC protocol, selection criterion of CH is different from the classical LEACH protocol; here CH is selected based upon the residual energy and mobility. In the proposed scheme, threshold of MBC is changed which includes residual energy and mobility factor. The new threshold is

$$T(n) = \frac{p}{1-p \left( r \bmod \frac{1}{p} \right)} \left( \frac{E_{n\_current}}{E_{max}} \right) \left( \frac{V_{max} - V_{n\_current}}{V_{max}} \right)$$

where  $E_{n\_current}$  is the current energy,  $E_{max}$  is the initial energy,  $V_{n\_current}$  is the current speed and  $V_{max}$  maximum speed of the node. Key parameters of MBC were packet delivery rate, stable link connection, energy efficiency and lifetime of the network. Assumptions made for MBC protocol are listed below.

- Radio model is symmetric.
- All SNs in the network are homogenous.
- Each SN in the network knows its location and velocity.
- The BS is fixed.
- All SNs in the network are synchronised with time.
- Each SN can estimate the time for transmitting a packet.

MBC protocol was the advanced version of LEACH-M and CBR. MBC has considered the problems of LEACH-M and CBR related



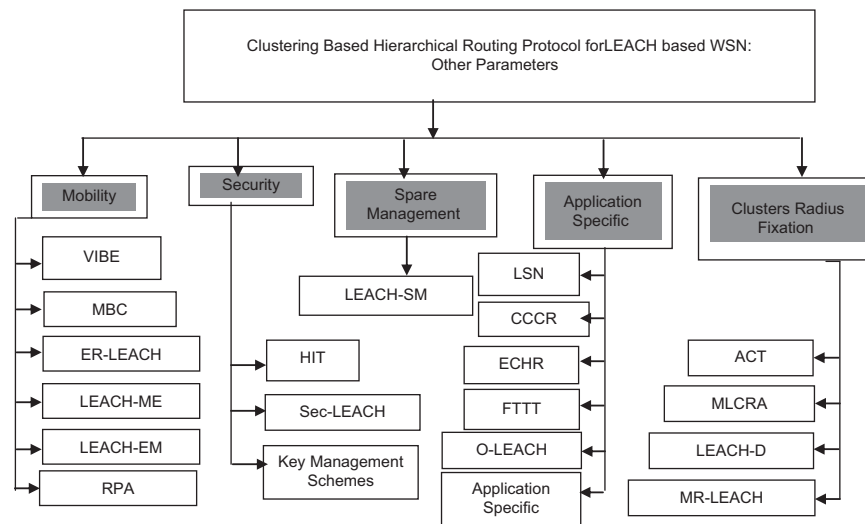


Fig. 11. Remaining parameters of cluster based routing protocols.

to energy consumption and overhead by taking the reliability of a path depending upon the stability of every link. Every CM is allocated a timeslot for data transmission. CM transmits its sensed data in its timeslot and broadcasts a fresh joint request message to join in a new cluster when it loses the connection with respective CH. SN joins appropriate CH and avoid more packet loss. Authors claim that for the highly mobile situation the MBC protocol can reduce the packet loss by 25% as compared with the CBR protocol and 50% as compared with LEACH-mobile protocol.

Al-Refai et al. (2011) have proposed Efficient Routing-LEACH (ER-LEACH). Authors have focused on the data as the interest of BS was to get the data from environment. So data can be aggregated by SNs rather than sending the original data to the BS as discussed above. Kumar et al. (2009) have proposed LEACH-Mobile-Enhanced Protocol (LEACH-ME). In mobility centric areas, all the SNs are moving and therefore it will be better to elect a SN as CH which is having less mobility related to its neighbors as discussed above.

Cheng et al. (2002) have proposed Event-driven data delivery and Mobile nodes based LEACH (LEACH-EM). Authors found that two factors can influence the performance of protocols WSN. First is the data delivery model which describes how the end user wants to access the data and second is network dynamics which include sensor mobility as well as changes in sensor data rates throughout the lifetime of the network. Therefore it is very important to match the protocol for a sensor network to a specific application. LEACH-EM allows LEACH to adapt to event-driven data delivery and mobile nodes.

Samdanis et al. (2009) have proposed a Re-Partition Algorithm (RPA) based on the reconfiguration mechanism. This algorithm provides both routing and mobility overhead and also focused on dropping and blocking rates to have better network performance.

### 2.5.2. Security

Culpepper et al. (2004) have proposed Hybrid Indirect Transmission (HIT) based on the hybrid architecture that consists of one or more clusters, each of which is based on multiple, multi-hop indirect transmissions as discussed above.

Oliveira et al. (2007) have proposed Security Based LEACH (SEC-LEACH). The proposed scheme has investigated the problem of adding security to hierarchical (cluster-based) SNs where clusters are formed dynamically and periodically like LEACH. The proposed scheme reduces the overhead incurred, memory

usage, and energy efficiency. Sec-LEACH preserves the structure of the original LEACH, including its ability to carry out data aggregation.

Zhang and Varadharajan (2010) have described taxonomy for various key management schemes for security management in WSNs. They have provided a complete list of various security mechanisms with respect to different metrics for WSNs.

### 2.5.3. Spare management

For the lifetime enhancement of the WSNs, Bakr and Lilien (2011) have modified LEACH protocol based on the spare management called as LEACH-Spare Management (LEACH-SM). Two major problems found by Bakr in LEACH were hot spot problem and redundant data. Due to these, there was extra burden on the CH in comparison to LEACH. Significant improvements in the Lifetime of WSNs can be achieved by making WSNs redundant with the addition of spare nodes. Spare nodes work just like as the passive nodes, i.e., switched off when not in used and will always ready as on when required. Objectives of scheme are listed below

- Prolonging the lifetime of WSN.
- Maintaining the above-threshold coverage.
- Reducing the transmission of redundant data to CHs.
- Allowing all SNs in all clusters to decide in parallel if they become actives or spares.
- Maintaining scalability by using local information only.

One additional phase known as spare selection phase is added to the LEACH. In this phase, each node in parallel decides if it is active or spare node to be worked in switched off mode. Important issue of this protocol was that spare nodes should be informed by any means prior to exhaust the active nodes in WSNs so that the task should be executing by means of spare nodes. Decentralized Energy-efficient Spare Selection Technique (DESST) is used for the spare selection in spare selection phase. DESST reduces the time duration of the active interval for CHs. Race conditions and deadlocks are two major problems of DESST which should be handled carefully by some special arrangements like tiebreakers and total ordering of SNs.

### 2.5.4. Application specific

Jawhar et al. (2011) have proposed Linear Sensor Network (LSN). The main objectives of LSN were to increase the

communication efficiency, reliability, fault tolerance, energy savings and network lifetime. LSN is suitable for both hierarchical as well as topological environment.

Tamboli and Younis (2010) have proposed the Coverage Conscious Connectivity Restoration (CCCR) algorithm and Energy-Centric optimized Recovery algorithm (ECR). Objective of CCCR algorithm was to maintain inter-sensor connectivity for the collection of data. This algorithm recovers the failure of SNs with the help of neighbor node or group of neighbors. Coverage and connectivity problem for the desired field are removed by C<sup>3</sup>R algorithm and this algorithm is further optimized in-terms of energy efficiency and named as ECR.

Jiang et al. (2011) have proposed Energy-Aware Coverage-Preserving Hierarchical Routing Protocol (ECHR). This protocol was suited for mission critical applications and for the situation in which losing any sensing data is not acceptable. ECHR algorithm is focused on energy efficiency and full coverage of network. Further ECHR has also considered the distance and residual energy of neighboring node while electing the energy efficient route for the nodes. Root node weight of each node  $n_i$  is given as

$$\alpha_i = (q_i)^{\tau_1} \left( \frac{\|O(s_i)\|}{\|C(s_i)\|} \right)^{\tau_2} \left( \frac{1}{d(s_i, BS)} \right)$$

where  $q_i$  is the residual energy of  $s_i$ ,  $d(s_i, BS)$  is the Euclidean distance between the BS and node  $s_i$  and  $\tau_1, \tau_2$  are the weighting coefficients for residual energy factor and coverage factor respectively.

Then ECHR estimate the path weight for the data transmission from a source node  $s_i$  to the destination node  $s_p$ , which is

$$\beta_{i,p} = \left( \frac{1}{d(s_i, s_p)} \right)^{\lambda_1} (q_p)^{\lambda_2}$$

where  $d(s_i, s_p)$  is the Euclidean distance between  $s_p$  and node  $s_i$ , and  $\lambda_1, \lambda_2$  are the weighing coefficient for distance factor and residual energy factor respectively. Major drawback of ECHR protocol is that it does not know the exact locations of SNs. Results shows that this protocol gives the guaranteed coverage in mission critical applications and for exact location and identification of SNs RSSI and Link Quality Indication (LQI) can be used.

Bhatti et al. (2011) have proposed Fault Tolerant Target Tracking Protocol (FTTT) for tracking a moving object. FTTT allows fault tolerance with minimum energy consumption and high tracking probability by varying the number of SNs, CHs and target speed. Key parameters of FTTT were minimum energy consumption, higher tracking probability and fault tolerance. Important feature of FTTT was that it supports target tracking even when the system is delicate while prolonging network lifetime. Assumptions made for FTTT protocol are listed below.

- Target can move according to random way point model.
- SNs have the capability to sense the signals emitted from the target.
- All SNs are position aware by any means.
- Number of CHs are fixed and placed at the particular locations.
- Each point within the desired area covered by at least  $m$  sensors so that  $m$  degree of redundancy can be achieved.

Based on the above assumptions, function of FTTT can be explained as follows:

- The cluster formed based on the communication range of SNs and the CHs.
- FTTT identifies root nodes working in the network and minimizing the energy consumption.

- CH fault-tolerance mechanism is applicable for a specific number of CH failures. CH could be identified faulty by any one reason, link failure with only one particular CH, energy depletion and complete damage.
- SN fault tolerance is applicable with the condition of at least  $m$  degree of deployment redundancy. SN could be identified faulty by any one reason, hardware failure, energy depletion and complete damage.

FTTT was evaluated based on six metrics; total energy consumption, tracking accuracy, network throughput, energy reduction in sleep state, average latency and fault tolerance. Based upon the evaluation, authors claim that in comparison to LEACH, FTTT consumes 25% less energy. Major drawbacks of FTTT were exclusion of tracking quality and recovery of target losses.

Yan et al. (2011) have proposed O-LEACH protocol which is based on Distributed Fiber Sensor (DFS) links located at the center of WSN fields. Actually it is the part of optical sensor networks and optical SNs can be converted to normal WSN nodes by optical to wireless signal conversion. The DFS link is located at the center of the whole sensor field. As per the requirement, scenario can be designed for the SNs for inter or intra communication for two WSN fields. The working of O-LEACH is similar to the classical LEACH. Few changes in the setup phase are as follows:

- SNs cannot be deployed in the DFS coverage area.
- CH and the SNs should be within the same WSN field if two WSNs cannot communicate with each other.

Based on FND, HNA and LND it is found that O-LEACH provides 20% better performance when two WSNs are isolated.

Kosar et al. (2011) have proposed an application specific algorithm for WSNs. Objective of the algorithm was to rectify the energy hole problem. Observations show that network provides very good sensing quality over a given threshold and have excellent network lifetime. Further it was found that the designed algorithm can work for border surveillance tasks.

### 2.5.5. Clusters radius fixation

Lai et al. (2012) have proposed Arranging Cluster Sizes and Transmission Ranges (ACT) for WSNs as discussed above. Liu et al. (2010) have proposed Multi Layer Clustering Routing Algorithm (MLCRA) as discussed above. Liu et al. (2010) have proposed LEACH-Density of Distribution of Node (LEACH-D). CH decides its cluster radius according to their distance from the BS and the degree of connectivity. CMs choose to join a cluster according to the energy of CH and the distance to the CH as discussed above. Farooq et al. (2010) have developed a Multi-hop Routing with Low Energy Adaptive Clustering Hierarchy (MR-LEACH) protocol as discussed above.

## 3. Comparison and discussion of existing protocols

Table 2 below provides a comparison of all the above protocols with respect to various parameters. As WSNs are applications specific, so we have selected various parameters depending upon applications where these can be applied. The detailed analysis of all the variants of LEACH based routing and clustering protocols with respect to various parameters are listed below in Table 2. Various parameters selected for discussion are data transmission, network type, routing type, latency, deployment strategy, energy efficiency, load balancing, coverage and connectivity, scalability, fault tolerance, mobility, reliability and communication cost. With respect to data transmission, one, two and multihop communication among the nodes in WSNs have been considered.

**Table 2**  
Relative comparison of various LEACH based protocols.

| Protocols (Year)                          | Data transmission | Network type  | Routing type  | Latency       | Deployment strategy | Energy efficiency            | Load balancing | Coverage and connectivity | Scalability | Fault tolerance | Mobility of nodes          | Reliability | Communication Cost |
|---|-------------------|---------------|---------------|---------------|---------------------|------------------------------|----------------|---------------------------|-------------|-----------------|----------------------------|-------------|--------------------|
| LEACH-C (2002)                            | Single-hop        | Homogeneous   | Cluster Based | Low           | Random              | Good                         | –              | –                         | low         | –               | Nodes are stationary       | –           | High               |
| LEACH-EM (2002)                           | Single-hop        | Homogeneous   | Cluster based | (Event based) | Random              | –                            | –              | –                         | Low         | –               | Nodes are mobile           | –           | High               |
| PEGASIS (2002)                            | Single-hop        | Homogeneous   | Chain based   | Very high     | Random              | Very good                    | –              | –                         | low         | –               | Nodes are stationary       | –           | High               |
| Binary schemes with & without CDMA (2002) | Single-hop        | Homogeneous   | Chain based   | High          | Random              | Very good                    | –              | –                         | low         | –               | Nodes are stationary       | –           | High               |
| HIT (2004)                                | Multihop          | Homogeneous   | Cluster based | High          | Random              | Good                         | –              | –                         | –           | Yes             | Nodes are stationary       | –           | Low                |
| HEED (2004)                               | Multihop          | Heterogeneous | Cluster based | High          | Random              | Good                         | Yes            | –                         | Medium      | –               | Nodes are stationary       | –           | Low                |
| SEP (2004)                                | Single-hop        | Heterogeneous | Cluster based | Low           | Random              | Good                         | Yes            | –                         | –           | –               | Nodes are stationary       | Yes         | High               |
| TL-LEACH (2005)                           | Two Level         | Homogeneous   | Cluster based | High          | Random              | Good                         | Yes            | –                         | Low         | –               | Nodes are stationary       | –           | Low                |
| BCDCP (2005)                              | Multihop          | Homogeneous   | Cluster based | High          | Random              | Good                         | –              | –                         | Low         | –               | Nodes are stationary       | Yes         | Low                |
| EB-PEGASIS (2006)                         | Single-hop        | Homogeneous   | Chain based   | Very high     | Random              | Very good                    | –              | –                         | low         | –               | Nodes are stationary       | –           | Low                |
| Modified HEED (2006)                      | Multihop          | Heterogeneous | Cluster based | High          | Random              | Good                         | Yes            | –                         | Medium      | –               | Nodes are stationary       | –           | Low                |
| Energy-LEACH (2007)                       | Single-hop        | Homogeneous   | Cluster based | Low           | Random              | Good                         | –              | –                         | –           | –               | Nodes are stationary       | –           | –                  |
| PEACH (2007)                              | Single-hop        | Homogeneous   | Cluster based | High          | Random              | Good                         | Yes            | –                         | Medium      | –               | Nodes are stationary       | –           | Low                |
| MEPA (2007)                               | –                 | Homogeneous   | Cluster based | High          | Random              | Very good                    | –              | –                         | Very high   | –               | Nodes are quasi-stationary | –           | –                  |
| Multihop-LEACH (2007)                     | Multihop          | Homogeneous   | Cluster based | High          | Random              | Good                         | –              | –                         | Medium      | –               | Nodes are stationary       | –           | –                  |
| Sec-LEACH (2007)                          | Single-hop        | Homogeneous   | Cluster based | Low           | Random              | Poor                         | –              | –                         | –           | –               | Nodes are stationary       | –           | High               |
| LEACH-ME (2008)                           | Single-hop        | Homogeneous   | Cluster based | –             | Random              | Depends upon mobility of SNs | –              | Yes                       | –           | –               | Nodes are mobile           | –           | –                  |
| TB-LEACH (2008)                           | Single-hop        | Homogeneous   | Cluster based | Low           | Random              | Good                         | Yes            | –                         | –           | –               | Nodes are stationary       | –           | –                  |
| ECCRA (2008)                              | Multihop          | Homogeneous   | Cluster based | Very low      | Random              | Good                         | –              | Yes                       | –           | –               | Nodes are stationary       | –           | High               |
| CCRP (2008)                               | Multihop          | Homogeneous   | Both          | High          | Random              | Very good                    | Yes            | –                         | –           | –               | Nodes are stationary       | –           | High               |
| EBCMS (2009)                              | Single-hop        | Homogeneous   | Cluster based | –             | Random              | Good                         | Yes            | –                         | –           | –               | Nodes are stationary       | –           | –                  |
| EBC (2009)                                | Single-hop        | Homogeneous   | Cluster based | –             | Random              | Good                         | Yes            | –                         | –           | –               | Nodes are stationary       | –           | –                  |
| T-LEACH (2009)                            | Single-hop        | Homogeneous   | Cluster based | –             | Random              | Good                         | Yes            | –                         | –           | –               | Nodes are stationary       | –           | –                  |
| RPCR (2009)                               | Single-hop        | Homogeneous   | Cluster based | –             | Random              | Good                         | Yes            | –                         | –           | –               | Nodes are stationary       | –           | High               |
| LEACH-H (2009)                            | Single-hop        | Homogeneous   | Cluster based | –             | Random              | Good                         | Yes            | –                         | –           | Yes             | Nodes are stationary       | –           | Very low           |
| EECFP (2009)                              | Single-hop        | Homogeneous   | Cluster based | Very low      | Random              | Good                         | –              | –                         | –           | –               | Nodes are stationary       | –           | –                  |
| ID-LEACH (2009)                           | Single-hop        | Homogeneous   | Cluster based | –             | Random              | Very good                    | –              | –                         | –           | –               | Nodes are stationary       | –           | –                  |

Table 2 (continued)

| Protocols (Year)        | Data transmission | Network type  | Routing type  | Latency | Deployment strategy     | Energy efficiency | Load balancing | Coverage and connectivity | Scalability | Fault tolerance | Mobility of nodes    | Reliability | Communication Cost |
|-------------------------|-------------------|---------------|---------------|---------|-------------------------|-------------------|----------------|---------------------------|-------------|-----------------|----------------------|-------------|--------------------|
| BCEE (2009)             | Multihop          | Homogeneous   | Cluster based | –       | Random                  | Good              | Yes            | –                         | High        | –               | Nodes are stationary | Yes         | –                  |
| LEACH-TM (2009)         | Multihop          | Homogeneous   | Cluster based | –       | Random                  | Good              | Yes            | –                         | –           | –               | Nodes are stationary | Yes         | –                  |
| SHRP (2009)             | Multihop          | Homogeneous   | Cluster based | –       | Random                  | Good              | Yes            | Yes                       | High        | –               | Nodes are stationary | Yes         | Low                |
| EAP (2009)              | Single-hop        | Heterogeneous | Cluster based | –       | Random                  | Good              | Yes            | Yes                       | –           | –               | Nodes are stationary | –           | –                  |
| EDL (2009)              | Single-hop        | Heterogeneous | Cluster based | –       | Random                  | Good              | Yes            | –                         | –           | –               | Nodes are stationary | –           | Very low           |
| EECHE (2009)            | Single-hop        | Heterogeneous | Cluster based | –       | Random                  | Very good         | –              | –                         | –           | –               | Nodes are stationary | –           | –                  |
| REFS, EEFS (2009)       | Multihop          | Heterogeneous | Cluster based | –       | Random                  | Good              | Yes            | Yes                       | –           | –               | Nodes are stationary | –           | –                  |
| BARC (2009)             | Multihop          | Homogeneous   | Cluster based | –       | Random                  | Good              | Yes            | Yes                       | High        | –               | Nodes are stationary | –           | –                  |
| ASFO (2010)             | Single-hop        | Homogeneous   | Cluster based | –       | Random                  | Very good         | –              | –                         | –           | –               | Nodes are stationary | –           | –                  |
| VR-LEACH (2010)         | Single-hop        | Homogeneous   | Cluster based | –       | Random                  | Very good         | Yes            | –                         | –           | –               | Nodes are stationary | –           | –                  |
| LEACH-B (2010)          | Single-hop        | Homogeneous   | Cluster based | –       | Random                  | Very good         | –              | –                         | –           | –               | Nodes are stationary | –           | –                  |
| N-LEACH (2010)          | Single-hop        | Homogeneous   | Cluster based | –       | Random                  | Very good         | Yes            | –                         | –           | –               | Nodes are stationary | –           | –                  |
| LEACH_Sin (2010)        | Single-hop        | Homogeneous   | Cluster based | –       | Random                  | Very good         | –              | –                         | –           | –               | Nodes are stationary | –           | –                  |
| KMMDA (2010)            | Single-hop        | Homogeneous   | Cluster based | –       | Random                  | Good              | –              | –                         | –           | –               | Nodes are stationary | –           | –                  |
| W-LEACH (2010)          | Single-hop        | Homogeneous   | Cluster based | –       | Uniform and non-uniform | Very good         | –              | –                         | –           | –               | Nodes are stationary | –           | –                  |
| DE-LEACH (2010)         | Single-hop        | Homogeneous   | Cluster based | –       | Random                  | Very good         | Yes            | –                         | –           | –               | Nodes are stationary | –           | –                  |
| LEACH-ER (2010)         | Single-hop        | Homogeneous   | Cluster based | –       | Random                  | Good              | –              | –                         | –           | –               | Nodes are stationary | Yes         | –                  |
| BEC (2010)              | Single-hop        | Homogeneous   | Cluster based | –       | Random                  | Very good         | –              | –                         | –           | –               | Nodes are stationary | –           | –                  |
| OEEM (2010)             | Single-hop        | Homogeneous   | Cluster based | –       | Random                  | Good              | –              | –                         | –           | –               | Nodes are stationary | –           | –                  |
| LEACH-D (2010)          | Multihop          | Homogeneous   | Cluster based | –       | Random                  | Very good         | Yes            | Yes                       | –           | –               | Nodes are mobile     | Yes         | –                  |
| MLCRA (2010)            | Multihop          | Homogeneous   | Cluster based | –       | Random                  | Very good         | Yes            | –                         | –           | –               | Nodes are stationary | –           | –                  |
| MR-LEACH (2010)         | Multihop          | Homogeneous   | Cluster based | –       | Random                  | Very good         | Yes            | –                         | –           | –               | Nodes are stationary | –           | –                  |
| C <sup>3</sup> R (2010) | Single-hop        | Homogeneous   | Cluster based | –       | Random                  | Very good         | Yes            | Yes                       | –           | –               | Nodes are stationary | –           | –                  |
| LEACH-SC (2011)         | Single-hop        | Homogeneous   | Cluster based | –       | Random                  | Good              | Yes            | –                         | –           | –               | Nodes are stationary | –           | –                  |
| ER-LEACH (2011)         | Single-hop        | Homogeneous   | Cluster based | High    | Random                  | Very good         | Yes            | –                         | –           | –               | Nodes are mobile     | –           | Low                |
| MBC (2011)              | Single-hop        | Homogeneous   | Cluster based | –       | Random                  | Good              | Yes            | Yes                       | –           | –               | Nodes are mobile     | Yes         | –                  |
| FTTT (2011)             | Single-hop        | Homogeneous   | Cluster based | Average | Random                  | Very good         | Yes            | –                         | –           | Yes             | Nodes are stationary | –           | –                  |



|                 |            |               |               |         |        |           |     |     |      |     |                      |      |
|-----------------|------------|---------------|---------------|---------|--------|-----------|-----|-----|------|-----|----------------------|------|
| O-LEACH (2011)  | Single-hop | Homogeneous   | Cluster based | -       | Random | Very good | Yes | Yes | -    | -   | Nodes are stationary | -    |
| ECHR (2011)     | Single-hop | Homogeneous   | Cluster based | -       | Random | Good      | Yes | Yes | -    | -   | Nodes are stationary | -    |
| LEACH-SM (2011) | Single-hop | Homogeneous   | Cluster based | -       | Random | Good      | -   | -   | High | -   | Nodes are stationary | -    |
| CCBRP (2011)    | Single-hop | Homogeneous   | Chain based   | Average | Random | Very good | Yes | -   | -    | -   | Nodes are stationary | Low  |
| IEEPB (2011)    | Single-hop | Homogeneous   | Chain based   | -       | Random | Good      | Yes | -   | -    | -   | Nodes are stationary | -    |
| SRMCF (2011)    | Single-hop | Heterogeneous | Cluster based | -       | Random | Good      | Yes | -   | -    | -   | Nodes are stationary | Low  |
| LSN (2011)      | Single-hop | Homogeneous   | Cluster based | -       | Random | Good      | Yes | -   | High | Yes | Nodes are stationary | Low  |
| ACT (2012)      | Multihop   | Homogeneous   | Cluster based | -       | Random | Good      | Yes | -   | -    | -   | Nodes are stationary | Low  |
| DEECIC (2012)   | Multihop   | Homogeneous   | Cluster based | -       | Random | Good      | Yes | Yes | -    | -   | Nodes are stationary | -    |
| EBRAMS (2012)   | Single-hop | Homogeneous   | Chain based   | Low     | Random | Good      | Yes | -   | -    | -   | Sink is mobile       | Low  |
| EHEED (2012)    | Multihop   | Heterogeneous | Cluster based | -       | Random | Good      | Yes | -   | -    | -   | Nodes are stationary | -    |
| VIBE (2012)     | Multihop   | Homogeneous   | Cluster based | -       | Random | Good      | Yes | Yes | -    | -   | Nodes are stationary | High |

Most of the existing protocols use multihop communication among the nodes, TL-LEACH uses two hop communication. SNs considered in most of the protocols are classified in homogeneous or heterogeneous depending upon different energy levels of nodes. HEED, SEP, EAP, EDL, EECHE, REFS, EEFS have used the heterogeneity of the nodes while rest of the protocols have taken homogeneity of the nodes. The nodes which are heterogeneous in nature adjust themselves at different levels for data transmission and performing various other operations to save the energy.

To save the energy of SNs most of the protocols have used the clustering approach in which SNs communicate with the CHs and then CHs communicate with the BS for data transfer. One of the SNs may be elected as the CH depending upon various parameters with the goal of saving the energy of the nodes. Also most of the protocols have used the random deployment of the SNs except W-LEACH in which both uniform and non-uniform deployment of SNs has been considered. The deployment of the SNs is used to estimate the coverage and connectivity of the nodes which is an important factor to be investigated. This is because some of the SNs may be located at the corners of the deployment region and have poor connectivity with the CHs so these nodes may not be able to send the collected data to respective CHs and BS. The issues of coverage and connectivity have been more investigated in the protocols such as LEACH-ME, ECCRA, SHRP, EAP, REFS, EEFS and EECHE. Moreover, the latency of transferring the data from SNs to CHs to BS has also been considered in most of the existing protocols. Latency depends upon the distance and location of the SNs in the deployed regions. The nodes which are closer to the CH or BS have low latency but energy of these nodes is depleted quickly as these nodes have to transfer large amount of data as compared to other nodes of the network.

Scalability is another important aspect which is used to save the energy in WSNs. The proposal which is used to save the energy for small networks consisting of few nodes can also be applicable for large network, i.e., the proposal should be adaptive to adjust for the larger network domain. Most of the exiting protocols have considered this aspect in which scalability varies from low, medium, high and very high values. MEPA protocol has highest scalability among all the proposals. In this protocol, the proposed algorithm can be used for larger network domain to save the energy of the nodes in WSNs.

As there are many requests which generated from the SNs and are passed to CHs, so these CHs may be overloaded in some situations. To overcome this issue, different proposals in literature have considered the concept of maintaining different queues at CHs and then some priority is maintained for efficient scheduling of the incoming requests from SNs. HEED, SEP, TL-LEACH protocols have used this concept for energy saving in WSNs. Also other protocols such as modified HEED, PEACH etc. have used the concept of load balancing for energy saving in WSNs.

Fault tolerance is also an important issue in which SNs overcome the node failure in the network. The nodes may fail due to hardware or software failure. To overcome the fault tolerance in WSNs, data replication and check pointing are the two most common techniques used in the literature. HIT, LEACH-H, FTIT, and LSN are the most prominent protocols which have used the concept of fault tolerance in WSNs to overcome the node failure.

BS in WSNs is usually considered to be static. But BS can also be considered as mobile in which case maintaining the mobile BS creates extra overhead in the network which results more energy consumption in the network. Keeping in view of the above, only few proposals have considered the mobility of the BS. VIBE has considered the mobility of the nodes and EBRAMS has considered the mobility of the BS. When the SNs transfer the data to the nearest CH and BS, reliability of the data transfer is also one of the crucial factors. In most of the proposals, metrics such as delay,

number of packets transferred in unit time, size of the data packets are considered to compute the effectiveness of the any proposed scheme. SEP, BCDP, BCEE, LEACH-TM, SHRP, LEACH-ER, LEACH-D, and MBC are the most prominent protocols in this category. During the execution of any operation, SNs use the wireless media for transferring the data to CH or BS, so some communication cost also occurs during this process. Depending upon the size of the data and available bandwidth the communication cost may vary from very low, low, medium and high. Table 2 below provides a detailed categorization of all the existing proposals based upon the above mentioned issues.

#### 4. Open issues

In this paper, we have presented various routing clustering protocols based upon LEACH protocol by selecting different parameters. Based upon these parameters, a detailed comparison is provided for various existing protocols. Although we have selected different parameters which are specific to the applications where WSNs can be applied but still there are many open issues which can be further investigated keeping in view of this newly emerging area. One of the open issues is the use of multimedia sensor network where SNs capture the images in the area where they are deployed. The parameters like jitter, delay and fault tolerance require specific attention for all such applications. Moreover, forward error correction (FEC) mechanism can be applied to overcome the existence of fault in the network. WSNs can be used in Vehicular Ad Hoc Networks (VANETs) where they can be deployed on the moving vehicles to capture the outside events. The key issues in these networks is how the data aggregation can be performed keeping in view of the high mobility of the nodes in VANETs. Research is going on in this direction and various government and private agencies have invested lot of money in this area.

As the SNs operate in open environment so security remains a paramount concern for all SNs in the network. Moreover, as the nodes are limited in terms of available resources so standard cryptographic techniques may not be applicable for providing security to the data transmission in WSNs. Keeping in view of the above challenge, a lightweight authentication mechanism is required in WSN which not only provides the secure communication in the network but also consume less resources.

#### 5. Conclusions

In WSNs, selection of CH node is very important aspect and the major research going in the direction is focused on how to minimize energy consumption during the process of extracting the essential data as the SNs are powered by batteries which have limited energy. Clustering has been used widely for efficient routing for the data communication from SNs to BS. It has been observed in the literature that Clustering reduces the energy consumption which prolong the life time of WSN. Low Energy Adaptive Clustering Hierarchy (LEACH) protocol is the fundamental clustering based routing protocol for WSNs. Taking LEACH as a benchmark protocol, various protocols have been developed.

In this paper, we have described many routing protocols based upon the standard LEACH protocol with their advantages and disadvantages with respect to the each other. Various parameters such as CH selection, load balancing, routing, security etc. are selected for comparison of the LEACH based protocols. The parameters are selected based upon the applications and environment for which the WSN is operating.

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#### References

- Al-Refai Hasan, Al-Awneh Ali, Batiha Khaldoun, Abu Ali Amer, Rahman Yehia MEL. Efficient routing LEACH (ER-LEACH) enhanced on LEACH protocol in wireless sensor networks. Part I. International Journal of Academic Research 2011;3(3):42–8.
- Allirani A, Suganthi M. An energy efficient cluster formation protocol with low latency in wireless sensor networks. World Academy of Science, Engineering and Technology 2009;51:1–7.
- Abdulsalam Hanady M., Kamel Layla K., W-LEACH: weighted low energy adaptive clustering hierarchy aggregation algorithm for data streams in wireless sensor networks. In: IEEE international conference on data mining workshops; 2010. p. 1–8.
- Alizadeh Sayyad, Ghaffari Ali. An energy-efficient hierarchical clustering protocols in wireless sensor networks. IEEE; 2010. p. 413–8.
- Hosseinalipour, Ali, KeyKhosravi, Davood, Mirzaei Somarin, Abbas. New hierarchical routing protocol for WSNs. In: Second IEEE international conference on computer and network technology; 2010. p. 269–72.
- Bian Xiaoxiang, Liu Xingcheng, Cho Haengrae. Study on a cluster-chain routing protocol in wireless sensor networks. Supported in part by the NSFC (nos. 60673086, 60711140419). The Science and Technology Plan of Guangdong Province of China (no. 2006B50101003), the Science and Technology Plan of Guangzhou City (no. 2007Z3-D0071) and the Joint KOSEF Project. IEEE; 2008. p. 1–5.
- Bakr Bilal Abu, Lilien Leszek, Extending wireless sensor network lifetime in the LEACH-SM protocol by spare selection. In: Fifth international conference on innovative mobile and internet services in ubiquitous computing. IEEE Computer Society, IEEE; 2011. p. 277–82.
- Bhatti S, Xu J, Memon M. Clustering and fault tolerance for target tracking using wireless sensor networks. IET Wireless Sensor Systems 2011;1(2):66–73.
- Cook DJ, Das SK. Smart environments: technologies, protocols, and applications. New York: John Wiley; 2004.
- Culpepper Benjamin J, Dung Lan, Moh Melody. Design and analysis of hybrid indirect transmissions (HIT) for data gathering in wireless micro sensor networks. Mobile Computing and Communications Review 2004;3(1):61–83.
- Cui Xiaoyan, Liu Zhao. BCEE: a balanced-clustering, energy-efficient hierarchical routing protocol in wireless sensor networks. In: Proceedings of IC-NIDC2009. IEEE; 2009. p. 26–30.
- Cheng Zhuo, Perillo Mark, Tuvli Bulent, Heinzelman Wendi, Tilak Sameer, Abu-Ghazaleh Nuel. Protocols for local data delivery in wireless microsensor networks. 2002;45(1):623–6.
- Ding Xuxing, Xie Fangfang, Wu Qing. Energy-balanced clustering with master/slave method for wireless sensor networks. In: Ninth international conference on electronic measurement and instruments (ICEMI'2009). IEEE; 2009. p. 3–20–3.
- Duan Cuiqin, Sun Jingjing, Zhou Duan, Zhang Jianxian. An energy efficient regional partitioned clustering routing algorithm for wireless sensor networks. In: Second international conference on intelligent networks and intelligent systems (ICINIS-2009). IEEE; 2009. p. 205–8.
- Derogarian Fardin, Ferreira João Canas, Grade Tavares Vítor M. A routing protocol for wsn based on the implementation of source routing for minimum cost forwarding method, SENSORCOMM 2011: In: Fifth international conference on sensor technologies and applications; 2011. p. 85–90.
- Deng S, Lil J, Shen L. Mobility-based clustering protocol for wireless sensor networks with mobile nodes. IET Wireless Sensor Systems 2011;1(1):39–47.
- Farooq Muhammad Omer, Dogar Abdul Basit, Shah Ghalib Asadullah. MR-LEACH: multi-hop routing with low energy adaptive clustering hierarchy. In: Fourth international conference on sensor technologies and applications. IEEE; 2010. p. 262–8.
- Guo Yinghui, Liu Yun, Zhang Zhenjiang, Ding Fei. Study on the energy efficiency based on improved leach in wireless sensor networks. In: Second international Asia conference on informatics in control. Automation and Robotics (CAR-2010). IEEE; 2010. p. 388–90.
- Guan Jian, Sun Dayang, Wang Aimin, Liu Yanheng. Energy balanced routing algorithm based on mobile sink for wireless sensor networks. Journal of Computational Information Systems 2012;8(2):603–13.
- Hou Rui, Ren Weizheng, Zhang Yaodong. A wireless sensor network clustering algorithm based on energy and distance. In: Second international workshop on computer science and engineering, (WCSE 2009). IEEE; 2009. p. 439–42.
- Heinzelman Wendi B, Chandrakasan Anantha P, Balakrishnan Hari. An application-specific protocol architecture for wireless microsensor networks. IEEE Transactions on Wireless Communications 2002;1(4):660–70.
- Handy MJ, Haase M, Timmermann D. Low energy adaptive clustering hierarchy with deterministic cluster-head selection. IEEE 2002;4(2):6–9.
- Hong Jiman, Kook Joongjin, Lee Sangjun, Kwon Dongseop, Yi Sangho. T-LEACH: The method of threshold-based cluster head replacement for wireless sensor networks. Information Systems Frontiers 2009;11:513–21.

- Junping Hu, Yuhui Jin, Liang Dou. A time-based cluster-head selection algorithm for LEACH. In: Proceedings of the of ISCC 2008, 6–9 July 2008, p. 1172–6.
- Wang Jun, Xin Zhang, Xie Junyuan, Mi Zhengkun. A distance-based clustering routing protocol in wireless sensor networks. National Science and Technology Specific Projects 2011.
- Jin Yan, Jo Ju-Yeon, Wang Ling, Kim Yoohwan, Yang Xiaozong. ECCRA: An energy-efficient coverage and connectivity preserving routing algorithm under border effects in wireless sensor networks. *Computer Communications* 2008;31: 2398–407.
- Jawhar Imad, Mohamed Nader, Agrawal Dharma P. Linear wireless sensor networks: Classification and applications. *Journal of Network and Computer Applications* 2011;34(5):1671–82.
- Jiang Joe-Air, Lin Tzu-Shiang, Chuang Cheng-Long, Chen Chia-Pang, Sun Chin-Hong, Juang Jehn-Yih, Lin Jiun-Chuan, Liang Wei-Wen. A QoS-guaranteed coverage precedence routing algorithm for wireless sensor networks. *Sensors* 2011;11:3418–38.
- Kumar Dilip, Aseri Trilok C, Patel RB. Multi-hop communication routing (MCR) protocol for heterogeneous wireless sensor networks. *International Journal of Information Technology, Communication and Convergence* 2011;1(2): 130–45.
- Kumar GSanthosh, Vinu Paul MV, Poulouse Jacob K. Mobility metric based LEACH-mobile protocol, ADCOM-2008. IEEE 2009.
- Kumar Dilip, Aseri TC, Patel RB. EECH: energy-efficient cluster head election protocol for heterogeneous wireless sensor networks. In: Proceedings of the International conference on advances in computing, communication and control (ICAC'09) vol. 1; 2009. p. 75–80.
- Kosar Rabun, Bojaxhiu Ilir, Onur Ertan, Ersoy Cem. Lifetime extension for surveillance wireless sensor networks with intelligent redeployment. *Journal of network and computer applications* 2011;34(6):1784–93.
- Liu Yuhua, Luo Zhenrong, Xu Kaihua, Chen Lilong. A reliable clustering algorithm base on LEACH protocol in wireless mobile sensor networks. In: International conference on mechanical and electrical technology (ICMET 2010). IEEE; 2010. p. 692–6.
- Liu Y, Xiong N, Zhao Y, Vasilakos AV, Gao J, Jia Y. Multi-layer clustering routing algorithm for wireless vehicular sensor networks. *IET Communications* 2010;4(7):810–6 [special issue on vehicular ad hoc and sensor networks].
- Liu Ming, Cao Jiannong, Chen Guihai, Wang Xiaomin. An energy-aware routing protocol in wireless sensor networks. *Sensors* 2009.
- Loscri V, Morabito G, Marano S, Two-Levels A. Hierarchy for low-energy adaptive clustering hierarchy (TL-LEACH). IEEE; 2005. p. 1809–13.
- Liao Wen-Hwa, Yang Hung-Chun. A power-saving data storage scheme for wireless sensor networks. *Journal of Network and Computer Applications* 2012;35(2):818–25.
- Liao Wen-Hwa, Kao Yucheng, Fan Chien-Ming. Data aggregation in wireless sensor networks using ant colony algorithm. *Journal of Network and Computer Applications* 2008;31(4):387–401.
- Li Xiaofang, Xu Lizhong, Wang Huibin, Song Jie, Yang Simon X. A differential evolution-based routing algorithm for environmental monitoring wireless sensor networks. *Sensors* 2010.
- Lan Yao, Fuxiang Gao, Peng Li. An energy-balanced clustering routing protocol in wireless sensor networks. In: Second international conference on power electronics and intelligent transportation system, (PEITS 2009). IEEE, 2009. p. 283–6.
- Lai Wei Kuang, Fan Chung Shuo, Lin Lin Yan. Arranging cluster sizes and transmission ranges for wireless sensor networks. *Information Sciences* 2012;183: 117–31.
- Liu Zhixin, Zheng Qingchao, Xuea Liang, Guana Xinping. A distributed energy-efficient clustering algorithm with improved coverage in wireless sensor networks. *Future Generation Computer Systems* 2012;28:780–90.
- Lin Chia-Hung, Tsai Ming-Jer. A Comment on HEED: a hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks. *IEEE Transactions on Mobile Computing* 2006;5(10):1471–2.
- Lindsey Stephanie, Raghavendra Cauligi S. PEGASIS: power-efficient gathering in sensor information systems. 3. 2002a. p. 1125–30.
- Lindsey Stephanie, Raghavendra Cauligi, Sivalingam Krishna M. Data gathering algorithms in sensor networks using energy metrics. *IEEE Transactions on Parallel and Distributed Systems* 2002b;13(9):924–35.
- Muruganathan Siva D, Ma Daniel CF, Bhasin Rolly I, Fapojuwo Abraham O. A centralized energy-efficient routing protocol for wireless sensor networks. *IEEE Radio Communications* 2005:S8–13.
- Ngo Hung Quoc, Lee Young-Koo, Lee Sungyoung. MEPA: a new protocol for energy-efficient, distributed clustering in wireless sensor networks. In: Proceedings of the ISWCS 2007; 17–19 October 2007. p. 40.44.
- Younis Ossama, Fahmy Sonia. HEED: a hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks. *IEEE Transactions on Mobile Computing* 2004;3(4):366–79.
- Oliveira Leonardo B, Ferreira Adrian, Vilaca Marco A, Wong Hao Chi, Bern Marshall, Dahab Ricardo, Loureiro Antonio AF. Sec-LEACH—On the security of clustered sensor networks. *Signal Processing* 2007;87:2882–95.
- Peng Zhiyong, Li Xiaojuan. The IMPROVEMENT AND SIMULATION of LEACH Protocol for WSNs. IEEE 2010.
- Peng Wei, Edwards, David J. K-means like minimum mean distance algorithm for wireless sensor networks. In: 2nd international conference on computer engineering and technology, vol. 1. IEEE; 2010. p. V1120–24.
- Papadopoulos Aris, Navarra Alfredo, McCann Julie A, Pinotti Cristina M. VIBE: an energy efficient routing protocol for dense and mobile sensor networks. *Journal of Network and Computer Applications* 2012;35(4):1177–90.
- Song Xin, Wang Cuirong, Wang Juan, Zhang Bin. A hierarchical routing protocol based on AFSo algorithm for WSN. In: International conference on computer design and applications (ICDDA 2010), vol. 2. IEEE, 2010. p. 635–39.
- Sen Feng, Qi Bing, Tang Liangrui. An improved energy-efficient pegasis-based protocol in wireless sensor networks. In: Eighth international conference on fuzzy systems and knowledge discovery (FSKD), IEEE; 2011. p. 2230–3.
- Smaragdakis Georgios, Matta Ibrahim, Bestavros Azer. SEP: a stable election protocol for clustered heterogeneous wireless sensor networks. Supported in part by NSF grants ITR ANI-0205294, EIA-0202067, ANI-0095988, and ANI-9986397; 2004. p. 1–11.
- Senouci Mustapha Reda, Mellouk Abdelhamid, Senouci Hadj, Aissani Amar. Performance evaluation of network lifetime spatial-temporal distribution for WSN routing protocols. *Journal of Network and Computer Applications* 2012;35(4):1317–28.
- Shih Kuei-Ping, Chen Hung-Chang, Chou Chien-Min, Liu Bo-Jun. On target coverage in wireless heterogeneous sensor networks with multiple sensing units. *Journal of Network and Computer Applications* 2009;32(4):866–77.
- Samia Aali, Refaay Shreen K. Chain-Chain based routing protocol. *IJCSI International Journal of Computer Science* 2011;8(3):105–12.
- Samdanis Konstantinos, Friderikos Vasilis, Hamid Aghvami A. Autonomic hierarchical reconfiguration for wireless access networks. *Journal of Network and Computer Applications* 2009;32(3):630–41.
- Tong Mu, Tang Minghao. LEACH-B: an improved leach protocol for wireless sensor network. *WiCom* 2010; 23–25 September 2010. p. 1–4.
- Torkzaban Vahid, Rahmani Soheila, Dehghan Mehdi. An ID-based routing protocol for WSN. IEEE 2009.
- Tamboli Neelofer, Younis Mohamed. Coverage-aware connectivity restoration in mobile sensor networks. *Journal of Network and Computer Applications* 2010;33(4):363–74.
- Villalba Luis Javier García, Orozco Ana Lucila Sandoval, Cabrera Alicia Triviño, Abbas Cláudia Jacy Barenco. Routing Protocols in wireless sensor networks. *Sensors* 2009.
- Heinzelman Wendi Rabiner, Chandrakasan Anantha, Balakrishnan Hari. Energy-efficient communication protocol for wireless microsensor networks. In: Proceedings of the 33rd Hawaii international conference on system sciences. IEEE; 2000. p. 1–10.
- Wang Linlin, Liu Jie, Wang Wei. An improvement and simulation of leach protocol for wireless sensor network. In: First international conference on pervasive computing, signal processing and applications. In: Proceedings of PCSPA 2010; 17–19 September 2010. p. 444–7.
- Wafat Mohamed K, Mirza Omar, Kawtharani Jad. BARC: a battery aware reliable clustering algorithm for sensor networks. *Journal of Network and Computer Applications* 2009;32(6):1183–93.
- Wang Wei, Wang Qianping, Luo Wei, Sheng Mengmeng, Wu Wanrong, Hao Li. Leach-H: an improved routing protocol for collaborative sensing networks. Supported by the Natural Science Foundation of Jiangsu Province of China. IEEE; 2009. p. 1–5.
- Weichao Wang, Fei Du, Qijian Xu. An improvement of LEACH routing protocol based on trust for wireless sensor networks. Supported by Chinese National Programs for High Technology Research and Development. IEEE; 2009. p. 1–4.
- Xiangning Fan, Song Yulin. Improvement on LEACH protocol of wireless sensor network. In: International conference on sensor technologies and applications (Sensor Communication-2007). IEEE; 2007. p. 260–4.
- Xiaoping Wu, Lin Hong, Li Gang. An improved routing algorithm based on LEACH protocol. In: Ninth international symposium on distributed computing and applications to business. Engineering and Science. IEEE; 2010. p. 259–62.
- Xunbo Li, Na Li, Liang Chen, Yan Shen, Zhenlin Wang, Zhibin Zhu. An improved LEACH for clustering protocols in wireless sensor networks. In: International conference on measuring technology and mechatronics automation. IEEE; 2010. p. 496–9.
- Yi Sangho, Heo Junyoung, Cho Yookun, Hong Jiman. PEACH: power-efficient and adaptive clustering hierarchy protocol for wireless sensor networks. *Computer Communications* 2007;30:2842–52.
- Yang Kun, Wu Yuan-ming, Zhou Hai-bo. Research of optimal energy consumption model in wireless sensor network. In: Second international conference on computer engineering and technology, vol. 7. IEEE; 2010. p. 421–4.
- Liu Yueyang, Ji Hong, Yue Guangxin. An energy-efficient pegasis-based enhanced algorithm in wireless sensor networks. *Technology Forum. China Communications*; 2006. p. 91–7.
- Yan Lianshan, Pan Wei, Luo Bin, Li Xiaoyin, Liu Jiangtao. Modified energy-efficient protocol for wireless sensor networks in the presence of distributed optical fiber sensor link. *IEEE Sensors Journal* 2011;11(9):1815–9.
- Zhao Yulan, Jiang Chunfeng. Research about improvement of LEACH protocol. *ICISE* 2010; 4–6 December 2010. p. 2281–4.
- Zhang Junqi, Varadharajan Vijay. Wireless sensor network key management survey and taxonomy. *Journal of Network and Computer Applications* 2010;33(2):63–75.