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Cluster head election techniques for energy-efficient routing in Wireless Sensor Networks-An updated survey

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Abstract– Energy efficient protocol design is a prime concerned for wireless sensor networks. Many techniques have been developed to extend the lifetime of Wireless Sensor Networks. This paper focuses on energy conservation in wireless sensor network using hierarchical routing techniques. In a hierarchical routing, few nodes elect themselves as cluster heads for a specific duration and serves to the remaining nodes. The paper summarizes the development of different cluster head election techniques for wireless sensor network and classifies them into different groups by considering various features used to elect cluster heads.
*Keywords:*Cluster head election, survey, energy-efficient routing, wireless sensor network.

1. Introduction

Wireless Sensor Networks (WSNs) provides a low-cost solution for a variety of application such as military applications, environment monitoring, inventory control, human-centric applications, agriculture applications, structural health monitoring, and much more [1]. WSN is made of a large number of tiny nodes having sensing, computation, and wireless communication capabilities. These nodes are battery operated. It is difficult to replace or recharge batteries of nodes because of a large-scale development. WSN nodes are also used in applications where human intervention is impractical, infeasible or risky [2]. This also makes it difficult to replace or recharge batteries of the sensor nodes. This imposes the requirement of extending the lifetime of a given sensor network so that it can serve the underlying application for a longer duration. Many techniques have been developed to extend the lifetime of WSN such as sleep scheduling, MAC protocols, routing protocols, data aggregation, topological control, etc. [3]. This paper focuses on a survey of routing protocols designed to extend the lifetime of WSNs.
Depending upon the underlying network structure, routing protocol can beclassified as flat-based routing, hierarchical-based routing and location-based routing [4]. This paper focuses on a survey of hierarchical routing schemes, as it is scalable and provides energy efficient communications [4]. The rest of the paper is organized as follows: Homogenous hierarchical clustering algorithms are discussed in section 2; Heterogeneous hierarchical clustering algorithms are discussed in section 3, and concluding remarks and future scope are given in section 4.

2. Homogeneous Hierarchical Clustering Algorithms

In homogeneous wireless sensor networks, all nodes have the same initial energy. The hierarchical routing scheme extends the lifetime of WSN by reducing the communication distance between sensor nodes and BS. In this scheme, few nodes elects themselves as Cluster Heads (CHs), and each CH serves a set of non-CH nodes called member nodes for a specific duration termed as round. Non-CH nodes transmit their data to either selected CH or Base Station (BS) whichever is energy-efficient. This reduces the long distance communication of non-CH nodes and helps to extend the lifetime of WSNs. However, this increases the overhead on selected CH as it collects data from non-CH nodes associated with it, and sends aggregated data to BS. This results in fast energy depletion of CH nodes and hence, the role of the CH should be on a rotation basis. This paper focuses on various techniques used for cluster head election and classifies them on various parameters.

2.1. Energy-Efficient Communication Protocol for Wireless Micro-sensor Networks [5]

LEACH is a prominent clustering technique which extends the lifetime of WSN. LEACH is a homogeneous clustering technique where in each node is given to the same initial energy. LEACH protocol operation is divided into rounds. Each round is divided into two phases: i) Cluster Setup Phase and ii) Steady state phase. Nodes elect themselves as CH during the cluster setup phase and BS receives data during steady state phase.

LEACH uses a stochastic approach to elect the CH. In this process, each node assumes a random number between *0* and *1*, and this number is compared with the threshold value *T(n)* given by equation 1. Here, *p* is the desired percentage of CH per round, *r* is the round number, and *G* is the set of nodes which are yet to be elected as CH in the current epoch. Here, the epoch is defined as 1/*p*.

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

If the selected random number is less than *T(n)*, the node elects itself as CH for the current round otherwise, it acts as a member node. Once the node is elected as CH for the current round of an epoch, it acts as a member node for the remaining round of the same epoch.

2.2. Low energy adaptive clustering hierarchy with deterministic cluster-head selection [6]

LEACH does not consider the energy of the nodes while electing them as CHs. This shortcoming of LEACH is overcome by Low energy adaptive clustering hierarchy with Deterministic Cluster-Head Selection (LDCHS). LDCHS has extended the CH election technique of LEACH protocol, and it is given by equation 2.

$$T(n)=\begin{cases}\dfrac{p}{1-p\left(r \bmod \dfrac{1}{p}\right)}\dfrac{En\_current}{En\_\max} & if\ n\in G\\ 0 & Otherwise\end{cases} \tag{2}$$

Here, *En_current* and *En_max* denote the current energy and initial energy of the node respectively. This protocol measures the lifetime of a WSN using new metric: First Node Dies (FND), Half of the Nodes Alive (HNA) or Half of the Nodes Die (HND) and Last Node Dies (LND). FND refers to the time between the network setup and the death of the first node, HNA (or HND) refers to the time between death of the first node to the death of *50%*nodes, and LND refers to the time between the death of *50%* nodes to the death of the last node. Using CH election scheme proposed in equation 2 enhances FND by *30%* and HNA by more than *20%* as compared to LEACH. However, the network does not progress after some round which is reported as the major disadvantage of this scheme.

To overcome this issue, a modified CH election scheme is proposed and it is given by equation 3. In equation 3, r_s refers to the set of consecutive rounds during which a node has not been elected as CH. The *T(n)* of equation 3 works similar to LEACH protocol as r_s attains the value of *1/p*.

$$T(n)=\begin{cases}\dfrac{p}{1-p\left(r \bmod \dfrac{1}{p}\right)}\left[\dfrac{En\_current}{En\_\max}+\left(r_s div \dfrac{1}{p}\right)\left(1-\dfrac{En\_current}{En\_\max}\right)\right] & if\ n\in G\\ 0 & Otherwise\end{cases} \tag{3}$$

2.3. A two-levels hierarchy for low-energy adaptiveclustering hierarchy (TL-LEACH) [7]

TL-LEACH protocol is randomized, adaptive and distributed cluster formation scheme that uses localized control for data transfer to achieve energy and latency efficiency. The protocol is divided into four phases i) advertisement phase ii) cluster setup phase iii) schedule creation and iv) data transmission. During the advertisement phase, each node decides whether it wish to act as a primary cluster head, secondary cluster head or a member node for the current round. A set of nodes who wish to act as a primary cluster head makes an advertisement to other nodes using CSMA mechanism. Subsequently, a set of nodes that have decided to act as secondary CH makes an advertisement to non-CH nodes after receiving advertisement from primary CH. Each secondary-CH node decides its primary-CH and informs the selected one through appropriate message. Similarly, each non-CH node decides its secondary-CH and informs the selected one with a message. During the third phase, each primary CH selects a CDMA code for its group and informs TDMA schedule for data transmission. This information is disseminated to non-CH nodes through secondary-CH. The actual data transmission occurs as per the TDMA schedule during the last phase. This protocol does data aggregation at both levels of CH. This helps to reduce the data transmission and conserve the energy. The proposed approach increases lifetime by *30%* as compared to LEACH.

2.4. An enhanced cluster based routing algorithm for wireless sensornetworks [8]

In this paper, authors have proposed a semi-centralised protocol that works in three phases: Cluster setup phase, steady state phase, and pre-setup phase. In cluster setup phase nodes elect themselves as CH using equation 4.

$$T(n) = \begin{cases} \dfrac{p}{1 - p\left(r \bmod \dfrac{1}{p}\right)} \dfrac{Eres}{E\max} & if\ n \in G \\ 0 & Otherwise \end{cases} \tag{4}$$

Here, Eres and Emax refer to the residual energy of the node and maximum residual energy of the entire network. BS receives data from CH or non-CH nodes during steady state phase. During the last round of each epoch, each CH sends the maximum energy of the cluster to BS. BS calculates the maximum energy of the network and sends this information to all the nodes of the network.

2.5. ALEACH: Advanced LEACH routing protocol for wireless microsensor networks [9]

In this paper, authors have proposed ALEACH approach which is distributed in nature and improves the lifetime of WSN by avoiding long-distance communication with BS. This protocol elects cluster heads without knowing the exact location of the nodes. It does not assume current state of any of the nodes to elect CHs. The protocol works in two phases: cluster setup phase and steady state phase. Nodes elect themselves as CH during cluster setup phase. Like LEACH, nodes assumes a random number and it is compared with threshold value *T(n)* given by equation 5.

$$T(n) = Gp + CSp \tag{5}$$

Here, Gp and CSp refer to the general probability and current state probability and it is given by equation 6 and 7 respectively.

$$Gp = \frac{k}{N - k\left(r \bmod \dfrac{N}{k}\right)} \tag{6}$$

$$CSp = \frac{Ecurrent}{En\_max} X \frac{k}{N} \quad (7)$$

Here, *k* is the desired number of CH per round, *N* is the total number of nodes in the network, *r* is the current round, *Ecurrent* is the current energy of a node and *En_max* is the initial energy given to the node.

2.6. Data dissemination based on ant swarms for wireless sensor networks [10]

This protocol is a hybrid protocol of TCCA clustering scheme along with ANT election scheme and it is termed as T-ANT algorithm. Like LEACH, this protocol also works in two phases. During cluster setup phase, sink releases a number of ants which chooses one of its neighbours randomly. The travel of ants is restricted by Time-To-Leave (TTL) field and CS timer. The TTL field is reduced by one as soon as ant reaches to the new neighbour. The ant is allowed to travel as deep as possible in the network only when TTL field consists of non-zero value and CS time is not expired. The nodes possess an ant act as CH for the current round and they inform same to other nodes by making an announcement. Upon reception of the CH announcement, each node records parameters like distance (hop count) to this CH, CH id and sender id as the parent etc. The node then rebroadcasts the packet by setting necessary parameters if TTL field permits. The protocol is a distributed in nature and achieves the separation and alignment behaviour, the two desired swarm behaviours.

2.7. MRLEACH:multi-hop routing with low energy adaptive clustering hierarchy [11]

The MRLEACH algorithm is designed with the motivation of reducing inter-cluster communication distance to evenly distribute the energy, to reduce computation energy of the CH located at second-level or higher and use of global TDMA schedule to overcome the problem of multi-hop routing with uneven clustering technique. MR-LEACH elects lowest level of CH by sending *hello* packets and the node with the highest energy amongst neighbour nodes will be elected as CH. Each node joins to a CH with highest received signal strength. BS elects CH for the remaining layers of the network. TDMA schedule is used to transmit data to BS using multi-hop communication. MR-LEACH provides energy efficient routing by introducing the concept of equal clustering.

2.8. Bio-inspired based optimized algorithm for cluster head election using RSSI and LQI [12]

In this paper, authors have extended T-ANT algorithm and proposed a Modified-TANT (MT-ANT) algorithm based on Received Signal Strength Indicator (RSSI) and Link Quality Indicator (LQI). This protocol is distributed in nature and uses the concept of ACO and cross-layer design to elect CHs. MT-ANT does not depend on the position of the nodes and has better packet reception rate as compared to T-ANT.

2.9. An Ant Colony Clustering Routing Algorithm for Wireless Sensor Networks [13]

In this paper, author uses Ant Colony Algorithm (ACA) for the inter-cluster communication to select the best path to send data from CH to sink. The nodes elect themselves as CH using equation 2. When any CH_i receives CH announcement from other CH_j, and if residual energy of newly elected CH_j is higher than the CH_i, then CH_i act as a member node. Simulation results show that this approach improves the lifetime of WSN by *30%* as compared to LEACH.

2.10.Energy-Driven adaptive clustering hierarchy(EDACH) for wireless sensor networks [14]

The authors have proposed EDACH algorithm, in which eachnode calculates the threshold value *T(n)* as per equation 1, but the value of *p*differs for each node depending upon its location from BS. *p* can take one of threesegment values termed as near, medium and far; and it is represented by $(1– x)p$, pand $(1 + x)p$ respectively, where $0 < x < 1$. This reduces the probability of nodes being elected as CH which are closer to BS, and vice-a-versa.

2.11.EECS: an energy efficient clustering scheme inwireless sensor networks [15]

EECS is a LEACH like protocol which is designed with the aim to elect cluster heads in a fully distributed manner with low control overhead and the load is balanced between the CHs as far as possible. During cluster head election phase each CANDIDATE node is likely to become CH with a probability T. Each CANDIDATE node broadcast COMPETE_HEAD_MSG within its radio range R. Each CANDIDATE nodes compare its energy and gives up if its energy is lower than the energy announced in the COMPETE_HEAD_MSG. Once a node with the highest energy within the radio range R is elected as CH, it broadcast the HEAD_AD_MSG within the network. The non-CH node joins to the nearest CH. BS periodically broadcast SYNCH messages to provide synchronization between each phase. Simulation results show that EECS improves the network lifetime by *35%* as compared to LEACH.

2.12.Topology-controlled adaptive clustering for uniformityand increased lifetime in wireless sensor networks [16]

This paper presents an adaptive CH election scheme TCAC with an aim to extend the lifetime of WSN along with maintaining the required network connectivity. The adaptive CH election scheme uses topological control that allows an optimal degree that results in well-balanced cluster formation. The algorithm is divided into three phases: i) periodic update, ii) cluster head election and iii) cluster formation. During periodic update phase, each node sets its power level to maintain degree threshold. A set of CANDIDATE cluster head and then subsequently CHs are identified during the cluster head election phase. Non-CH nodes join to CH nodes during cluster formation as per the priority list to maintain the desired degree of each CH node. Simulation results show that TCAC improves network lifetime by *12%* compared to LEACH and energy-based LEACH.

2.13.Q-LEACH: A New Routing Protocol for WSNs [17]

Q-LEACH is designed with an aim to extend lifetime of the WSN. The protocol virtually divides entire network area in for equal quadrants, and elects CH from each quadrant using equation 1 until the required number of CHs is elected.

2.14.CVLEACH: Coverage based energy efficient LEACH Algorithm [18]

CVLEACH is designed with an aim to enhance the lifetime of WSN using the overhearing property of the sensor nodes. CVLEACH works similar to LEACH protocol with an exception: when a candidate node receives the CH announcement during a particular round, the candidate node acts as a member node for that round and withdraws its participation to become CH for the round. This creates non-overlapping clusters and provides enhanced network lifetime with no overhead.

2.15.An Improved Energy-efficient Algorithm based on L-DCHS inWSN [19]

Double CH election strategy is used in IEAL by introducing Master CH (MCH)and Vice-CH (VCH). MCHs are elected as per equation 3. After the announcement ofMCHs, other nodes calculate the node factor and send it with the join message givento MCH; where the node factor is given by equation 8.

$$Di = \frac{Ei\_current}{Ei\_bs} \tag{8}$$

Here, Ei_current and Di_bs denote current energy of the node and the distance betweennode and BS, respectively. A node having maximum node factor will be elected asVCH by MCH.

2.16.WALEACH: Weight based energy efficient Advanced LEACH algorithm [20]

WALEACH algorithm is designed with an aim to improve the network lifetime and packet reception rate (PRR). It is an extension of ALEACH algorithm with modification in Gp and CSp of equation 6 and 7 respectively. Apart from these changes, WALEACH works similar to ALEACH protocol. Gp and CSp for WALEACH are given by equation 9 and 10 respectively.

$$Gp = \frac{k}{N - k\left(r \bmod \frac{N}{k}\right)} X \frac{N - |w * k|}{N} \tag{9}$$

$$CSp = \frac{Ecurrent}{En\_max} X \frac{w * k}{N} \tag{10}$$

Here, *w* represents the weight (importance) factor for Gp and CSp.

2.17.A novel energy-efficient algorithm for wireless sensor networks [21]

This paper has present a novel routing algorithm, NEAW with an aim to solve the problem of hot spot problem of intra-cluster communication along with improving the lifetime of WSNs. This protocol selects tentative cluster heads whose energy is higher than the average energy of the network. Each tentative CH calculates its competition range based on its distance from the BS, and maximum and minimum distance of a node from the BS. This approach creates more CHs near to the BS as CHs near to the BS should require to forward data from other sensor nodes. Final CHs are elected based on the residual energy of nodes. Inter-cluster communication between CHs is achieved by selecting best suitable CH node to forward data to BS. The selection of the next hop is based on Particle Swarm Optimization (PSO). This helps to achieve energy-balancing across the network.

2.18.Improving on LEACH Protocol of Wireless Sensor Networks Using Fuzzy Logic [22]

In this paper, authors have proposed LEACH-FL algorithm in which, CHs are selected based on probability, which is given by equation 11.

$$probability = battery\_level * 2 + node\_density + |2 - dist| \tag{11}$$

A node with the highest battery level, lowest node density and nearest to BS have the highest probability to be elected as CH and a node with lowest battery level, lowest node density and farthest from the BS have the lowest probability to be elected as CH. A total *27* rules are defined to get probability value. To get the crisp value of probability, centroid based defuzzification is used.

2.19.WCVALEACH: Weight and Coverage based energy efficient Advanced LEACHalgorithm [23]

WCVALEACH is a hybrid protocol that takes the advantage of CVLEACH protocol to create non-overlapping cluster region along with it assigns the importance to *Gp* and *CSp* as defined in WALEACH protocol.

2.20.Research and improvement of adaptive topology algorithm LEACH for wireless sensor network [24]

This paper discusses improved LEACH algorithm named EC-LEACH with the aim to reduce the possibility of low energy nodes being elected as CH and to achieve well-balanced energy load of network nodes. EC-LEACH has modified the CH election scheme which is given by equation 12.

$$T(n) = \begin{cases} \dfrac{p}{1 - p\left(r \bmod \dfrac{1}{p}\right)} \dfrac{Er\_e - Er\_c}{Er\_e} & \text{if } n \in G \\ 0 & Otherwise \end{cases} \tag{12}$$

Here, *Er_e* denotes the remaining energy of a node at the end of *r* round, *Er_c* denotes energy consumption of nodes due to data transfer, *p* is the desired percentage of CH and *G* is the set of nodes which are yet to be elected as CH for the current epoch. EC-LEACH reduces average energy consumption by *6.7%* as compared to LEACH.

2.21.An application-specific protocol architecture for wireless microsensor networks [25]

LEACH protocol is distributed in nature. However, it does not guarantee the number of CHs per round and their placement within the region of interest. This shortcoming of LEACH protocol is reported in the paper and authors have proposed a centralized clustering scheme for LEACH named LEACH-C wherein cluster formation is carried by BS. During the setup phase, each node sends its energy and location information to BS. BS uses simulated annealing algorithm to find *k* optimal cluster heads. Once the node has identified the CHs, BS broadcasts a message that contains CH IDs. Each node compares its own ID with the CH IDs mentioned in the message. If a match is found node identifies itself as CH otherwise it acts as a member node for the current round.

2.22.Alive Nodes Based Improved Low Energy Adaptive Clustering Hierarchy for WirelessSensor Network [26]

In this paper, authors have extended LEACH protocol by assigning weights to the random numbers generated by nodes. The weight parameter is dynamic and it is given by the percentage of alive nodes in the network. This protocol uses the same threshold value *T(n)* as LEACH.

2.23.Solar-aware Clustering in Wireless Sensor Networks [27]

In this paper, authors have proposed Solar-aware centralized LEACH (sLEACH) with an aim to improve the lifetime of the sensor network wherein solar aware nodes are preferred to do energy intensive task over normal nodes. The authors have presented a simple heuristics to elect k CHs. Initially k+3 nodes are elected as CANDIDATE CHs. In the next steps, nodes with the minimum sum of the distance from all other CANDIDATE CHs are removed from the CANDIDATE CH list. At last, one of the two nodes is removed from the CANDIDATE CH list which is closest to each other.

This paper also presents solar aware extension of distributed sLEACH protocol (sdLEACH) wherein solar-powered nodes are having a higher probability of being elected as CH as compared to normal nodes. The threshold value *Ts(n)* for solar aware distributed LEACH is given by equation 13.

$$Ts(n) = sf(n) * \frac{p}{1 - \left(\dfrac{cHeads}{numNodes}\right)} \tag{13}$$

Here, *cHeads*denotes the number of cluster heads that increases with every round. It resets to zero when cHead attains the value of *numNodes*. The parameters *sf(n)* should be higher than 1 so that solar aware nodes get higher priority of being elected as CH as compared to normal nodes.

2.24.S-LEACH: A sequential selection approach to elect cluster heads for LEACH protocol [28]

LEACH uses a stochastic approach to elect cluster heads. However, due to stochastic nature of LEACH, a huge variation is found in the number of CHs elected per round. S-LEACH overcomes this shortcoming of LEACH and elects required number of CHs sequentially. Simulation results show that S-LEACH improves the network lifetime as compared to LEACH and maintains the desired number of CHs/round.

2.25.Uneven Clustering Routing Algorithm for Wireless Sensor NetworksBased on Ant Colony Optimization [29]

This paper proposed an ACO based algorithm for inter-cluster data transmission. It also creates uneven clusters based on the distance between the selected CH and the sink node. The protocol is divided into three phases: i) Election of cluster heads ii) Formation of clusters and iii) inter-cluster routing design based on ant colony optimization. CHs are elected during the first phase. During this phase, each node assumes a random number between 0 and 1, which is compared with threshold value *T(n)* given by equation 14. A node elects itself as probable CH, if selected random number is smaller than *T(n).*

$$T(n)=\begin{cases}\dfrac{p}{1-p\left(r \bmod \dfrac{1}{p}\right)}\dfrac{Eresidual}{Eo} & if\ n\in G \\ 0 & Otherwise\end{cases} \tag{14}$$

Here, *Eresidual* and *Eo* denote residual energy and initial energy of a node respectively. Each probable CH calculates the cluster range *Rc* using equation 15.

$$Rc=\left(1-c\frac{d\max-d\left(Sj,DS\right)}{d\max-d\min}\right)Ro \tag{15}$$

Here, *c* is a controlling parameter which takes the value between *0* and *1*, *Ro* is the maximum range of CH, *dmax* and *dmin* denote the maximum and minimum distance of the farthest and nearest node from the sink, and *d(Sj,DS)* is the distance between node *Sj* and sink. Each candidate CH makes an announcement within its cluster range R*c*. If a candidate CH does not receive any announcement from other CHs, it announces itself as CH, otherwise the node having lower energy withdraws itself from the list of candidate CH for the current round. After election of the final CHs, each non-CH node transmits its data to the selected CH as per the TDMA schedule announced by the selected CH. At last, ACO is used to identify inter-cluster routes to transmit data to sink.

2.26.Cluster Head Election for Energy and Delay Constraint Applications of Wireless Sensor Network [30]

This paper has proposed a CH election technique named EDIT to optimize energy and delay both objectives. The EDIT protocol is designed for time-critical applications like forest fire detection, battlefield monitoring wherein data should be received by the sink within bounded delay to avoid disaster. The protocol consists of two phases: i) cluster setup phase and ii) steady state phase. A setup phase named neighbour discovery phase is executed only once before the commencement of the first round. Cluster setup phase is commenced with the identification of CANDIDATE CH nodes. The node with higher remaining energy has higher possibility to become CANDIDATE CH. EDIT is

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used to break the tie between the CANDIDATE CH nodes which are having the same remaining energy and they are in the communication range of each other. EDIT is calculated as per the equation 16.

$$EDIT = \left(\frac{TotalNeighbours}{TotalNodes}\right)^{\alpha} + \left(\frac{1}{Avg\_Dist\_from\_Sink}\right)^{\beta} \quad (16)$$

Here, α and β are controlling parameters and their values lie between [0,1]. In equation 16, $\alpha+\beta\neq0$. The paper has analyzed energy-delay trade-off by proposing EDIT protocol.

2.27.Ant Colony Optimization Based Hierarchical DataDissemination in WSN [31]

This paper has proposed an energy efficient algorithm named Power Aware Scheduling and Clustering Algorithm based on Ant Colony Optimization (PASC-ACO). The protocol divides network area into zones. All nodes are active during each round and each node selects a random delay before it can announce that it is a CH for the current round. The node with the smallest delay within the zone will be elected as CH for that zone. Each non-CH node within the zone sends its energy information back to the CH in the response to the CH announcement. CH prepares the TDMA scheduled on the basis of energy information received by it and announces to its member nodes. ACO based scheduling algorithm is used to transmit data from each CH to sink using multi-hop communication. This phase is termed as data communication phase.

2.28.P-LEACH: Energy Efficient Routing Protocol forWireless Sensor Networks [32]

This paper presents a hybrid algorithm named P-LEACH which combines LEACH and PEGASIS algorithm for data transmission to BS. The node with the highest energy within the cluster is elected as CH. CHs are responsible for forwarding data to BS. The CH node nearest to BS acts as the leader of the chain.

2.29.A new Bollinger Band based energy efficient routing for clustered wireless sensor network [33]

In this paper, authors have developed a Bollinger Band based cluster head election technique for grid-based data transmission. Bollinger Band is a technical trading tool. Bollinger Band selects a node with maximum residual energy and minimum energy variance as CH. Authors have also shown that maximum grid size would be $L/\sqrt{5}$ m x $L/\sqrt{5}$ m if a node can transmit up to L meters with maximum transmission power $T_{max.}$ The approach proposed in the paper is distributed in nature and scalable as multi-hop communication used by CHs to provide data to the sink.

2.30.A Cluster Routing Algorithm based on RSSI for An Efficient Multi-Hop Data Forwarding [34]

This paper proposed a centralized clustering scheme based on RSSI value. In this protocol, each node forwards RSSI value to BS. Based on the RSSI value received from the nodes, BS forms clusters and assigns cluster code to each cluster. Each member node transmits its data to the cluster only if the newly sensed value differs from the value communicated to the BS in recent past. This help to conserve energy of the member nodes. The simulation results show that RSSI based clustering approach reduced energy consumption by *28%* compared to LEACH.

2.31.An improved modified LEACH-C algorithm for energy efficient routing in Wireless SensorNetwork [35]

In this paper, authors have proposed an extension of LEACH-C protocol named a modified LEACH-C (LEACH-CM). In this protocol, each member node decides data transmission based on its distance from the CHs and BS whichever is energy efficient. It also considers the number of alive nodes in the network rather than considering total nodes in the network. LEACH-CM provides better energy efficiency and delivers a higher number of packets as compared to LEACH-C.

2.32.Multi-hop LEACH Protocol with modified Cluster Head selection and TDMA schedule for Wireless Sensor Networks [36]

This paper presents an energy-efficient algorithm with three modification as compared to LEACH: i) A modified threshold value T(n) for CH election is presented which is given by equation 17, ii) a modified TDMA schedule is presented wherein a non-CH node assigns its TDMA slot to the next node in the TDMA schedule if it has no data to be sent during the current slot of TDMA schedule and iii) multi-hop communication is used to transmit data to BS in place of direct or single-hop communication.

$$T(n) = \begin{cases} \dfrac{p}{1-p\left(r \bmod \dfrac{1}{p}\right)} \dfrac{Erem}{Etot\_net} & if\ n \in G \\ 0 & Otherwise \end{cases} \tag{17}$$

Here, *Erem* and *Etot_net* denote the remaining energy of a node and total network energy at the end of round *r* respectively.

2.33.NEECP: Novel energy-efficient clusteringprotocol for prolonging lifetime of WSNs [37]

A Novel Energy-Efficient Clustering Protocol (NEECP) is designed to improve the lifetime of sensor network. NEECP elects cluster heads in effective manner and each cluster has different sensing range to balance the load on the CH. The protocol also takes advantage of chain based data aggregation schemes to extend the lifetime of WSN. In addition, NEECP avoids redundant data transmissions that further improve the network lifetime. NEECP uses stochastic CH election process to select CHs. The threshold value *T(n)* is given by equation 18.

$$T(n) = \begin{cases} \dfrac{Popt}{1-Popt\left(r \bmod \dfrac{1}{Popt}\right)} \dfrac{Eresidual}{Einitial} \dfrac{Dn}{N} & if\ n \in G \\ 0 & Otherwise \end{cases} \tag{18}$$

Here, *Popt* is the optimal percentage of CH, *r* is the round number, *Eresidual* is the residual energy of the node, *Einit* is the initial energy given to the node, *N* is the total nodes in the network and *Dn* is the number of nodes in the sensing range.

2.34.DUCF: Distributed load balancing Unequal Clustering in wireless sensor networks using Fuzzy approach [38]

This paper presents the DUCF algorithm based on fuzzy approach. DUCF considers three parameters to elect cluster heads: residual energy, node degree and distance from the BS. A total twenty-seven DUCF fuzzy rules are defined and output is given in terms of Chance and Size. Here, Chance represents the ability of a node to act as CH and Size represent the maximum number of member nodes of a cluster. It uses multi-hop communication to transmit data to BS through CHs.

2.35.HEED: A Hybrid, Energy-Efficient, Distributed Clustering Approach for Ad Hoc Sensor Networks [39]

This paper presents a hybrid energy efficient distributed clustering scheme named HEED. This protocol assumes that each node can transmit data at multiple power level. Except for this assumption, HEED does not make any assumptions about node capability or underlying network. It elects cluster heads based on the residual energy of the node and proximity of the node or node degree. Each node elects itself as CH with a probability defined by equation 19. Here, *Eresidual* and *Emax* denote the residual energy of the node and initial energy given to the node respectively, *Cprob* is the initial percentage of CHs that limits the initial CH announcements. The probable cluster head becomes final cluster heads if its *CHprob* reaches to a value 1 over a period of time. If a node is not covered by any of the CH then it declares itself as a final CH.

$$CHprob = CprobX\ \frac{Eresidual}{E\max} \tag{19}$$

2.36.Improving on HEED Protocol of Wireless Sensor Networks using Non ProbabilisticApproach and Fuzzy Logic (HEED-NPF) [40]

Cluster head election of HEED-NPF is divided into three phases: initialization phase, main processing phase, and finalization phase. During initialization phase, each node builds or updates a neighbour table and computes the fuzzy cost associated with the node based on node centrality and node degree. The initial number of CHs is computed as per equation 19.During main processing phase, each node waits for a time inversely proportionate to their residual energy. Hence, a higher energy node has a shorter wait time and vice-a-versa. If a node does not receive CH announcement till the expiration of wait timer then it declares itself as CH and sends a status message. This eliminates probabilistic election of CHs. During the finalization phase a node joins to the least-cost CHs if it has received CH announcement from CHs, otherwise it declares itself as final CH. HEED-NPF extends network lifetime by *20%* compared to HEED for a given network setup.

2.37.Reliable State-Full Hybrid Energy Efficient Distributed clustering protocol for wireless sensor networks: RS-HEED [41]

Authors have presented reliable query driven state-full hybrid energy efficient distributed clustering protocol named RS-HEED. Like HEED, RS-HEED uses residual energy as primary parameter and communication cost as a secondary parameter to elect cluster heads periodically. Once CHs are elected, a connection setup phase is executed that does the reliable data delivery from sensor nodes to BS.

2.38.A Comparison of HEED Based Clustering Algorithms -- Introducing ER-HEED [42]

In this paper, authors have presented a novel variation of R-HEED named ER-HEED. ER-HEED creates equal size cluster to improve the network lifetime of WSN compared to HEED. The cluster head election and cluster formation phase of ER-HEED is same as the HEED. A rotation phase is introduced in ER-HEED wherein current CH designates the role of CH to a node with the highest residual energy within the cluster. A re-clustering is required when any node dies.

3. Heterogeneous Hierarchical Clustering Algorithms

LEACH-like homogeneous protocols fail to provide prolonged network lifetime in heterogeneous environments wherein all the nodes of a network do not have same initial energy. Hence, different protocols have been designed that can work in heterogeneous environments and few of them are discussed and summarized in this section.

3.1. SEP: A Stable Election Protocol for clustered heterogeneous wireless sensor networks [43]

SEP is designed with the aim to extend stability period (the time between network setup and the death of the first node) and to minimize instability period (the time between the death of the first node and death of the last node). SEP is designed for heterogeneous WSN wherein *m* fraction of total nodes (*n*) is given α times higher energy.These nodes are called as advanced nodes and the remaining nodes are called as normal nodes. The cluster head election probability for advanced nodes and normal nodes is given by equation 20 and 21 respectively. Here, *Popt*refers to the optimal cluster head election probability which is known to the algorithm in advance, and it is set to *10%* for SEP.

$$Padv = \frac{Popt(1+\alpha)}{1+\alpha m} \tag{20}$$

$$Pnrm = \frac{Popt}{1+\alpha m} \tag{21}$$

The threshold values for advanced and normal nodes are given by *T(Sadv)* and *T(Snrm)* respectively and it is given by equations 22 and 23. Here, *r* is the round number, *G"* is the set of nodes which are yet to be elected as CH in last *1/Padv* rounds, *G'* is the set of nodes which are yet to be elected as CH in last *1/Pnrm* rounds, and *Padv* and *Pnrm* are the cluster head election probabilities for advanced nodes and normal nodes respectively.

$$T(Sadv) = \begin{cases} \dfrac{Padv}{1 - Padv\left(r \bmod \dfrac{1}{Padv}\right)} & if\ n \in G'' \\ 0 & Otherwise \end{cases} \tag{22}$$

$$T(Snrm) = \begin{cases} \dfrac{Pnrm}{1 - Pnrm\left(r \bmod \dfrac{1}{Pnrm}\right)} & if\ n \in G' \\ 0 & Otherwise \end{cases} \tag{23}$$

3.2. Enhancing Clustering in Wireless Sensor Networks with Energy Heterogeneity [44]

In this paper, SEP-E protocol is presented that extends SEP protocol and works with three levels of nodes heterogeneity. SEP-E assigns α times higher energy to *m* fraction of total nodes (*n*) called advanced nodes, β times higher energy to μ fraction of total nodes (*n*) called intermediate nodes, and the remaining nodes are normal nodes. The cluster head election probabilities for advanced node, intermediate nodes, and normal nodes are given by equation 24, 25 and 26 respectively.

$$Padv = \frac{Popt(1+\alpha)}{1+\alpha m+\beta\mu} \tag{24}$$

$$P\text{int} = \frac{Popt(1+\mu)}{1+\alpha m+\beta\mu} \tag{25}$$

$$Pnrm = \frac{Popt}{1 + \alpha m + \beta \mu} \tag{26}$$

The threshold value for advanced node, intermediate node, and normal node is given by equation 22, 27 and 23 respectively. Here, *T(Sint)* denotes the threshold value for intermediate nodes.

$$T(S\text{int}) = \begin{cases} \dfrac{P\text{int}}{1 - P\text{int}\left(r \bmod \dfrac{1}{P\text{int}}\right)} & if\ n \in G''' \\ 0 & Otherwise \end{cases} \tag{27}$$

3.3. REEH: Residual Energy Efficient Heterogeneous Clustered Hierarchy Protocol for Wireless SensorNetworks [45]

REEH uses equation 3 to calculate threshold value *T(n)* for each node, but it differs from [6] in terms of heterogeneity. REEH assigns more energy to *10%* of the total node to increase the lifetime of WSN.

3.4. Design of a distributed energy-efficient clustering algorithm for heterogeneous wireless sensor networks [46]

Authors have presented a new distributed energy-efficient clustering algorithm for heterogeneous wireless sensor networks named DEEC that does the probability based cluster head election wherein the probability is given by the ratio between residual energy of each node and the average energy of the network. This increases the probability of higher energy nodes to become CHs as compared to lower energy nodes. The epoch size is also different for each node. DEEC also supports multi-level of nodes' heterogeneity.

3.5. Advanced Low Energy Adaptive ClusteringHierarchy [47]

Advanced Low Energy Adaptive Clustering Hierarchy (A-LEACH) uses heterogeneous architecture by providing α times more energy to*m* fraction of nodes called the CAG i.e. nodes selected as clusterheads or gateways, and rest of (*1– m*) **n* will be the normal nodes. A-LEACH usesthe similar approach proposed in LEACH to select CH. CAG nodes will be workingas gateway nodes, except those are selected as a CH for the current round. It helpsto increase the stability period.

3.6. Distance Based Multi Single Hop Low Energy Adaptive Clustering Hierarchy (MS LEACH) Routing Protocol in Wireless Sensor Network [48]

In this paper authors have proposed a heterogeneous routing protocol named MS LEACH with the aim to improve the lifetime of the WSN. The MS LEACH protocol uses two-hop communication to transmit data from CH_i to sink if the distance between CH_i to sink is larger than average distance of all the CHs from sink; otherwise the protocol uses direct communication between CH and sink.

3.7. Energy efficient hybrid clustering protocol for multilevel heterogeneous wireless sensor network [49]

This paper proposed a new energy efficient hybrid clustering protocol (EEHCP) to enhance the lifetime of heterogeneous WSN with three improvements: i) limits number of CHs per rounds, ii) each node transmits its data to BS using either single-hop direct communication or multi-hop communication depending upon its residual energy and distance to BS, and iii) optimal CH election probability is defined on the basis of residual energy of the nodes. It has been shown in the paper that EEHCP improves stability period by *75%* when compared to SEP and LEACH protocols.

3.8. Multi-level stable and energy-efficient clustering protocol in heterogeneous wireless sensor networks [50]

A stable and energy-efficient clustering (SEEC) protocol for heterogeneous WSNs is proposed in this paper. A network consists of *m*advanced node and *n* normal nodes. Hence, the network is made of total *N* nodes where $N=m+n$. The *m* advanced nodes act as cluster heads throughout the lifetime of the network. These advanced nodes are equidistant from each other including BS. The normal nodes transmit their data to CHs and CH forwards data to BS. This paper also presented M-SEEC protocol with three-levels of heterogeneity and three levels of data transmission.

3.9. Energy efficient heterogeneous DEEC protocol for enhancing lifetime inWSNs [51]

Authors have proposed a model parameter θ in the paper that makes the WSN as homogeneous network (hetDEEC-1), heterogeneous network with two-levels of node heterogeneity (hetDEEC-2) or heterogeneous network with three-levels of node heterogeneity (hetDEEC-3). The model parameter θ takes a value between [0,1]. The paper has derived the optimal value of θ for all three types of networks to reduce the cost of the network as the cost of the sensor nodes increases with increase in the capacity to store maximum energy. The CH election probability for normal, advanced and super nodes for hetDEEC-3 network is given by equation 28, 29 and 30 respectively.

$$Pnrm = \frac{Popt * Ei(r)}{\left(\theta+\theta^2 * \frac{E1}{E0} + \left|1-\theta-\theta^2\right| * \frac{E2}{E0}\right) * \overline{E(r)}} \tag{28}$$

$$Padv = \frac{Popt(1+\alpha) * Ei(r)}{\left(\theta+\theta^2 * \frac{E1}{E0} + \left|1-\theta-\theta^2\right| * \frac{E2}{E0}\right) * \overline{E(r)}} \tag{29}$$

$$P\sup = \frac{Popt(1+\beta) * Ei(r)}{\left(\theta+\theta^2 * \frac{E1}{E0} + \left|1-\theta-\theta^2\right| * \frac{E2}{E0}\right) * \overline{E(r)}} \tag{30}$$

Here, *E0, E1*and *E2* denote the initial energy of normal nodes, advanced nodes, and super nodes respectively, *Ei(r)* is the residual energy of a node at round r and $\overline{E(r)}$ is the average energy of the network at round *r*. The threshold value for normal nodes, advanced nodes, and super nodes is given by equation 1, wherein *p* is replaced with *Pnrm*, *Padv* and *Psup*(equations 28, 29 and 30).

3.10.An Energy-Aware Distributed Unequal Clustering Protocol for Wireless Sensor Networks [52]

An Energy-Aware Distributed Unequal Clustering (EADUC) protocol is proposed which is distributed in nature, balances energy consumption of a network by evenly generating CHs with acceptable overhead, and avoids isolation points and the energy-hole problem for homogeneous and heterogeneous networks. The protocol has two phases: cluster setup phase and data transmission phase. Cluster setup phase is further divided into three phases: neighbour node information phase, cluster head competition phase, and cluster formation phase. Each phase has associated time duration by which the corresponding phase is completed. Each node communicates its current energy to its neighbouring nodes during neighbour node information phase. During cluster head election phase each node waits for *Ti* time. A node elects itself as CH if it does not receive CH announcement within *Ti* time, otherwise it works as a member node. Each non-CH node joins to the nearest CH during cluster formation phase. A CH sends its data directly to BS if its distance from BS is less than threshold DIST_TH; otherwise it sends data through relay nodes during data transmission phase.

3.11.An improved energy aware distributed unequal clustering protocol for heterogeneous wireless sensor networks [53]

This paper presents an improved version of EADUC that considers the location of the BS, residual energy of nodes and node degree to elect cluster heads. The relay nodes are selected based on energy metric rather than distance metric. It also reduces clustering overhead by using the same CHs for a few consecutive rounds.

3.12.Z-SEP: Zonal-Stable Election Protocol for Wireless Sensor Networks [54]

Z-SEP divides the entire network into three zones: zone-0, zone-1 and zone-2. BS is available in the centre of the node deployment area. Normal nodes are deployed in zone-0, while advanced nodes are deployed in zone-1 and zone-2. Zone-1 and zone-2 are far away from BS as compared to zone-0. Normal nodes transmit their data directly to BS, while advanced nodes transmit their data through CH. The cluster head election probability and the threshold value for advanced nodes are given by equation 20 and 22 respectively. Z-SEP improves stability period by *50%* compared to SEP by deploying different types of nodes into different zones.

3.13.Energy Consumption Rate based Stable Election Protocol (ECRSEP) for WSNs [55]

Energy Consumption Rate based Stable Election Protocol (ECRSEP) is proposed in the paper wherein each node elects itself as CH based on the weighted election probability given by energy consumption rate (ECR) of the node. The optimal CH election probability of advanced nodes and normal nodes is given by equation 31 and 32 respectively.

$$Padv = \frac{Popt\left(\frac{E(i)-E(r)}{r-1}\right)}{1+\alpha m} \qquad (31)$$

$$Pnrm = \frac{Popt(1+\alpha)\left(\frac{E(i)-E(r)}{r-1}\right)}{1+\alpha m} \qquad (32)$$

Here, *Popt* is the optimal number of cluster heads per round and it is *10%* for ECRSEP, *E(i)* is the initial energy given to the node *i*, *E(r)* is the remaining energy of the node *i* at round *r*, *m* is the percentage of advanced nodes with α times more energy compared to normal nodes. The threshold value for advanced nodes and normal nodes is given by equations 22 and 23 respectively wherein *Padv* and *Pnrm* take the value as per the equations 31 and 32.

3.14.EM-SEP: An efficient modified stable election protocol [56]

EM-SEP has extended the SEP protocol to enhance the stability period of WSN. The optimal cluster head election probability of EM-SEP is same as SEP. The threshold value for advanced node and normal nodes for EM-SEP and SEP are also same with one exception. The epoch size for advanced nodes and normal nodes are different for SEP and it is given by *1/Padv* and *1/Pnrm* respectively. However, EM-SEP uses the same epoch size for advanced nodes and normal nodes and it is given by *1/Pnrm*.

3.15.TSEP: Threshold-sensitive Stable Election Protocol for WSNs [57]

TSEP defined cluster head election probability for advanced node, intermediate node and normal node given by equation 24, 25 and 26 respectively and corresponding threshold values are given by equation 22, 27 and 23 respectively. TSEP defines the hard threshold value (HT) and the soft threshold value (ST). Each node sense the physical phenomenon of interest (SV) continuously within the given region of interest. The node transmits its data only when SV is greater than HT or the different between the current sensed value and sensed value in the recent past is greater than the ST.

3.16.SEP-E (RCH): Enhanced Stable Election Protocol Based on Redundant Cluster Head Selection for HWSNs [58]

This paper has proposed a new protocol named SEP-E(RCH) that elects the initial cluster head for the current round based on the residual energy of the node and redundant cluster heads (RCHs) is to be elected based on its residual energy and mean distance from the member nodes. The optimal CH election probability for advanced node, intermediate node, and normal nodes are given by equation 33, 34 and 35 respectively.

$$Padv = \frac{Popt(1+\beta)}{1+m*(\alpha+\beta m0)} \tag{33}$$

$$P\text{int} = \frac{Popt(1+\alpha)}{1+m*(\alpha+\beta m0)} \tag{34}$$

$$Pnrm = \frac{Popt}{1+m*(\alpha+\beta m0)} \tag{35}$$

The threshold values for advanced nodes, intermediate nodes, and normal nodes are given by equations 22, 27 and 24 respectively. Each node generates a random number *rand(s)'* (see equation 36), which is compared with the threshold value given by equation 22, 27 and 24 for advanced nodes, intermediate nodes, and normal nodes. If the random number is smaller than threshold value node elects itself as Initial CH (ICH) for the current round.

$$rand(s)' = rand(s)*\left(E\max - \frac{Ecurrent}{E\max}\right) \tag{36}$$

Here, *rand(s)* is the random number between 0 and 1, *Emax* and *Ecurrent* denote the initial and current energy of the node. The node within the cluster that has higher energy than all other node except the initial cluster head (ICH) can be selected as the redundant cluster head (RCH). The final cluster head is to be selected from ICH and RCH based on the current residual energy and mean distance from the member nodes.

4. Concluding remarks and future scope

This paper summarizes the survey of various clustering schemes for homogeneous and heterogeneous networks. Recent development in clustering algorithms is summarized in Table 1 on the basis of the methodology adopted to elect cluster heads, various parameters considered to elect CHs, the level of heterogeneity (if applicable), the number of hop-counts to communicate data to BS for both types of networks. The protocols are also classified on the basis of scalability, energy efficiency and data aggregation requirements. It has been observed from the survey that the residual energy of nodes is the most important parameter for the cluster head election algorithms to enhance the lifetime of WSNs. Distance to BS, node degree and mean distance from neighbour nodes are also good parameters for the CH election scheme. WSN lifetime can be extended further if multi-hop communication with in-network aggregation scheme is used for data communication. Selection of "next-hop" in multi-hop communication also plays a major role as far as network longevity is concerned.

This survey has considered the clustering schemes with stationary nodes only. A survey on clustering algorithms for networks consisting of mobile nodes, mobile sink or both can be considered as future scope.

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Table1: Summary of Clustering Technique

Protocol	Methodology adopted for CH election	Node Parameters considered for CH election	Homogeneous	Heterogeneous	Level of Energy Heterogeneity	Mobility	Scalability	Distributed	Centralize	Hop-count	Simulator	Energy efficiency	Data Aggregation
[5]	Stochastic	--	Y	N	Not Applicable	N	Good	Y	N	Single	MATLAB [59]	Good	Good
[6]	Stochastic	Residual and initial energy of Nodes	Y	N	Not Applicable	N	Good	Y	N	Single	YANA Sim	Very Good	Good
[7]	Stochastic	--	Y	N	Not Applicable	N	Very good	Y	N	Two	NS-2 [60]	Very Good	Very Good
[8]	Stochastic	Residual energy of a node and average network energy	Y	N	Not Applicable	N	Good	N	Semi centralized	Two	NS-2 [60]	Very Good	Good
[9]	Stochastic	Residual and initial energy of Nodes	Y	N	Not Applicable	N	Good	Y	N	Single	NS-2 [60]	Very Good	Good
[10]	ACO	Residual and initial energy of Nodes, distance between CHs	Y	N	Not Applicable	N	Very Good	Y	N	Multiple	Not Specified	Very Good	Good
[11]	Stochastic	--	Y	N	Not Applicable	N	Very Good	Y	N	Multiple	Not Specified	Very Good	Very Good

Protocol	Methodology adopted for CH election	Node Parameters considered for CH election	Homogeneous	Heterogeneous	Level of Energy Heterogeneity	Mobility	Scalability	Distributed	Centralize	Hop-count	Simulator	Energy efficiency	Data Aggregation
[12]	ACO	Residual and initial energy of Nodes, distance between CHs, RSSI and LQI values	Y	N	Not Applicable	N	Very Good	Y	N	Multiple	Castalia [61]	Very Good	Good
[13]	Stochastic, ACO for path selection	Residual and initial energy of Nodes	Y	N	Not Applicable	N	Good	Y	N	Multiple	Not specified	Very Good	Good
[14]	Stochastic	--	Y	N	Not Applicable	N	Good	Y	N	Single	Not specified	Good	Good
[15]	Probabilistic followed by Competitive	Residual energy of a node	Y	N	Not Applicable	N	Good	Y	N	Single	MATLAB [59]	Good	Good
[16]	Probabilistic followed by Competitive	Residual energy of a node and average network energy	Y	N	Not Applicable	N	Good	Y	N	Single	Not specified	Good	Good
[17]	Stochastic within the zone	--	Y	N	Not Applicable	N	Good	Y	N	Single	MATLAB [59]	Good	Good

Protocol	**Methodology adopted for CH election**	**Node Parameters considered for CH election**	**Homogeneous**	**Heterogeneous**	**Level of Energy Heterogeneity**	**Mobility**	**Scalability**	**Distributed**	**Centralize**	**Hop-count**	**Simulator**	**Energy efficiency**	**Data Aggregation**
[18]	Probabilistic followed by Competitive	--	Y	N	Not Applicable	N	Good	Y	N	Single	Castalia [61]	Good	Good
[19]	Stochastic	Residual and initial energy of a node, distance between CH and BS	Y	N	Not Applicable	N	Good	Y	N	Two	Not specified	Good	Very Good
[20]	Stochastic	Residual and initial energy of Nodes	Y	N	Not Applicable	N	Good	Y	N	Single	Castalia [61]	Very Good	Good
[21]	Stochastic within the region and PSO for selection of next-hop	Residual and initial energy of a node, distance between CH and BS	Y	N	Not Applicable	N	Good	Y	N	Two	Not specified	Very Good	Very Good
[22]	Fuzzy rule	Distance, node density and battery level	Y	N	Not Applicable	N	Good	Y	N	Single	MATLAB [59]	Very Good	Very Good

Protocol	**Methodology adopted for CH election**	**Node Parameters considered for CH election**	**Homogeneous**	**Heterogeneous**	**Level of Energy Heterogeneity**	**Mobility**	**Scalability**	**Distributed**	**Centralize**	**Hop-count**	**Simulator**	**Energy efficiency**	**Data Aggregation**
[23]	Probabilistic followed by Competitive	Residual and initial energy of Nodes	Y	N	Not Applicable	N	Good	Y	N	Single	Castalia [61]	Good	Good
[24]	Stochastic	Residual energy of the node and energy consumption due to data transfer	Y	N	Not Applicable	N	Good	Y	N	Single	nesC language	Good	Good
[25]	Simulated annealing	Residual energy and location of a node	Y	N	Not Applicable	N	Good	N	Y	Single	NS [60]	Very Good	Good
[26]	Stochastic	Alive nodes in the network	Y	N	Not Applicable	N	Good	Y	N	Single	MATLAB [59]	Good	Good
[27] (for sdLEACH)	Probabilistic	Node density	Y	N	Not Applicable	N	Good	Y	N	Single	OmNet ++ [62]	Good	Good
[27] for (sLEACH)	Probabilistic followed by Competitive	Residual energy of nodes	Y	N	Not Applicable	N	Good	N	Y	Single	OmNet ++ [62]	Good	Good
[28]	Sequential selection	--	Y	N	Not Applicable	N	Good	Y	N	Single	MATLAB [59]	Good	Good

Protocol	Methodology adopted for CH election	Node Parameters considered for CH election	Homogeneous	Heterogeneous	Level of Energy Heterogeneity	Mobility	Scalability	Distributed	Centralize	Hop-count	Simulator	Energy efficiency	Data Aggregation
[29]	Stochastic for CH election with ACO path selection	Residual and initial energy of Nodes	Y	N	Not Applicable	N	Good	Y	N	Multi-hop	MATLAB [59]	Very Good	Good
[30]	Competitive election	Residual energy, node degree, distance from BS	Y	N	Not Applicable	N	Very Good	Y	N	Multi-hop	Castalia [61]	Better	Very Good
[31]	Node with Smallest delay within the zone, ACO for multi-hop communication	--	Y	N	Not Applicable	N	Very Good	Y	N	Multi-hop	MATLAB [59]	Very Good	Good
[32]	Competitive	Residual energy of nodes	Y	N	Not Applicable	N	Very Good	Y	N	Multi-hop	MATLAB [59]	Very Good	Good
[33]	Bollinger Band	Current energy	Y	N	Not Applicable	N	Very Good	Y	N	Multi-hop	Castalia [61]	Better	Very Good
[34]	RSSI	--	Y	N	Not Applicable	N	Very Good	N	Y	Multi-hop	MATLAB [59]	Very Good	Good

Protocol	Methodology adopted for CH election	Node Parameters considered for CH election	Homogeneous	Heterogeneous	Level of Energy Heterogeneity	Mobility	Scalability	Distributed	Centralize	Hop-count	Simulator	Energy efficiency	Data Aggregation
[35]	Simulated annealing	Alive nodes in network	Y	N	Not Applicable	N	Good	N	Y	Single	NS [60]	Very Good	Good
[36]	Stochastic	Residual energy of the node and total network energy	Y	N	Not Applicable	N	Very Good	Y	N	Single	MATLAB [59]	Good	Good
[37]	Stochastic	Residual and initial energy of a node, neighbouring nodes, total nodes	Y	N	Not Applicable	N	Very Good	Y	N	Multi-hop	NS-2 [60]	Very Good	Very Good
[38]	Fuzzy approach	Residual energy, node degree, distance from BS	Y	N	Not Applicable	N	Very Good	Y	N	Multi-hop	MATLAB [59]	Very Good	Very Good
[39]	Probabilistic followed by Competitive	Residual energy of node	Y	N	Not Applicable	N	Very Good	Y	N	Multi-hop	Not specified	Very Good	Very Good
[40]	Competitive	Residual energy of node	Y	N	Not Applicable	N	Very Good	Y	N	Multi-hop	MATLAB [59]	Very Good	Very Good

Protocol	**Methodology adopted for CH election**	**Node Parameters considered for CH election**	**Homogeneous**	**Heterogeneous**	**Level of Energy Heterogeneity**	**Mobility**	**Scalability**	**Distributed**	**Centralize**	**Hop-count**	**Simulator**	**Energy efficiency**	**Data Aggregation**
[41]	Probabilistic followed by Competitive	Residual energy of node, Communication cost	Y	N	Not Applicable	N	Very Good	Y	N	Multi-hop	MATLAB [59]	Very Good	Very Good
[42]	Probabilistic followed by Competitive	Current energy of node	Y	N	Not Applicable	N	Very Good	Y	N	Multi-hop	Not specified	Very Good	Very Good
[43]	Stochastic	-	N	Y	Two-level	N	Good	Y	N	Single-hop	Not specified	Very Good	Good
[44]	Stochastic	-	N	Y	Three-level	N	Good	Y	N	Single-hop	Not specified	Very Good	Good
[45]	Stochastic	Residual energy of a node	N	Y	Two-level	N	Good	Y	N	Single-hop	NS-2 [60]	Very Good	Good
[46]	Stochastic	Residual energy of a node	N	Y	Multi-level	N	Good	Y	N	Single-hop	MATLAB [59]	Very Good	Good
[47]	Stochastic	Residual energy of a node	N	Y	Two-level	N	Good	Y	N	Single-hop	MATLAB [59]	Very Good	Good
[48]	Stochastic	--	N	Y	Two-level	N	Good	Y	N	Multi-hop	MATLAB [59]	Very Good	Good
[49]	Stochastic	Residual energy of a node and average network energy	N	Y	Three-level	N	Good	Y	N	Multi-hop	MATLAB [59]	Very Good	Good

Protocol	**Methodology adopted for CH election**	**Node Parameters considered for CH election**	**Homogeneous**	**Heterogeneous**	**Level of Energy Heterogeneity**	**Mobility**	**Scalability**	**Distributed**	**Centralize**	**Hop-count**	**Simulator**	**Energy efficiency**	**Data Aggregation**
[50]	Fixed	--	N	Y	Two-level/Three-level	N	Good	Y	N	Single-hop/Two-hop	MATLAB [59]	Very Good	Good
[51]	Stochastic	Residual energy of a node and average network energy	N	Y	Three-level	N	Good	Y	N	Single-hop	Not specified	Very Good	Good
[52]	Competitive	Residual energy of a node and average energy of neighbour nodes	N	Y	Multi-level	N	Good	Y	N	Single-hop	NS-2 [60]	Very Good	Good
[53]	Competitive	Residual energy of a node and average energy of neighbour nodes	N	Y	Multi-level	N	Good	Y	N	Single-hop	MATLAB [59]	Very Good	Good
[54]	Stochastic	-	N	Y	Two-level	N	Good	Y	N	Single-hop	MATLAB [59]	Very Good	Good
[55]	Stochastic	Residual and initial energy of nodes	N	Y	Two-level	N	Good	Y	N	Single-hop	MATLAB [59]	Very Good	Good
[56]	Stochastic	-	N	Y	Two-level	N	Good	Y	N	Single-hop	Not specified	Very Good	Good
[57]	Stochastic	-	N	Y	Three-level	N	Good	Y	N	Single-hop	MATLAB [59]	Very Good	Good

Protocol	**Methodology adopted for CH election**	**Node Parameters considered for CH election**	**Homogeneous**	**Heterogeneous**	**Level of Energy Heterogeneity**	**Mobility**	**Scalability**	**Distributed**	**Centralize**	**Hop-count**	**Simulator**	**Energy efficiency**	**Data Aggregation**
[58]	Stochastic followed by competitive	Residual energy of nodes and mean distance from neighbour nodes	N	Y	Three-level	N	Good	Y	N	Single-hop	MATLAB [59]	Very Good	Good

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