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REVIEW PAPER

Descriptive Study and Characterization of Energy Efficient Clustering Protocols for Wireless Sensor Networks

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Abstract Wireless sensor network is comprised of some sensors. These sensors collect data from the external environment and communicate the information to the dedicated device. Energy efficiency of the wireless sensor network is a critical challenge as battery replacement is not possible in some applications like underwater surveillance, Forest surveillance, Habitat monitoring, etc. Clustering plays an important role to achieve energy efficiency. Clusters are made up some sensors with one node as cluster head among them that is responsible for aggregation and transmission of information. Cluster heads that are placed near to base station have much workload which results in continuous energy drainage at cluster head. Due to this, all nearby cluster heads become dead early. If selection of node as a cluster head and its relocation is based on the residual energy of nodes, then it results in to prolong the lifetime of cluster heads. Another issue is that when sensor nodes are not transmitting any data, still dissipate some amount of energy on idle listening. Scheduling of nodes using sleep and wake up approach can be used to increase the lifetime of the network. This paper described a review of energy efficient protocols of wireless sensor network.

Keywords WSN · Clustering · LEACH · Energy efficiency · Residual energy · Sleep and wake-up

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Introduction

Wireless Sensor Network

Wireless sensor network is an interconnection of sensors nodes to monitor physical or environmental parameters such as pressure, temperature sound, vibration etc. Sensors nodes communicate this data to the sink or base node where the data are analyzed, and useful inferences are drawn from it. A wireless sensor node in a WSN has sensing, computing device(s) apart from radio transceivers and power components. These sensor nodes have limited storage capacity, processing speed, and short duration lasting power. WSN find its applications where laying out the wires physically is difficult or is more useful to have wireless network like in healthcare, agriculture, underwater surveillance, forest fire detection, etc. But then WSN has its own challenges like Energy efficiency, Security, Coverage, Connectivity, and Responsiveness, etc. Among the challenges listed, energy efficiency is the biggest challenge as battery replacement is almost impossible in many of the cases and therefore the need is to improve techniques so that the energy consumption could be reduced to a substantial level. The paper discusses merits and demerits of some of the clustering protocols like LEACH, DEEC, LEACH-C, T-LEACH, QAC, LESCA, EBUC, BPSO-T, TCH-MAC, HEEC, etc (Fig. 1).

Clustering

Clustering is done to achieve a high energy efficiency of the network and to increase network lifetime. A cluster is a group of sensor nodes. In the process of clustering, the whole sensing field containing sensor nodes is divided into some clusters. Each cluster has a cluster head (CH) node.

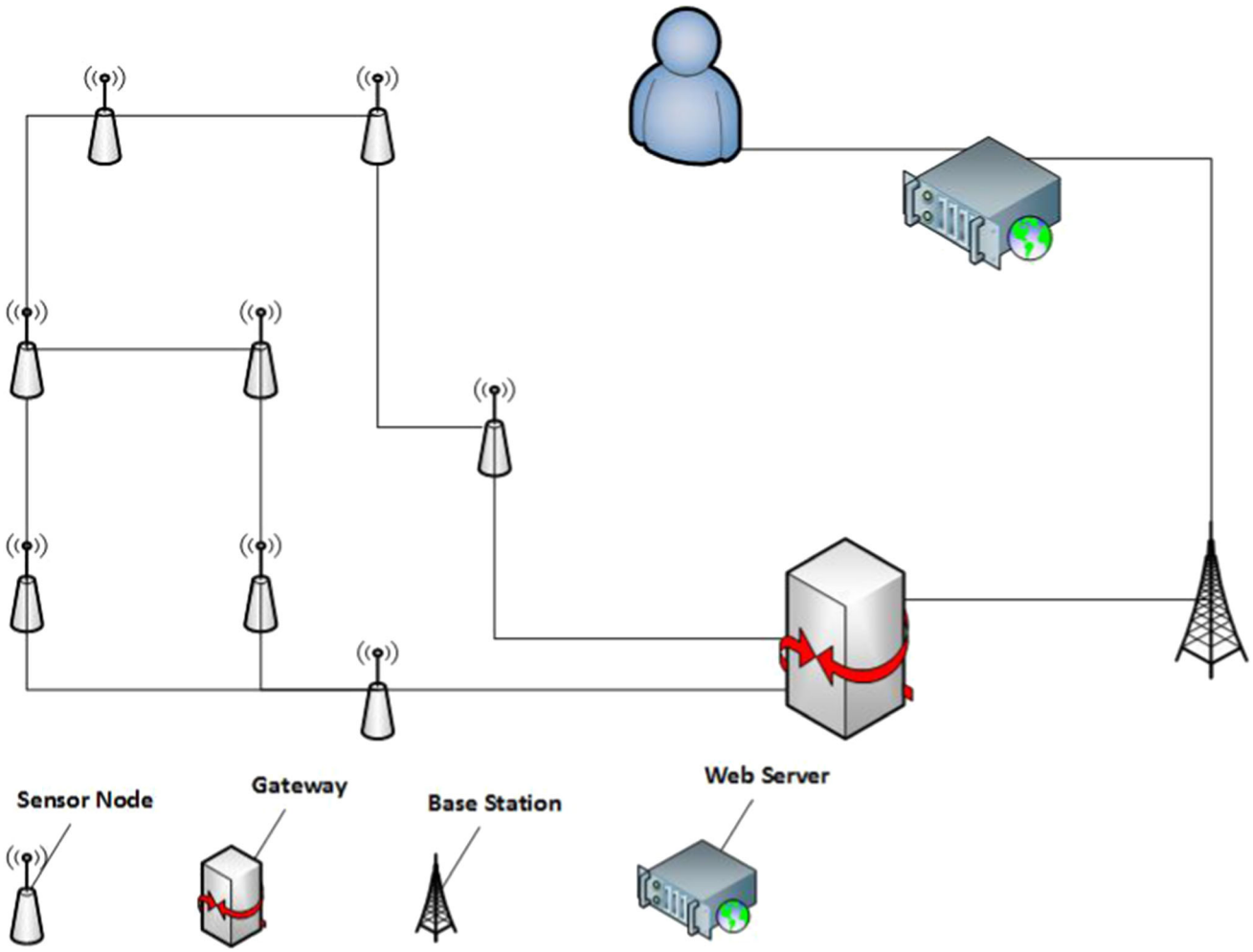

Fig. 1 WSN Architecture

All sensor nodes of a cluster send information to their respective cluster head, and then that cluster head is responsible for sending data to the base station. There are so many clustering techniques like LEACH, DEEC, LEACH-C, T-LEACH, QAC, LESCA, EBUC, BPSO-T, TCH-MAC, HEEC, etc. All clustering techniques follow their respective methods for making clusters, cluster head selection and data transmission (Fig. 2).

WSN Models and Architectures [1]

- Small, Medium, Large Scale
- Flat or Hierarchical
- Single hop or Multihop
- Stationary, Mobile, and Hybrid
- Homogeneous or Heterogeneous

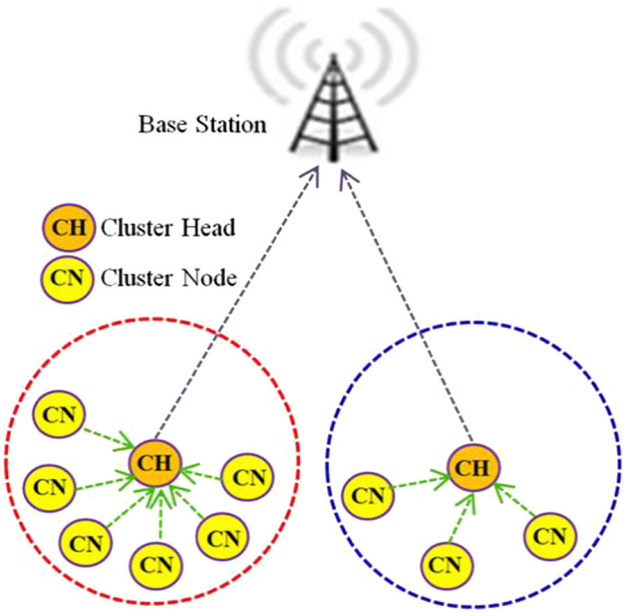

Fig. 2 Clustered WSN [30]

Literature Review

There are various clustering protocols, each having some merits and demerits. Some of the clustering protocols which have been discussed and used are LEACH, DEEC, LEACH-C, T-LEACH, QAC, LESCA, EBUC, BPSO-T, TCH-MAC, HEEC, etc. Details of the various clustering protocols are as under: -

LEACH (Low Energy Adaptive Clustering Hierarchy)

Clustering protocol LEACH has some repeated iterations, and each iteration runs with two phases: set-up and stable phase [2]. Whole sensing field division into clusters and a node selection as cluster head of a cluster is done at set-up phase. Data collection and communication were done through sensors during the stable phase. LEACH partitions the nodes into clusters containing one node as head among all nodes of the cluster. All cluster members of a cluster communicate their data to the cluster head of that cluster. The cluster head is responsible for data aggregation and transmission to the desired destination. TDMA schedule is allotted to all sensors to send their data. LEACH was introduced by Heinzelman et al. [3]. It is hinges on distributed strategy so prior network knowledge is not required, and it gives less energy consumption as data aggregation is performed by cluster head(CH) by which energy is saved by removing redundant and bulk data. Some limitations of LEACH are: LEACH assumes all nodes with the same energy capabilities when the cluster head election is done. but in reality, after some transmission of data energy capabilities become different for all nodes due to the energy consumption of data aggregation and transmission [4]. Another limitation of LEACH is that all nodes should support both TDMA(for time slot distribution) & CDMA(for data transmission).

LEACH is distributed in nature and CH selection is done by itself. Load balancing can be done with some centralized approach to elect CH. Heinzelman et al. [5] came up with an alternative of LEACH called LEACH-C. This allocation of clusters and cluster head is controlled by Base station. Like LEACH it also has Set-up and Steady Phase. Setup phase clusters are made using simulated annealing optimization algorithm on nodes by the base station (BS). Then load balancing on nodes is done by calculating the average node energy of nodes and allowing the nodes in CH selection only when they are having more energy than average. After completion of cluster formation and selection of cluster head selection, the base station disseminates this information of all nodes. The steady phase remains the same as it is in LEACH.

At each round, CH election is done, so some energy is consumed at each round. To overcome this Heinzelman et al. [5] proposed a protocol called LEACH-F. Clusters are formed using a centralized approach. A list is composed of cluster heads for upcoming rounds. The base station uses the simulated annealing optimization algorithm to find optimal clusters. Communication distance between nodes is a significant factor for energy consumption. To minimize communication distance between sensors, Chen et al. [6] proposed a protocol named ME-LEACH-L. It has four phases: CH selection, Energy-aware virtual backbone tree construction, selection of closest EVT node by CH, and communication phase. It is an energy efficient method and also adds up in the lifetime of the network, but EVT construction also adds some overhead.

Residual energy-based cluster-head election can improve the lifetime of network. Hong et al. [7] proposed threshold energy-based protocol named as T-LEACH. This cluster heads and threshold energy are predefined. When surviving energy of cluster head goes down than a threshold energy, then re-election of CH is done. It reduces the energy consumption due to CH election at every round. Threshold energy specification is a challenge here. Wang et al. [8] came up with a protocol named LEACH-H. In this, no. of CHs is fixed at each round. In the first round, the base station selects CH using simulated annealing method. Current round's CH selects the CHs for next round. This method is perfect for large scale WSN, but there is an overhead on CH to select CHs for the next round.

CH drains more energy due to communication, in case if CH dies, then there should be a node which can take responsibilities of CH. Sasikala et al. [9] proposed V-LEACH protocol. It considers the energy of CH. Besides CH and sensor nodes, there is a vice cluster-head which has the most residual energy. When the main cluster-head dies, then this Vice cluster-head takes the responsibility of main cluster-head. It gives good result in network lifetime but with some overhead.

The genetic algorithm can be used in clustering to obtain optimal results. Liu et al. [10] proposed a genetic-based Leach. It uses GA-based cluster formation and CH selection for clustering. Firstly, candidate CH selection is made. And then these share their information. The base station selects the optimal probability to form an optimal cluster. It gives good energy efficiency result with some message overhead.

Residual Energy-Based Clustering

Nodes having more residual energy should be elected as CH to prolong network lifetime. Li et al. [11] proposed a protocol called Distributed Energy-Efficient Clustering (DEEC). It is for heterogeneous wireless sensor network

and is based on the residual energy of nodes. In DEEC, cluster head selection is made on the basis of residual energy and the average energy of the network. DEEC is for the heterogeneous network where some nodes have more initial energies than others. All nodes are divided into two types: Advanced nodes and Normal nodes [11]. Nodes with more initial energy are called as Advanced nodes, and these have more chances to become a cluster head, and rest are called Normal nodes. Liu. et al. [12] proposed a protocol called Energy-Aware Routing Protocol (EAP). Nodes exchange the information of residual energy with its neighbor nodes. A table is formed at each node regarding the surviving energy of neighboring nodes. And this table is getting updated. Every node of cluster considers the broadcasting delay as contending factor to become CH. It is also based on residual energy and the average energy of the network. Chen et al. [13] came up with a protocol called QoS-based Adaptive Clustering (QAC). In QAC algorithm, there are master CH and slave CH. Some provisional CHs are allotted as master CHs. In this, a threshold value of the number of nodes is used for slave CH election by the master CH. Other member nodes of the cluster can select cluster head from master CH and slave CH. Master CH and Slave CH can relocate their functions if any out of them become dead. Ali et al. [14] proposed a protocol called LESCA. It is based on spectral classification. It considers residual energy and distance of a node to the base station to select CH. As the distance between nodes and base station is a very significant factor for energy consumption, so these distances are considered as quality parameters. Santosh et al. [15] proposed a protocol called EECPEP-HWSN. Proposed protocol selects any node as a cluster head considering current surviving energy, energy at start, and number of nodes for data transmission between node and base station.

Static and Balanced Clustering

Re-clustering consumes some amount of energy. It can be saved by static clustering. Zahematiet al. [16] proposed a protocol called EEPSC (Energy Efficient Protocol with Static Clustering). It is based on a static clustering method. The whole process has various rounds. At every round, there are three phases. Setup phase is for network subdivision. Base station makes the clusters. BS broadcast a message to all nodes with an id of desired CHs in the network. Nodes join their respective CHs. This scheme is energy efficient as it doesn't perform Re-clustering. CH election is done considering nodes survival strength. There are some flaws like scaling is not possible, as clusters are static. Cluster heads that are residing near the base station are busier than other cluster heads. If the cluster size of clusters that are near to the base station is kept small, then load on cluster head can be balanced. Jiang et al. [17] proposed a protocol called Energy-Balanced Unequal Clustering (EBUC). This protocol arranges unequal clusters. Clusters are unbalanced in the number of nodes in it. For cluster head selection energy of nodes is considered and particle swarm optimization is applied for this at Base Station. Size of clusters is small near at Base station to decrease the effect of Hot-spot. Node's distance from cluster head and cluster size can be considered in clustering to achieve energy efficiency and prolonging network lifetime. Vipin et al. [18] proposed a balanced clustering. It has two phases: Setup and Steady phase. It works on two parameters ThCluster and ThDistance. Any node can join the CH if it has members $<$ Thcluster and distance $<$ ThDistance. During Rescue Phase if above conditions do not match then the node will join the nearest cluster. This approach extends the network lifetime and lowers the node death rate. As LEACH uses the probabilistic function to select CH. Some energy is consumed due to CH rotation. Muhammad et al. [19] proposed a protocol named EE-MRP. It uses multistage data transmission. Network field is divided into multiple stages, CHs are evenly distributed which increases the throughput and overall lifetime of the network. Static cluster head selection is used to minimize energy consumption.

Sleep and Wake-up Approach for Idle Listening Problem

When sensor nodes are not transmitting any data, still dissipate some energy. This is called idle listening. To save energy, sleep and wake-up approach can be used. Sasikalaet al. [20] proposed a method in which on the basis of residual energies, nodes are kept inactive or sleep mode. Some nodes are dedicated to select cluster heads. Clusters remain in an active state while it's surviving energy is greater than a predefined threshold value. Nazir et al. [21] proposed a method of sleep and wake-up in WSN. It considers three parameters:-Transmission distance from a node to the base station, Location significance of node, and the existing environment where an event occurs. According to these three parameters, a sleep–wake up approach is applied. Dayong et al. [22] proposed a technique in which the operation manner of each node is decided by its own that whether it will sleep, listen, or transmitting. The time axis is divided into several time slots. Location and surrounding of each node decide it's appropriate time slot. Sivakumar et al. [23] proposed a method of sleep and wake-up in which CH can create a path to the BS. The request message for data is initiated by BS and is sent to the destined cluster head. Cluster head then sends a message to the required awaken nodes and sends sleep message to other nodes. Xin et al.[24] proposed a protocol named

TCH-MAC. It is based on hybrid TDMA/CSMA. It uses sleep and wakeup to reduce energy consumption. To manage data traffic of network, an adaptive approach of TDMA is used. In addition, CSMA is used for energy efficiency.

Hybrid Unequal Clustering

To achieve energy efficiency hybrid clustering can be used. Unequal clustering makes nodes more energy efficient that are near to base station. Seyed et al. [25] proposed a HEEC(Hybrid unequal energy efficient clustering). Cluster head can share some workload with cluster members.

Nature Inspired Optimization Algorithm-Based Clustering

Dexim et al. [26] proposed a protocol named DCH-NPSO. It uses two cluster head MCH and SCH in each cluster. Energy continuously consumed so remaining energy of nodes and the transmission distance between the node and the base station is considered in clustering to enhance the active age of network and energy efficiency. Niching PSO is used to select MCH and SCH in a cluster. It is used for single hop routing. Efficient placement or deployment of sensors are very important to achieve energy efficiency objective. Shanmugasundaram et al. [27] proposed a method called BPSO-T. Binary particle swarm optimization in combination with an efficient transfer function is used in clustering to make it energy efficient. Madhusudan et al. [28] proposed a nature-inspired optimization-based protocol with inherited features from firefly algorithm. In this tournament, selection algorithm is used to select population and then this selected population is used for further crossover and mutation process. The proposed method gives decreased packet loss rate. Rajeev et al. [29] proposed a protocol named ABC-ACO. In ABC-ACO, some sub regions are made from the whole region of interest. A stratified manner is used to follow some nature inspired strategies to get optimal results. At the starting phase, ABC (artificial bee colony) approach is used to select a node as cluster head. When cluster head selection is done, then ACO (Ant colony optimization) is used to find the optimal routing path. This approach helps to improve lifetime of the network by reducing energy consumption due to distance (Table 1).

Results

Since one of the major challenges in wireless sensor networks (WSN) is the energy efficiency of the sensors and therefore it is important to compare the various protocols in terms of sensors energy and for which WSN was simulated on MATLAB using the following steps and parameters with assumed values mentioned in Table 2:

1. (A) Scenario or Network Generation
2. Sensors are deployed randomly to create a region of interest (ROI) using the Random Sensors Deployment Technique.
3. (B) Cluster Head Selection
4. Few of the deployed sensors are selected as Cluster-Heads based mostly on residual energy of sensors.
5. (C) Cluster Formation
6. Grouping of sensors to form clusters each having a cluster head.
7. (D) Data Transmission
8. Information in the form of packets is transmitted from sensors in each cluster to its cluster head and cluster heads forwards the entire information to the sink after performing aggregation.

Following steps are used to simulate the implementation of protocols (Fig. 3):

The implementation requirement for any of the scenario/network created and for all protocols described above requires assigning number of sensors in the scenario/network (N),assigning initial energy to the sensors (E_0), number of rounds (R) to be used since data transmission takes place from sensors to their cluster-head and from cluster heads to sink in steps termed as Round, EDA is the energy consumed by cluster-heads in aggregating data received from sensors of their cluster, transmitting data some amount of energy is dissipated by sensors, Efs and Emp are the quantities of this dissipation in free space and multipath, respectively.

Table 3 shows comparison of various clustering protocols in terms of when the first node and last node became dead. FND denotes the round no. when the first node became dead and LND denotes the round number when last node became dead. Network lifetime can easily be seen using FND and LND and the table clearly shows that among all the protocols, LEACH has better efficiency.

Analysis of previous search trends shows that among all existing clustering protocols, in terms of network lifetime, LEACH gives good results. LEACH uses probabilistic approach for clustering. Cluster-head selection is on the basis of residual energy of nodes. Results show that taken parameter FND and LND are used to analyze the energy efficiency of clustering protocol and network lifetime. Some previous studies are also focused to determine the best performance in energy efficiency with other parameters like cluster head selection, cluster formation, etc. This work is also dedicated to analyze network lifetime (Fig. 4 and 5).

Table 1 Existing clustering protocols

Protocol	Author(s)	Year	Contribution
LEACH [3]	W. R. Heinzelman et al	2000	Energy Efficient protocol, distributed, all participants assumed as same energy efficiency
LEACH-C [5]	W. R. Heinzelman et al	2002	A centralized approach, a variant of LEACH
LEACH-F [5]	W. R. Heinzelman et al	2002	Simulated Annealing optimization is used to select cluster heads for certain no of rounds; thus energy consumption due to many CH election can be reduced
DEEC [11]	Q. Li et al	2006	Some nodes have applied with more initial energy than others. Surviving energy is a prime consideration to select cluster head for a cluster
QAC [13]	Chen et al	2006	An approach to selecting Master and Slave CHs is used. If Master CH dies then Slave will become the Master
EEPSC [16]	Zahemati et al	2007	Static clustering, it saves energy as cluster are formed once, but scalability is not possible
ME-LEACH-L [6]	Chen et al	2008	Energy-aware virtual backbone tree is constructed with residual energy of nodes. It can be used further for making some clustering decisions
EAP [12]	Liu. et al	2009	Considers the surviving energy of neighboring nodes and average network energy
T-LEACH [7]	J. Hong et al	2009	Threshold residual energy is considered to be elected as CH
LEACH-H [8]	W. Wang et al	2009	Current round's CH elect the CH for next round. There is an overhead on CH to select CH
EBUC [17]	C. Jiang et al	2010	Heterogeneity in size of the network is used. Near the base station, the size of the cluster is small than farther clusters
Genetic-based Leach [10]	J.L. Liu et al	2011	Genetic algorithm-based cluster formation. It gives good energy efficiency with some message overhead
Based on Sleep–wake up approach [21]	B.Nazir et al	2011	Node's location is used to apply sleep and wakeup approach
Sleep–Wake up Leach[20]	Sasikala et al	2013	Based on the residual energy of nodes, active nodes are only responsible for data transmission
Self-adaptive approach[22]	Dayong et al	2013	Using machine learning, the node itself decide its state: transmission, sleep or listening
Clustering on Sleep–Wake up approach[23]	Sivakumar et al	2014	A path has established to the sink that is active for transmission
Balanced Clustering[18]	Vipin et al	2015	This approach considers no. of nodes in a cluster and cluster distance to make balanced cluster
V-LEACH[9]	Sasikala et al	2015	Highest residual energy node is as vice CH and responsible for transmission of data
LESCA[14]	Ali et al	2015	It is based on spectral classification. Selection of Cluster head depends on its position with respect to the base station and its residual energy
DCH-NPSO [26]	Dexim et al	2015	Uses two cluster head MCH and SCH in each cluster. Residual energy and distance from BS is considered in clustering to prolong lifetime of network and energy efficiency
BPSO-T [27]	Shanmugasundaram et al	2015	Binary particle swarm optimization and the improved transfer function are used in clustering to make it energy efficient
Firefly based clustering Protocol [28]	Madhusudan et al	2015	Firefly algorithm is used to select the cluster head. It helps to increase the network lifetime
ABC-ACO [29]	Rajeev et al	2016	It inherits the features of Artificial bee colony optimization for CH selection and Ant colony optimization for data transmission
HEEC [25]	Sayed et al	2018	Energy consumption and overhead have reduced by eliminating excess control messages
EECPEP-HWSN [15]	Santosh et al	2018	To maximize energy efficiency, cluster head is selected in consideration with Surviving energy, energy at start, and number of nodes in between transmission path of that node and base station
TCH-MAC [24]	Xin et al	2018	It is based on hybrid TDMA/CSMA. it uses sleep and wakeup to reduce energy consumption
EE-MRP [19]	Muhammad et al	2018	Multistage data transmission and static cluster head selection is used to minimize energy consumption

Table 2 Simulation parameters (MATLAB) for implementation of protocols

Parameter Name	Description	Value
E0	Initial energy	0.5 J
Efs	Energy dissipation in free space	10 pJ
Emp	Energy dissipation in multipath transmission	0.0013 pJ
N	Total no. of nodes	200
EDA	Energy consumption for data aggregation	0.5 nJ/bit
R	Total no. of rounds	5000

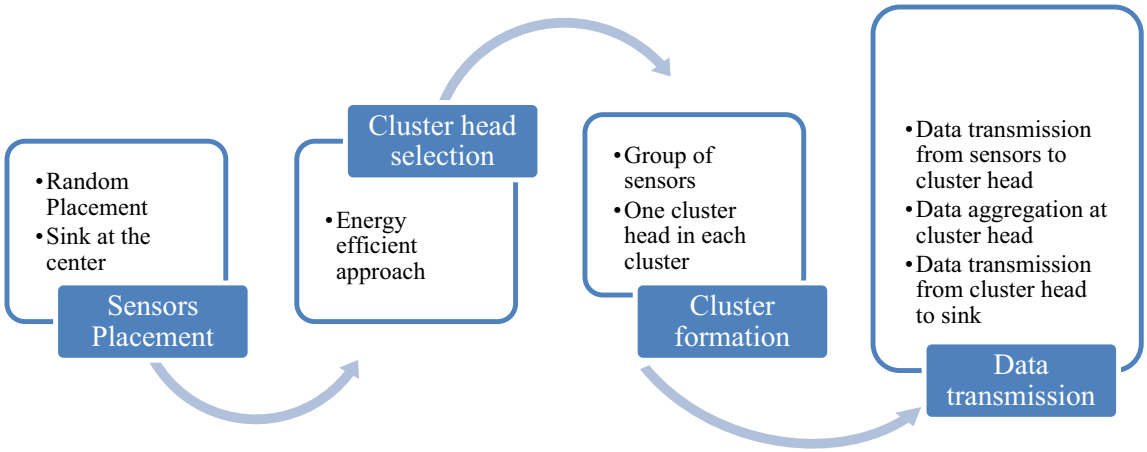

Fig. 3 Simulation steps for implementation of clustering protocols

Table 3 Comparative simulation results of clustering protocols

Parameters	LEACH	DEEC	SEP	TEEN	LEACH with heterogeneity
First node dead at round (FND)	992	1339	617	138	699
Last node dead at round (LND)	3708	3054	2166	550	3299

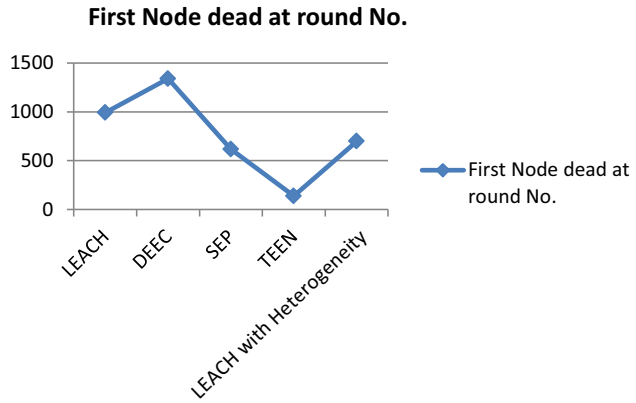

Fig. 4 Network Nodes start to become dead comparison graph of some clustering protocols

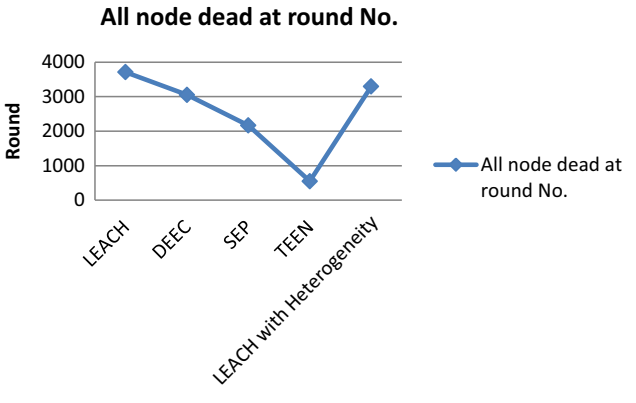

Fig. 5 Network's all node become dead comparison graph of some clustering protocols

Conclusion and Future Scope

This paper carries a meticulous review of clustering protocols in wireless sensor network considering WSN challenges. Energy efficiency in WSN is one of the major challenge problems that is very critical. For energy efficiency, there are so many topologies and strategies; clustering is one of them. A literature review has been done on some existing clustering protocols. Through this review, various attempts have been made to highlight specific simulation results related to the domain of existing clustering protocols. By analyzing results, it can be drawn that LEACH gives better results in terms of network lifetime. In this paper research of period, 2000 to 2018 is considered. This paper focuses on the energy efficiency issue, so energy efficient clustering protocols are contemplated. Sensor nodes near to base station become dead early due to excess data transmission. Some work has been done to overcome it by cluster head selection considering residual energy of nodes, the distance of nodes from the base station, the range of sensor nodes from their respective cluster heads, etc. Although existing protocols are producing good results yet there is the need to improve it. Another issue related to energy efficiency is the idle listening problem. When nodes are in an idle state (not transmitting any data), still consumed some amount of energy in listening to the data. Some papers addressed this problem and tried to decrease energy consumption by sleep and wake-up schedule. There is also some scope in the research towards efficient sleep and wakeup approach implementation.

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