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A survey on LEACH and other's routing protocols in wireless sensor network

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ABSTRACT

An extensive range of applications of Wireless Sensor Networks such as military, environment, surveillance, home, vehicle tracking/detection, traffic flow and medical make it hot-spot in the epoch of wireless networks. A WSN consisting of numerous sensor-nodes is equipped with inadequate energy, memory, and computation capability issues. Further, such networks are limited to reinstate the dead nodes caused by energy's depletion and to maximize the life-span of the system. To achieve this aim, several routing algorithms are proposed and investigated. In this work, an attempt is carried out to assess the diverse hierarchical routing protocols, developed from LEACH and is extended to other presented routing protocols like TEEN, APTEEN, and PEGASIS. Depending upon the observations and scrupulous consideration, a relative conclusion is drawn in the last.

1. Introduction

Wireless Senor Network (WSN) is a collection of large number of small size and moderately inexpensive computational nodes that forward the valuable information to a central point for appropriate processing. The environment can be an information technology framework, a biological system or a physical work. There are four parts of sensor network: (i) sensors (ii) network connecting different sensors (iii) centralized information gathering store (iv) resources performing computation which include data mining, data correlation etc. [1–3]. Sensors nodes make an ad hoc network that are useful to monitoring temperature, pressure, humidity, military surveillance, disaster management, forest fire-tracking and many more [4]. Routing in WSN is different from other wireless network due to sensor node have constraints of energy, processing activities, transmitting collected data from multiple nodes to a single sink, unique global address is not possible due to random deployment of nodes etc. Due to all of these reasons, different types of routing protocols were developed for such scenarios. All these routing protocols had considered all those inherited features of WSNs. Main aim of these protocols were to reduce power consumptions and increasing network life time. This can be achieved by implementing routing protocols that consume minimum energy, choose path between sensor nodes and base station in such manner that increase network life time. Basically, WSN routing protocols are classified into four main categories: Network structure, communication models, topology based and reliable routing schemes [5]. Network structure protocols, basically, rely upon the architecture

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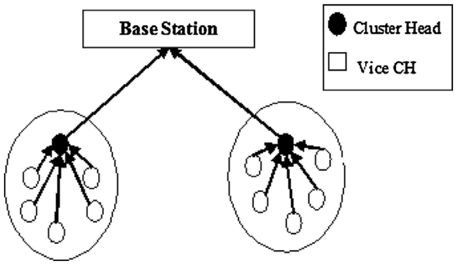

Fig. 1. LEACH clustering hierarchical model [7].

of network. Routing protocols in this category are differentiated on basis of nodes interconnection and route they follow to transmit data packets from source to destination. This leads to following types of categorisation as:

- Flat Protocol: Nodes are deployed uniformly and have same role i.e. every node is at same level inside network. FLAT protocols can be further classified as; pro-active, reactive and hybrid protocols [6].
- Hierarchical Protocols: In these types of protocols nodes are arranged into clusters and node having maximum energy becomes CH (cluster-head) of the cluster. Cluster-head coordinates activities inside and outside cluster. Cluster-head is responsible for collecting data from nodes of their cluster and removing redundancy among collected data to reduce energy requirement for transmitting of data packets from cluster-head to base station e.g. LEACH, SEP, TEEN, APTEEN etc. [7,8].
- Location based Protocols: Nodes are distinguished on basis of their location inside network. Distance among sensors nodes are calculated on basis of signal strength, higher the signal strength lesser the distance between nodes. Some protocols in this category allow nodes to go into sleep mode if there is no activity going on at that node e.g. GEAR and GPSR [9,10].

Among these categories of routing protocols of WSN, FLAT protocols have minimum overhead to maintain resources among communicating nodes [6] and hierarchy protocols reduces the size of routing tables [8]. Main aim of this paper is to review the hierarchical energy efficient routing protocols along with modifications over some of these protocols.

2. Hierarchaical protocols

In hierarchical routing protocols, nodes organize the network into set of clusters. Each cluster is managed by a selected cluster-head [11]. Cluster-head periodically collects data from member nodes of their cluster, compresses it and then removes duplicacy among collected data to reduce the number of transmission between cluster-head and base-station.

2.1. LEACH (Low energy adaptive clustering hierarchy) and its variants

LEACH is a routing protocol that collects and sends data to base station with following main objectives [7]:

- Increase network life-time.
- Decrease energy dissipation of sensor nodes.
- Reduce the number of communication messages.

To attain these objectives, nodes organizes themselves into clusters. As shown in Fig. 1, member nodes of a cluster sends their respective data to their cluster-head, which is further responsible for sending collected to base station. This results in saving the energy of sensor node because they have to spend lesser energy to send their data to cluster-head instead of base-station.

Moreover, cluster-heads aggregates collected data to remove redundancy among similar data and hence reduces the transmitted data to the base station. This results in saving large amount of energy, as aggregated data is sent over a single hop. LEACH operates in two diverse phases including setup- and state-phase. The setup phase is further categorised as cluster-head selection and cluster formation. Cluster-head selection ensures that this role rotates among all sensor nodes; to evenly distribute energy consumption among all network nodes. So, selected cluster-head last long only for a round and this role is rotated among other nodes so that selected cluster-head did not die soon. To find out its turn to act as cluster-head, node 'n' generates a random number between 0 and 1 and compare with the cluster-head selection threshold T (n). A node becomes cluster-head if its generated number is less than a threshold T (n) [4,11]. Cluster-head threshold ensures two things: First, only predetermined fractions of nodes, P, become cluster-head. Second, node which acts as cluster-head in last 1/P rounds are not selected as cluster-head. To meet these requirements threshold is set as:

$$T(n) = \begin{cases} P/1\text{-}p^{*}(r \bmod 1/p) & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases}$$

where, r is the current round, and G is the set of nodes that have not been cluster-heads in the last 1/p rounds. At the end of cluster-head selection process, every node selected as cluster-head advertise its new role to rest of the network. After receiving the cluster-head advertisement, remaining nodes selects a cluster to join on basis of received signal strength and inform their selected cluster-head of their wish to become a member to this cluster. After cluster formation, each cluster-head creates and distributes TDMA schedule among each member of their cluster. This ends the setup phase and starts the setup state phase. During steady phase each node transmits sensed data to cluster-head during its allocated time slots.

3. Different LEACH variant's

Non-uniform distribution of cluster-head is the main drawback of LEACH that leads to early fading of battery of cluster-head and hence, lowers the network life-time. This limitation is overcome in descendants of LEACH protocol which are discussed as:

3.1. C-LEACH (Centralized LEACH)

In LEACH, every node takes its own decision to become a cluster-head, but the main limitation is that there is no guarantee for cluster-head position and number of nodes in each cluster. In other words, LEACH algorithm does not guarantee about the location of cluster-head, which may effectively decrease the overall performance during some rounds.This may makes LEACH ineffective protocol. C-LEACH, a central control algorithm is used to make clusters in such a way that cluster-heads are scattered throughout the network [12]. This algorithm is implemented at base station, which selects nodes to make them cluster-head for current round. Every sensor node sends their current location (using GPS) and residual energy to the base station. Base station calculates the average node energy and nodes that have energy less than average cannot become cluster-head for that round. After cluster-head formation, base station broadcast this information to all nodes in the network, using a message which contains the cluster-head ID for every node. Node having same ID became cluster-head for that round and rest of nodes goes into sleep mode until their turn comes up for data transmission. Cluster formed on such basis are better than the cluster formed in LEACH. Steady-state phase of C-LEACH is same as that in LEACH, every node sends their data to cluster-head and cluster-head after doing data aggregation sends compressed data to base station. Overall, C-LEACH performs better than LEACH because it consider position of nodes inside network and creates cluster-head in such a way that they are scattered throughout network which makes loads to distribute evenly among the cluster-heads.

3.2. MODLEACH

MODLEACH another cluster based algorithm differs from LEACH mainly on two points. One, there is no need to change cluster-head until and unless it has more energy than the certain required threshold. Second, MODLEACH did not amplify all the signals to same level.

In LEACH, cluster-head is changed after every round, so as to save the cluster-head to die early. But, in MODLEACH current cluster-head is replaced by new one only if current cluster-head does not have energy less than the required threshold. It saves energy consumed in cluster formation and forwarding the routing packets for searching another new cluster-head [13]. In each round, if the residual energy of current cluster-head finds to be more than the minimum threshold value, then the current cluster-head will remain cluster-head for new round. MODLEACH categorised communication into three categories: (1) Intra cluster communication (2) Inter cluster communication (3) Data transmission from cluster-head to base station. Energy required for intra cluster communication is different from inter cluster or cluster-head to base station communication. So, different kind of amplification is required for different packets depending upon their type. Earlier in LEACH all packets are being amplified in same manner irrespective of type of communication.

3.3. Stable election protocol (heterogeneous LEACH)

In LEACH, every sensor node is initialized to same energy level but in Stable Election Protocol (SEP) there are two different types of nodes called as normal nodes and advanced nodes [14]. These nodes have different initial energy. There are m numbers of advance nodes in network with α additional energy. Advance node have energy $Eo^{*}(1+\alpha)$ where Eo is energy of normal nodes [14]. Advance nodes are made cluster-heads more often as compared to normal nodes because advance nodes have more energy as compared to normal nodes. So, in SEP initial energy is increased by $\alpha^{*}m$. and hence the overall life time of network increases, so instability period decreases. The observations are evaluated by considering the following parameters given in Table 1:

If death of node occurs early in the network, it results in the early death of other nodes in the network. As depicted in Table 2, it is observed that the first node of SEP dies in the last and offers the highest stability period even after increasing the node density. This is due to fact that in SEP advance nodes are made cluster-head more often and energy required for cluster-head replacement is saved. Further, it is observed that MOD-LEACH outperforms as nodes density increases because it saves energy that incurred on replacement of current cluster-head with new cluster-head.

Table 1
Performance Parameters.

Parameters	Values
Sink Location	50,50
Network Size	100 m
Number of nodes	100
CH probability	5%
Initial node power	0.5 J
Nodes Distribution	Nodes are uniformly distributed
Control Packet Size	50 bits/s
Data Packet size	1000 bits/s
Energy dissipation (Efs)	10 pJ/bit/m^2
Energy for Transmission (E_{TX})	50 nJ
Energy for Reception (E_{RX})	50 nJ
Energy for Data Aggregation (EDA)	5 nJ/bit/signal

Table 2
Comparison of Network life-time (first node dead) for LEACH, CLEACH, MOD LEACH and SEP.

No. of nodes	Round number when first node dies			
	LEACH	Centralized LEACH	MOD LEACH	SEP
100	757	1012	941	1012
200	783	1023	1003	1038
300	790	997	1017	1098
400	785	950	1019	894
500	772	921	981	930

Table 3
Comparison of percentage of dead node for LEACH, CLEACH, MOD LEACH and SEP.

Percentage of Dead Nodes (%)	LEACH	Centralized LEACH	MOD LEACH	SEP
1	755	978	1001	1068
20	989	1074	1109	1204
50	1156	1156	1200	1298
70	1232	1212	1287	1361
90	1384	1334	1407	1460
100	1665	1677	1569	1832

Table 4
Comparison of first node and last node dead in LEACH, CLEACH, MOD LEACH and SEP.

Initial Energy (J/Node)	LEACH		Centralized LEACH		MOD LEACH		SEP	
	First node dies	Last node dies	First node dies	Last node dies	First node dies	Last node dies	First node dies	Last node dies
0.25	365	841	461	795	448	778	512	1225
0.5	755	1665	978	1677	1001	1569	1068	1832
1	1507	3842	2028	2963	2116	3163	1884	3953

Table 3 shows that SEP again outperforms among the others and possesses maximum number of rounds in achieving 100% of dead nodes. This is because of making higher energy nodes as cluster-head, SEP saves energy to be incurred on cluster- head replacement. Also, it is apparent from the observations, depicted in Table 3, that as percentage of dead nodes increases, life-span of the network decreases. This happens because it creates more burdens on alive nodes that leads to more energy consumption and hence, shorter life.

Table 4 shows comparison of LEACH, Centralized LEACH, MOD LEACH and SEP over different initial energy of node.

As it is clear that as the initial energy of node increases, the death of first node and last node gets delayed in all protocols. It is also observed that in all of these protocols, the life-span of first- and last-node increases approximately two times on increasing the initial energy of node by twofold. For initial energy of 0.25 J and 0.5 J, SEP shows better results but at 1 J of initial energy, MOD-LEACH outperforms among the other protocols. This is occurred due to overhead replacement of current cluster-head with new one is more and consumes the energy (Table 5).

3.4. MH- LEACH (Multi hop LEACH)

MH-LEACH protocol makes further development in LEACH to save energy by using nodes that lies on the way to base stations [15]. MH-LEACH uses same practice of LEACH to select the cluster-heads and cluster formation. Role of cluster-head is also same i.e. performing data fusion to the received packets so as to reduce the transmitting and forwarding data in the network [4,11]. But, multi-hop LEACH possesses more life-span of nodes. This is because, during inter-cluster

Table 5
Comparison of LEACH with its variants.

Protocol	Difference from LEACH
Centralized-LEACH	Base station is responsible for making cluster by considering current position and remaining energy of sensor nodes. Base station implements optimal algorithm to select cluster-head for current round
Modified LEACH	Modified LEACH did not change cluster-head until and unless it has more energy than the certain required threshold. Also, MODLEACH amplify signals on basis of their packet types
Stable Election Protocol	SEP has heterogeneous nodes called as normal nodes and advanced nodes. Advance nodes have higher energy than normal nodes, so advance nodes are made cluster-heads more often as compared to normal nodes
Multi hop LEACH	Cluster-head instead of sending collected packet directly to base station uses sensor nodes that lie on way to base station. Protocol increases network life time by using neighbour nodes for data transmission which results in lesser energy consumption
Two Level LEACH	In TL LEACH there are two types of cluster-heads: secondary cluster-head and primary cluster-head. TL LEACH divides task of collection and transmission to secondary cluster-head and primary cluster-head respectively
Vice-LEACH	In V- LEACH there is extra cluster-head called as vice cluster-head that performs duty of cluster-head in case cluster-head dies

communication, cluster-head sends data packets to nearby cluster-head that lies on way to base station instead of sending it directly to base station and hence saves energy of cluster-head. In addition, in intra-cluster communication, nodes instead of sending data packets directly to cluster-head, it sends data to neighbour nodes that lies on way to cluster-head and saves energy. Intermediate cluster-head or node makes a decision at its own depending upon their energy level whether to accept data packets or not. So, if a cluster-head or node did not accept data packets, sensor node try to locate another cluster-head or node as per its routing Table entry.

Multi hop LEACH protocol operates in two phases. In phase 1, all the cluster-heads broadcast an announcement message and construct their routing Table depending upon level of signal (RSSI) received. Then, they make their route to base station via closest cluster-head. In phase 2, each cluster-head sends these initial routes (from routing table) to the base-station. The performance of MH-LEACH is investigated by designing a network of 200 m × 200 m consisting of 100 nodes with sink at a distance of 50 m from the network [16]. It is reported that the designed network considered cluster-head probability of 10%, packet size of 4000 bits, Efs of 10 pJ, E_{TX} of 50 pJ, E_{RX} of 50 pJ, and EDA of 5 pJ. Each node is fed by initial energy of 0.5J. The first node of simulated MH-LEACH died after 70–80 rounds as compared to LEACH because MH-LEACH saves energy by instead of transmitting data directly to base station uses intermediate node or cluster head for communication. Also, this is reason behind the 25–30 percent more network life time of MH-LEACH as compare to LEACH for varying packet size (between 1000 and 10,000 bits).

3.5. TL-LEACH (Two levels LEACH)

TL-LEACH solves the uneven energy distribution problem of LEACH that occurs due to random selection of cluster-heads. Earlier, cluster-heads were selected randomly, so different cluster-heads had different residual energy. If any low energy node or node far away from base station becomes cluster-head, cluster-head dies quickly. TL-LEACH solves this problem by dividing task of collection cum aggregation of data from nodes within cluster and transmission of collected data to base station into secondary and primary cluster-heads respectively [17–19]. Secondary cluster-head is responsible for collecting and aggregating data collected from member nodes and then forwarding to primary cluster-head; primary cluster-head is responsible for transmitting received data from secondary cluster-head to base station. TL-LEACH adheres to cluster-head selection and cluster formation process of LEACH protocol. TL LEACH evaluates following two conditions:

- Current Cluster-head (E_{cur}) energy less than the average energy (E_{avg}) i.e, $E_{cur} < E_{avg}$ where$E_{avg} = \sum_{n-1}^{n} E(i)_{cur}$.
- Distance (d) between cluster-head and base station is larger than the average distance (d_{avg}) i.e, $d > d_{avg}$ where $d_{avg} = \Sigma_{n=1}^{n} d_i$.

If primary cluster-head has either lesser energy as compare to average energy or have distance more than average distance, then another node is chosen having maximum energy in the cluster to act as secondary cluster-head. Secondary cluster-heads creates and distributes TDMA schedule among their member nodes. If there did not exist any secondary node, then it is responsibility of primary cluster-head to create and distribute TDMA schedule among the member nodes.

The author evaluated the performance of TL-LEACH, over a network of size 200 × 200 m having 200 nodes with each node have an initial energy of 0.5J and sink at a distance of 100 m from the network [18]. The designed network considered cluster-head probability of 7%, packet size of 4000 bits, Efs of 10 pJ, E_{TX} of 50 pJ, E_{RX} of 50 pJ, and EDA of 5 pJ. It has been observed that the total energy of drained out after 4000 rounds as compared to 3000 rounds for LEACH in the network

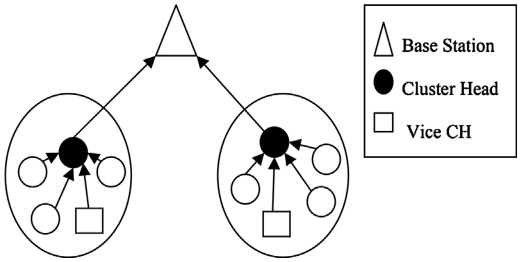

Fig. 2. V-Leach Protocol [20].

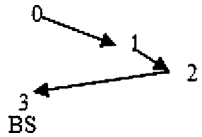

Fig. 3. Chaining in PEGASIS.

consisting of 100 nodes placed randomly in area of 100 m × 100 m. The main reason behind the prolonged life-span of the network incorporated TL-LEACH is due to the fewer cluster-head replacement.

3.6. V- LEACH (Vice-cluster-head LEACH)

In LEACH, due to random selection of cluster-heads it is quite possible that selected cluster-head has not had enough energy to transmit data to base station and dies. So, all the data that lies within cluster-head lost. V-LEACH provides solution to this problem by making an extra cluster-head called vice cluster-head [20–22]. In V- LEACH:

- Cluster-head performs same function as in LEACH i.e. collect, compress and transmit data to base station.
- If cluster-head dies vice cluster-head perform duty of cluster-head.

Cluster-head and vice-cluster-head selection are done on basis of energy, distance and residual energy. But this protocol also does not provide any solution for problem where vice cluster-head dies, results in increase of energy dissipation and hence decreasing network life time. Topology of V-LEACH is shown in Fig. 2 as:

Due to distribution of load among cluster-head and vice cluster-head, V-LEACH has 49% more network life time as compared to LEACH protocol for a designed network of size 100 m × 100 m with 100 nodes; with each node have an initial energy of 0.5J. The designed network had a cluster-head probability of 20%, base station at distance of 50 m away from filed, E_{TX} 50 pJ, E_{RX} 50 pJ, EDA 5 pJ.

4. Other heirarchial routing protocols

4.1. PEGASIS (Power efficient gathering sensor information system)

PEGASIS protocols aims at increasing network life-time of network by increasing energy efficiency and uniform energy consumption across network nodes. Further, it reduces the delay that occurs to data during their way to base station. PEGASIS assume that every node has global knowledge about other nodes positions. As compared to other protocols, PEGASIS uses chain structure for data gathering and dissemination [23–25]. In this protocol, every node work as receiver as well as transmitter to close neighbours. This means every node sends and receives one packet in each round and acts as leader of the chain one time among the other nodes of the network.

Fig. 3 shows construction of chain in a network. In this node 0 connects to closes neighbour node 1, node 1 find closest neighbour node 2 and neighbour node 2 connects to node 3. If a node among these dies, then the chain is reconstructed without the dead node. Every node except last node in chain fuses own data with its neighbour's data and then pass that to next neighbour in the chain. In the above figure node 0 will send its data to node 1. Node 1 fuses own data with this received data and forwarded this data to node 2 and pass on this data to node 3. Finally, node 3 transmits whole data to BS. PEGASIS ensures that a relatively far away node did not become leader of chain, which make node to consume more energy for transmission in every round and hence decreasing network life time. This condition was implemented by setting a threshold value on neighbour distance for any node to become leader of chain. Further, an improvement was achieved on PEGASIS that evaluates the threshold neighbour-distance along with the threshold energy-level of nodes those offer themselves to act as a leader. PEGASIS performs better than LEACH due to elimination of overhead of dynamic cluster formation, reduction of transmission distance between non cluster-head nodes and transmission of data from chain leader to base station in one

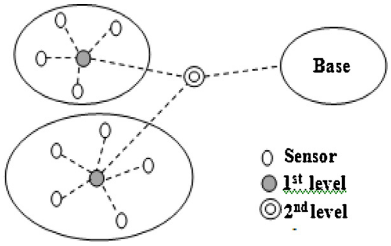

Fig. 4. Hierarchical clustering in TEEN and APTEEN Protocols [26,27].

go only. In a network of 100 randomly distribute nodes, PEGASIS protocol prolonged the life-span of the network two times as compared to LEACH. The results are reported for a network size of 50 m × 50 m with base station located at distance of 25,150 m. In second scenario, it has three times more life as compared to LEACH when 1%, 20%, 50% and 100% of nodes died in a network of size 100 m × 100 m with base station located 50,300 m away from the field area. This behaviour is due to the uniform distribution of load among all the nodes in the network (Fig. 4).

4.2. TEEN (Threshold sensitive energy efficient sensor network)

TEEN is a first reactive cluster based hierarchical routing protocol in which the cluster-head is also responsible for broadcasting hard threshold and soft threshold values to its member nodes [26]. In this scheme, the nodes keep on sensing the environment continuously and start transmitting sensed data to the cluster-head only when attribute cross its hard threshold value. Initially, if sensed attribute reaches its hard threshold; this value is stored in the parameter called as sensed-value (SV) parameter. Further, node will transmit data if it finds sensed value is either greater than the hard threshold-value or the difference between the sensed-value and SV parameter is more than or equal to soft threshold. This leads to decrease in number of data transmission attempts and saves energy. In addition to it, soft threshold also decreases the numbers of transmissions. It did not allow any further transmissions if the sensed value is smaller than the broadcasted soft threshold value. Major limitation of this protocol is if sensed attribute never reaches its threshold, node will not send any data to cluster-head i.e. there will be no communication and hence, the user will be unaware of the death of all nodes. So, TEEN is never used where application requires data constantly. Furthermore, it has been observed that TEEN (soft-threshold) offered energy dissipation at half rate as compared to LEACH for a designed network of 100 nodes having initial energy of 2 J placed randomly in filed size of 100 m × 100 m due to periodic transmission to base station.

4.3. APTEEN (Adaptive threshold TEEN)

Both TEEN and APTEEN uses two level clusters to send their data to base station as shown in Fig. 3. Basically APTEEN is an enhancement over TEEN protocol and designed especially for hybrid networks in which cluster-head broadcasts following parameters to their member nodes [27]:

- Physical parameters
- Threshold values.
- TDMA schedule.
- Maximum time between consecutive reports.

In TEEN, TDMA scheduling ensures that no collision occurs during data transmission from member nodes to cluster-head, but causes delay. APTEEN resolves this problem by modifying TDMA schedule by adding CDMA schedule to it [27]. This modification allows sleeping nodes to send their data followed by idle nodes. APTEEN helps in historical analysis of previous data values, monitoring of an event and snapshot of the current network. The author has evaluated the performance of APTEEN with LEACH and TEEN in terms of energy consumption and no of alive nodes [27]. And found that performance of APTEEN lies in between LEACH and TEEN because APTEEN transmits data periodically whereas TEEN transmits time critical data.

5. Improvement over heirarchail routing protocol

5.1. DFCA (Distributed fault tolerance clustering algorithm)

In DFCA, gateways have more energy than the normal node and made as cluster-heads [28]. These special nodes are also battery operated and hence, limited life time. Consequently, their proper usage in network increases the life-time of the network. DFCA also implemented fault tolerance to tackle the death of gateways [28]. A sensor node select nearby gateways on the basis of: remaining energy of gateway, distance of node to gateway and distance of gateway to base station. Nodes are

Table 6
Comparison of DFCA between 100 v/s 360 nodes over different parameters.

Parameters	DFCA	
Area	300 × 300	100 × 100
No of nodes	360	100
Covered Nodes	290	69
No of gateways	36	9
Nodes having backup	34	22
Energy Left	120.1256	28.9414
Routing Overhead	9.0580	5.8500
Number of Rounds When First Node Dies	1398	1238

Table 7
Comparison of EDFCA between 100 v/s 360 nodes over different parameters.

Parameters	EDFCA	
Area	300 × 300	100 × 100
No of nodes	360	100
Covered Nodes	310	84
No of gateways	36	7
Nodes having backup	14	22
Energy Left	160.2568	43.1022
Routing Overhead	2.8540	0.8400
Number of Rounds before First Node Dies	1470	1267

distributed randomly in WSN and due to random deployment cluster-heads may have unequal number of nodes and some nodes may be left uncovered. These uncovered nodes communicate with the cluster-head indirectly (by using cluster-head of the covered set). But as number of uncovered nodes increases, energy to find cluster-head increases and hence network life-time decreases.

In DFCA, base station assigns unique identity to all nodes including gateways in the network and then sends HELLO messages (consisting of gateway identity, residual energy and distance to base station) to each gateway. From the strength of received HELLO message gateway compute their distance from base station. As in LEACH, sensor nodes join nearest gateway and every gateway made their own clusters. After completion of cluster formation, steady phase starts in which gateways starts receiving data from sensor nodes of their cluster, aggregate them and send them to base station using TDMA scheduling.

Fault tolerance is implemented during steady state. If sensor nodes of any cluster did not receive any data or any message from gateway that means some fault occurs at gateway. So, all nodes of this cluster become inactive nodes. This can be confirmed by broadcasting HELP message to nodes of neighboring nodes. If reply comes from the sensor node of the neighbour cluster then that inactive nodes start sending their data to neighbour gateway through neighboring node(s) called as backup node (s). Later, inactive node join's this new gateway and start sending data to new gateway directly i.e. without using backup node. But the load over the newly joined gateway tends to increases which ultimately decreases life of that gateway. The author has investigated two networks over size of 100 m × 100 m and 300 m × 300 m consisting of 100 and 360 nodes with 9 and 36 gateways respectively [28]. In both networks each node has an initial energy of 2 J whereas each gateway has an initial energy of 10 J. Table 6 shows the performance of DFCA algorithm over these two networks.

From Table 6, it is clear that DFCA performs better with 300 nodes randomly distributed over area of 300 m × 300 m than network of 100 nodes randomly distributed over field size of 100 m × 100 m although both are fed with same initial energy. This means in spite of catering more number of nodes in larger area, there are lesser overhead spent on searching backup nodes using HELLO messages (again an overhead or source of energy wastage). Also, more number of back up nodes in this network means easier availability of backup nodes, results in lesser energy consumption for searching of backup node.

Further, an improvement over DFCA named as EDFCA is reported in which whole area is divided into grids. In these grid-areas, the nodes are randomly distributed but with the condition that every grid should have equal number of nodes. Main advantage of implementing grid approach is that it increases the covered nodes, decreases broadcast messages sent by uncovered nodes for finding new gateway. So EDFCA decreases the routing overhead and hence decrease the energy consumption for routing.

EDFCA also improved fault tolerance algorithm of DFCA (Distributed Fault Tolerance Clustering Algorithm). In DFCA, whenever the gateway of any cluster is dead, then the inactive nodes of that cluster joins neighboring gateway and start sending their data to base-station using this new gateway. But the load over the newly joined gateway increases and by virtue of this network life-time decreases.

This limitation is removed in EDFCA by making maximum residual energy node among all inactive nodes as new cluster-head and forwarding member nodes data to base station using this new cluster-head.

EDFCA evaluated two networks of size 100 m × 100 m (divided in grid of 3 × 3) and 300 m × 300 m (divided in grid of 6 × 6) consisting of 100 and 360 nodes with one gateway for every grid i.e. 9 and 36 respectively. In both networks each node was fed with initial energy of 2 J and each gateway was fed with initial energy of 10 J. Table 7 shows the performance of EDFCA over these two networks:

It is also clear from Table 7 that EDFCA shows better results for larger network with number of nodes. Also, it outperforms DFCA because of lesser uncovered nodes and more number of backup nodes. This results in lesser energy consumption, would incurred on searching covered node and backup node.

5.2. TSEP (Threshold sensitive stable election protocol)

TSEP is a reactive protocol in which nodes continuously sense environment but transmit only when threshold of different parameters (set by user) is reached [29]. Main disadvantage of this protocol is sensed parameters did not cross threshold values, used did not get any information. It has three different types of nodes: normal nodes, intermediate nodes and advance nodes. Advance nodes have maximum energy, nodes having minimum energy are normal nodes and nodes having energy between advance nodes and normal nodes are called as intermediate nodes. TSEP selects cluster-head on principle of LEACH i.e. if generated value is less than threshold then this node become CH. But threshold is calculated on following basis:

$$T_{\mathrm{nrm}} = \begin{cases} \dfrac{Pnrm}{1 - Pnrm\left[r.mod\dfrac{1}{Pnrm}\right]} ifNnrm \in G' \\ 0 otherwise \end{cases}$$

$$T_{\mathrm{int}} = \begin{cases} \dfrac{Pint}{1 - Pint\left[r.mod\dfrac{1}{Pint}\right]} ifNint \in G'' \\ 0 otherwise \end{cases}$$

$$T_{\mathrm{adv}} = \begin{cases} \dfrac{Padv}{1 - Padv\left[r.mod\dfrac{1}{Padv}\right]} ifNadv \in G''' \\ 0 otherwise \end{cases}$$

where G′, G″ and G‴ are normal, intermediate and advance nodes that have not become CH in the previous rounds. After cluster-head selection, cluster-head broadcast two values: hard threshold and soft threshold. Nodes will not transmit data packets until and unless sensed value does not reach hard threshold. As we know that soft threshold is minimum change that node should observe, so it further reduces number of transmission, results in energy saving.

RFLSEP is an improvement of TSEP, in which level of heterogeneity is increased from three to five namely—normal nodes, advance nodes, intermediate nodes, super nodes and ultra nodes. Hierarchy of nodes with respect to energy is ultra nodes, super nodes, advance nodes, intermediate nodes and normal nodes. All types of nodes are 0.2% of total nodes except for normal nodes. In this protocols, the threshold for all five different types of nodes are being deliberated as

$$T_{\mathrm{nrm}} = \begin{cases} \dfrac{Pnrm}{1 - Pnrm\left[r.mod\dfrac{1}{Pnrm}\right]} ifNnrm \in G' \\ 0 otherwise \end{cases}$$

$$\mathrm{Tint} = \begin{cases} \dfrac{Pint}{1 - Pint\left[r.mod\dfrac{1}{Pint}\right]} ifNint \in G'' \\ 0 otherwise \end{cases}$$

$$T_{\mathrm{adv}} = \begin{cases} \dfrac{Padv}{1 - Padv\left[r.mod\dfrac{1}{Padv}\right]} ifNadv \in G''' \\ 0 otherwise \end{cases}$$

$$\mathrm{Tsup} = \begin{cases} \dfrac{Psup}{1 - Psup\left[r.mod\dfrac{1}{Psup}\right]} ifNsup \in G'''' \\ 0 otherwise \end{cases}$$

Table 8
Comparison of first node and last node dead in TSEP and RFLSEP.

Area(m^2)	No of Nodes	TSEP		RFLSEP	
		First node dies	Last node dies	First node dies	Last node dies
100 × 100	100	2215	8831	2487	15566
100 × 100	250	2346	8934	2486	15465
250 × 250	250	1593	8798	2405	15424
250 × 250	100	1165	9139	2246	15768

$$T_{\text{ult}} = \begin{cases} \dfrac{Pult}{1 - Pult\left[r.mod\dfrac{1}{Pult}\right]} ifNult \in G''''' \\ 0otherwise \end{cases}$$

where, G′, G″, G‴, G⁗ and G”"' are normal, intermediate, advance, super and ultra nodes that have not become CH in the previous rounds. The proposed work investigated two protocols TSEP and RFLSEP over varying number of network size and number of nodes, where each node was fed with initial energy of 0.5 J. Table 8 shows the comparison of first node and last dead (rounds) in these two protocols and found that RFLSEP always outperforms TSEP. We also found that in both protocols, as we increase the field area for same number of nodes, death of first node occurs early because nodes have to spent large energy to transmit their data to base station. Also, if we increases number of nodes over same field area then life of nodes increases because they have to cover lesser distance (due to denser network) and that helps in energy saving.

In the last, a number of other optimization based algorithms are also investigated to enhance the network life-span for instance by combining the intra-node spatial distance with the rate of battery drain out with respect to signal transmission using modified ant colony optimization algorithm (mACO) approach [30–32].

6. Conclusion

This work presented different types of hierarchical routing protocols for wireless sensor networks. In the beginning, LEACH protocol was defined to increase the network life-time by rotating the role of data collection, aggregation and transmission to offer uniform distribution of load among all nodes. But, LEACH positioned the cluster-head randomly inside the network that restricted the prolonged network life-span. Further, to overcome this issue, the work is extended to diverse variants of LEACH for instance C-LEACH, MOD-LEACH, SEP, MH-LEACH, V-LEACH and TL-LEACH. It is observed that SEP outperforms as compared to LEACH, C-LEACH, and MOD-LEACH as the advance nodes consistently contribute to act as cluster-head that leads to less energy dissipation. Furthermore, it is computed that if nodes are fed with initial energy of 1 J (instead of 0.25 J and 0.5 J), MOD- LEACH outperforms among the other protocols. This is due to the overhead replacement of current cluster-head with new one is more that enhances the energy consumption. On introduction of PEGASIS, it has been observed that it offers prolonged network life-span about two times more than LEACH in the network. Further, it is revealed out the on increasing the network area in conjunction with the distance of base-station from field area, network life-span improves three times the LEACH. The work is extended to investigate TEEN and APTEEN hierarchical routing protocols and observed that after incorporating CDMA scheduling rather than TDMA scheduling, APTEEN performs in between LEACH and TEEN in terms of energy consumption. In the last, we proposed grid based EDFCA algorithm by dividing network into grid consisting of equal number of nodes. Each node having high initial energy relatively in a grid acts as a cluster-head and named as Gateway. The proposed scheme is the modification pre-existed DFCA protocol. The obtained observations revealed out that the proposed EDFCA exhibits high network life-time, lesser routing overhead, lesser energy consumption.

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