Low Energy Adaptive Clustering Hierarchy (LEACH) Protocol: A Retrospective Analysis

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***Abstract*—Main challenge in WSN (Wireless sensor network) faced by researcher is – battery life (energy of a node). In this paper general framework of distributed mechanism of multi-hop WN (wireless network) is considered. Cluster based routing protocols like Low Energy Adaptive Clustering Hierarchy (LEACH) , Hybrid Energy Efficiency Protocol (HEEP) , Threshold sensitive energy efficient network Protocol (TEEN) and PEGASIS efficiently manages the energy usage. But still these protocols should be thoroughly studied and revised to achieve more energy efficiency. Paper focuses on LEACH protocol, where cluster Head (CH) selection process termed as 'round' (r). Each round costs setup and steady state phase of the network. Based on study of LEACH and its variants, researcher proposes vantage point focusing on energy model (EM). EM is applied to CH and non-CH nodes for balancing energy in network.**

Keywords—Sensor Node (SN), Faulty Sensor Node *(FSN),* Wireless Sensor Network *(WSN), LEACH*

NOMENCLATURE

N	Number of nodes
t^T_{hello}	Transmission time for HELLO message
t^w_{hello}	Delay after transmitting HELLO message
t^R_{hello}	Receive frame time for HELLO message
t^T_{conn}	Transmission time for connect request
t^w_{conn}	Connect request response time delay
t^R_{conn}	Receive frame time for connected message
T_{setup}	Cluster formation time
K	Number of Clusters
T_{pow}	Transmit power
R_{pow}	Receive Power
T_{RTCT}	Response time after sending request
T_{period}	Periodic time for broadcasting HELLO message
NID	Neighbour ID
t^T_{NID}	Transmission time for NID frame
t^w_{NID}	NID response time delay
t^R_{NID}	Receive frame time for NID
LSR	Link state report
$T_{LSRPeri}$	Periodic time for sending link state report
T_{WLSR}	Response delay or maximum delay tome CH waits for not receiving LSR
T_{Topoup}	Time to transmit topology update message
QoS	Quality of service
SN	Sensor nodes
$WSBN$	Wireless body sensor network
WAN	Wide area network
AP	Access point
BS	Base station
FSN	Faulty sensor node
$AFSO$	Artificial Fish Swarm Optimization

I. INTRODUCTION

Emerging field of WSN combines sensing, computation and communication in a single tiny embedded device. Each node as single device may have restrictions, but when its collection of 'N' numbers of battery operated SN distributed in a zone deterministically or randomly based on an application then they form a sea of connectivity and extend up to physical world providing real time data for analysis [20]. These tiny devices in combination provide massive data to base station (BS). Examples one can quote are, wild life monitoring system, weather monitoring system, WSBNs –a e-health solutions for remote patient monitoring. SN are supposed to gather sensor related information and exploit communication path by hopping data from node to node in search of destination. Typically destination node may be termed as base station. Smart grid, smart homes, smart water network intelligent transportation are all connected to physical world, also referred to as Internet of Things (IoT). WSNs are regarded as a revolutionary information gathering method to build the information and communication system which will greatly improve the reliability and efficiency of infrastructure systems. These nodes are deployed in hazardous and remote area, so changing batteries is impossible or may be not feasible. Battery life matters a lot to keep node alive, where large capacity batteries cannot be deployed. Major energy utilization is due to computational operation performed and data transmission / reception.

Fig.1 depicts WSN generalized view with Sensors, CH and BS. Data flow management is achieved by routing, scheduling of different nodes [21]. Inherently grouping of

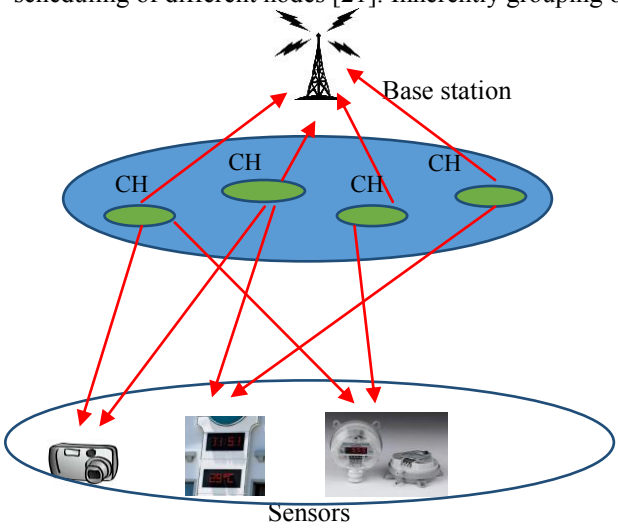

Fig. 1: Wireless Sensor Network Architecture

nodes into cluster is adopted to achieve energy efficiency which leads to prolonging network lifetime if it is WAN. Efforts are made to reduce power consumption and make network fault tolerant. Development of algorithm for improvising the network efficiency should consider routing protocol, clustering of nodes and analysis of fault conditions which may occur due to node failure.

Further part of paper is organized as follows. In Section II, background of LEACH is discussed. This section briefs about setup and steady state phase of LEACH protocol. Section III, elaborates upon network setup and management with timing considerations. Section IV, provides taxonomy of cluster based protocol i.e. LEACH protocol. It provides brief information of research done by researchers. It analyses variants of LEACH protocol, with the assumptions considered. It will focus on key conclusions of specific protocol. Efforts has been put up to indicate that variants have added up extra node may be a normal node (non-CH) or may be CH. Modified protocol has also given major responsibilities to BS. This may add up energy loss. Section V, analyses 802.15.4 standard and explains issues. Section VI gives summary of literature survey. Section VII propounds technique based on EM for prolonging network lifetime.

II. BACKGROUND OF LEACH PROTOCOL

Research work on improvising energy efficiency is reported in this literature. It has been observed that researchers started with routing protocol based on clustering technique. The base protocol taken is LEACH [19]. Majority of the research work is extension to the same.

LEACH introduced by Heinzelman in year 2000 [25] is self-organizing, adaptive clustering protocol which does energy load distribution equally in all the nodes of a cluster. Setup and steady-state are two main phases in the protocol. In setup phase SNs organizes into local cluster where CH is declared based on energy, probability function. Rule based selection of CH is done which follows:

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

Where p is desired percentage of CHs, r is current round and G is set of SNs which were not CH for last $1/p$ rounds. Startup and setup phase algorithm for LEACH are as follows.

Setup phase algorithm

1. Start round r = 0
2. All the SN has probability of becoming CH.
3. For round r, after node is elected as CH, it will start broadcasting 'Hello' message to nodes in a cluster.
4. Energy used to broadcast message is equal for all the cluster heads.
5. Initially, all the nodes those are not CH are supposed to keep their receiver ON to receive broadcasted message.
6. For round r, non-cluster head nodes will choose the cluster based on minimum energy criteria required to transmit/receive messages/data.
7. Random selection of CH will be done if more number of nodes declare themselves as CH.

Steady state phase Algorithm

1. Non-CH node informs CH about its presence in that cluster.
2. CH will have list of member in cluster due to Step - 1
3. CH schedules communication of non-CH nodes with itself based on TDMA.
4. The scheme is used to minimize power consumption in non-CH nodes. Transmitter is switched off.
5. Data aggregation is done by CH after collecting data from non-CH nodes.
6. CH finally transmits the same to BS.

Time based activity is shown in Fig. 2.

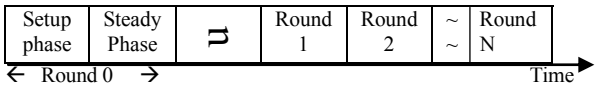

Fig – 2: Operation time of LEACH

Round(s) in LEACH are related to CH selection, and its time based. After predefined time slot CH selection process is initiated.

Each round of LEACH inherently covers activity of CH selection protocol and steady phase, as round r, *never selects* present CH, as CH *again.* Every round ends up with, new node as CH. New CH selection leads to steady phase as well.

In LEACH typical parameter settings are,

Parameters	Description
Area	100 x 100
Number of nodes	100
Location of data sink	(50,50)
B_{pow}	0.5 J
Transmit Energy	50nJ / bit
Free Space Receive Energy	10pJ / bit
Multipath Receive Energy	0.0013pJ/bit
Data Aggregation Energy	5nJ / bit
Data packet size(bits)	800
Broadcast packet size(bits)	64
Schedule packet size(bits)	64
Transmission range(m)	15

Table – 1: Simulation parameters

LEACH follows multi-hop concept. Following section elaborates timing consideration for network setup and management.

III. NETWORK SETUP AND MANAGEMENT

A. *Timing consideration for Network setup*

Basics of LEACH and its variant from different researchers overviewed, so let's start thorough analysis of steps for cluster set up in multi-hop network, Fig-2.

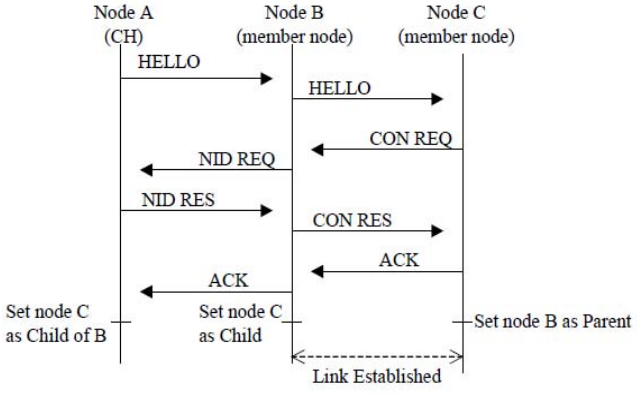

Fig – 3: Multihop cluster setup procedure (IEEE P802.15 Wireless Personal Area Networks)

It shows communication between different nodes for establishing mesh network.

$t^{total}_{hello} = t^{W}_{hello} + t^{R}_{hello,}$ same way t^{total}_{conn} and $t^{total}_{NID.}$ (Eq.2)

$t^{total}_{node\_setup} = 2 * t^{total}_{hello} + t^{T}_{conn} + t^{total}_{NID} + t^{R}_{conn} + 2 * t_{ack}$ (Eq.3)

$$T_{setup} = \sum_{m=2}^{N} (m-1)\left(t^{total}_{hello} + t^{total}_{NID} + t_{ack} \right) + t^{T}_{conn} + t^{R}_{conn} \quad \text{(Eq.4)}$$

The process will be more complete after sending LSR report to CH, leads to total time $T_{setup} + T_{LSRPeri}$.

B. *Network Maintainance*

Network Maintenance algorithm

1. CH broadcasts 'Hello' message periodically.
2. Member nodes also transmit 'Hello' after receiving message from CH.
3. Step- 2 is for announcing themselves to their neighbour.
4. Every node updates list of neighbouring node.
5. If no acknowledgement from neighbour, within timeout period, a particular entry about that node is deleted.

Fig – 4 depicts the same [1].

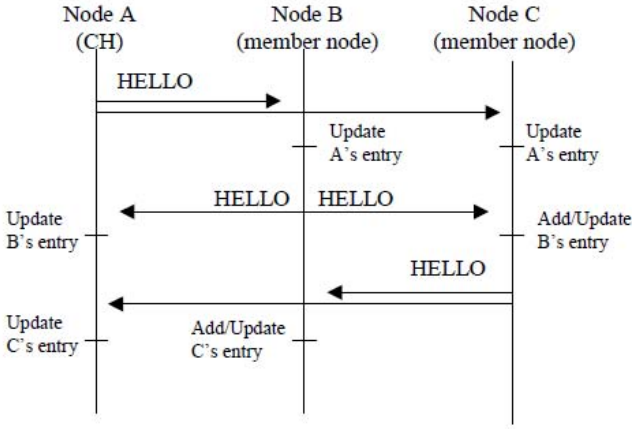

Fig – 4: Hello message and neighbor list update

Network maintenance is continuous overhead, after fixed interval of time, let's define the same in terms of maintenance round Ř.

$$T_{nwmaintain} = (m * N)\left(t^{T}_{hello} \right) \quad \text{(Eq.5)}$$

NOTE - 1: Refer Fig-2, LEACH protocol in addition, also adds overhead by declaring round r, for CH selection based on given Eq.1. Every time new CH, adds cost to battery life by transmission for duration T_{setup} + $T_{LSRPeri.}$ Number of round increases exponentially with life of network, as battery energy drain leads to frequent change of CH.

IV. TAXONOMY OF CUSTER BASED PROTOCL

Variants of LEACH can be classified in following categories.

1. Power Efficiency
2. Energy efficiency
3. Lifetime enhancement with load balancing
4. Optimal CH calculation
5. Network lifetime enhancement
6. Orphan node management
7. Energy efficiency with minimizing routing attacks

A. Power Efficiency based LEACH variants

PEACH and power saving LEACH are protocol under this category.

Yi et al. (2007) [26] proposed Power-Efficient and Adaptive Clustering Hierarchy Protocol (PEACH) for WSNs. Researcher aimed at minimizing energy consumption, using adaptive approach when cluster formation is done. Present clustering protocols consumes large energy while formatting cluster in dense network. By using overhearing characteristics of wireless communication PEACH forms clusters without additional overhead and supports adaptive multi-level clustering. PEACH is used for location-unaware and location-aware WSNs, resulting in extension of the network lifetime.

Liao and Yang (2012) [27] proposed a network to be partitioned in 2-dimensional grid-based architecture. They used sleep mode concept for saving energy and hence power management. In grid based architecture two SNs always are active keeping other SNs into sleep mode. Sleep and active modes of SN is scheduled using snake like structure,

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

N = total number of nodes (m + n)

m = rows, n = columns

Nodes in rows and columns are selected sequentially for sleep and active mode.

B. Energy Efficiency based LEACH variants

Allirani, and M. Suganthi (2009) [28] proposed an Energy Efficient Cluster Formation Protocol (EECFP) uses three techniques to exploit sensor networks' functionality of application specific task and achieving energy and latency efficiency

1. Cluster formation is randomized, adaptive and self-configuring
2. Data transfer has localized control
3. Data processing is using compression technique

Protocol is based on mainly two cycles,

First cycle and consecutive cycle.

In first cycle nodes will send data to CH only when it possess certain amount of energy. Calculation of energy is done using radio model. CH then sends consolidated data to BS.

Now in consecutive cycles % nodes having higher energy compared to other SN will be new CH for consequent cycles. For this the energies of all the SNs are compared. The steps continued till energy dried out. It achieves low power latency and energy. Author proposed to compare their techniques with rest energy efficient algorithms.

Heinzelmanetal.(2002) [29] proposed Centralized-LEACH (LEACH-C) protocol for BS cluster formation.

Setup phase algorithm – LEACH-C

1. All the SN sends current location [using GPS] with balance energy to BS.
2. BS needs to ensure that the energy load is evenly distributed among all the SNs.
3. BS calculates average energy E_{AV} of all SNs.
4. BS founds CH using Simulated Annealing (SA) algorithm.
5. Once the CH and associated clusters are found, the BS broadcasts a message that contains the cluster head ID for each node.
6. If a node's CH ID matches its own ID, the node is a CH
7. Else the node determines its TDMA slot for data transmission and goes to sleep until it is time to transmit data.

SA algorithm tries to reduce amount of energy for the non-CH SN to transmit their data to the CH by minimizing the total sum of squared distances between all the non-CH nodes and the closest CH. Steady-state phase of LEACH-C is same as LEACH.

Kumar et al. (2011) [30] proposed energy efficient Multi-hop Communication Routing (MCR) protocol. Key points are load balancing, life time enhancement, stability and energy efficiency for the given WSNs. MCR utilize fusion concept of single hop and multi-hop. CHs are selected on the basis of weighted probability. SNs communicate with the CH using a single hop communication and CH communicates with the BS using the multi-hop communication. Authors have introduced the concept of advanced and super advanced nodes along with the normal nodes so that their resulting network becomes a heterogeneous network. The advanced nodes are those nodes which are having ß times more energy than the normal nodes and n_0 are those nodes which are having μ times more energy than the normal nodes. The rest of the m (1-n) nodes are treated as normal nodes. If E_0 is the initial energy of the nodes then energy of the super and advanced nodes is $E_0(1+ß)$ and $E_0(1+\mu)$ respectively.

Total network energy $E = m*E_0(1 + n(ß - n_0(ß - \mu)))$ Eq. 6

Three different thresholds are there for normal, advanced and super advanced SN. The proposed scheme also has phases like cluster formation, route selection and data transmission. Proposed MCR was found to be better than M-LEACH and

MEECHCP comparing metrics such as number of nodes alive, number of CHs and average number of message transmitted into the network.

Xiaofang Li et al. (2010) [31] proposed A Differential Evolution-Based Routing Algorithm for Environmental Monitoring WSNs (DE-LEACH). DE is optimization algorithm based on the theory of swarm intelligence. Each round execution is divided into four phases:

1. Partitioning of initial clusters,
2. Collecting status information about the nodes inside clusters by auxiliary cluster head nodes,
3. Optimizing and selecting cluster heads with differential evolution algorithms
4. Forming optimized clusters.

Phase 1, is same as traditional LEACH protocol. Eq-1 is followed for partitioning. CHs in this phase is defined as auxiliary CHs. CHs and clusters are basically determined, but blind nodes tend to appear in the clusters. In phase 2, auxiliary CH collects information of location and energy of normal SN and stores into an array. It also provides ID to SNs. In phase 3 DE algorithm is executed to finally determining CH. It uses ID and number of SNs those are neighbour to auxiliary CHs. In phase 4, auxiliary CH nodes send the information of optimized CHs to nodes inside the cluster, Optimized CH collect and integrate information of nodes inside the cluster. Forming optimized clusters comprehensively considers status information of neighbour nodes.

DE_LEACH routing algorithm can effectively prevent blind nodes in normal clustering routing algorithms. It improve the life cycle of large-scale WSNs and make WSN routing protocols more suitable for outdoor environmental monitoring applications like meteorology and hydrology, wetland ecology field. Next research will focus on improvising the selection for each parameter to adaptively meet the needs of various applications in order to reduce the computing amount as much as possible.

Torkzaban et al. (2009) [32] proposed routing algorithm based on ID referred to as Identification Based LEACH (ID-LEACH).

ID-LEACH has two phases, setup and steady state. Setup phase is same as LEACH basic protocol. It uses Eq. 1 for forming cluster. Once CH are selected, it advertise to SN declaring that they are new CH. Based on signal strength of advertisement SN inform appropriate CH that they are member of cluster.

ID– LEACH

1. Tree structure is formed.
2. ID-LEACH assigns binary number to each SN.
3. Information about SN distance (hop count between deepest child of a node and itself) and degree is transmitted to father.
4. CH determines maximum degree and distance among received number and sends to upstream.
5. Repeat step 4 till sink gets maximum degree and distance of tree.
6. Maximum degree * maximum distance → sink stores this.
7. Sink makes binary no = 0, and assigns to itself. Sink ID = 0.
8. Length of this number is multiply degree with distance.
9. Each SN saves maximum degree and distance. This data packet is small.

Above process is repeated for each round as CH changes for each round. Using binary ID, ID sink can send data to the special node on single path for unicast or geocast transfer, thus improvising lifetime of network.

Guo et al. (2010) [33] proposed LEACH-Ensuring Reliable Data Delivery (LEACH-ER) protocol. Concept is based upon the election of CH with the objective of energy efficiency and data reliability. It keeps list of sink nodes. Format as follows.

Pointer Field	ID	Energy Level (ENG)	FLAG

Pointer field points to next node. ID is identity of node. ENG shows residual energy (level 0 to 5). FLAG decides if SN can serve as CH.

LEACH-ER – CH selection

1. ENG of CH has not changed and is greater than 0, CH directly delivers data packet
2. ENG of CH changes and is greater than 1, CH will subtract 1 and updates ENG and then deliver data packet. It won't send ID to sink node.
3. CH ENG =0, then CH will deliver ID frame to sink and exit from role of CH.
4. Now sink node confirms if FLGAG of first node in the list will become new CH. Old CH FLAG and ENG changes to 0.
5. Old CH broadcasts information to all nodes in cluster, so SN can communicate with new CH.

LEACH-ER tries to reduce packet delivery between CH and SN, thus reduces energy consumption. It outperforms LEACH-L protocol.

Hu Junping, Jin Yuhui, Dou Liang (2008) [9] proposed TB-LEACH i.e. Time Based CH selection algorithm. Concept is nodes which have the shortest time interval will win the competition and become cluster heads.

TB-LEACH CH selection

1. DecideCH (node n)

   If HasbeenCH = YES

   Then Random_timer = MAX_time

Else Random_timer = Random_generator(MAX_time)

2. *Backoff(Random_Timer)*

if ReceiveCH_ADVERTISE < 4
then send(CH_ ADVERTISE)
set_CH()
HasbeenCH = YES
else HasbeenCH = NO

TB-LEACH form constant number of cluster using random timer concept, so it doesn't need any global information. It provides longer network lifetime.

Handy et al. (2002) [34] modified LEACH protocol with respect to the criterion for selection of a CH (LEACH CH Selection). Important assumption is all nodes are able to reach BS. BS located far from the SN. SN are unaware of their positions and all SN has energy constraint.

Only local information has been used for the selection of CH. Each SN determines whether it can become CH or not based upon three important metrics as First Node Dies (FND), HNA, and Last Node Dies (LND). Authors have modified the threshold level T(n) of the nodes to become a CH in deterministic manner as:

$$T(n) = \frac{p * Ecurrent}{1-p\left(r \bmod \frac{1}{p}\right) * Einit} \quad \text{Eq - 6}$$

$E_{current}$ present energy of node and E_{init} is initial energy of node. To improvise energy saving T(n) again modified to following equation.

$$T(n) = \frac{p}{1-p\left(r \bmod \frac{1}{p}\right)} \left[\frac{Ecurrent}{Einit} + \left(r \; div \; \frac{1}{p}\right)\left(1 - \frac{Ecurrent}{Einit}\right)\right] \quad \text{Eq- 7}$$

Where r is number of consequent round for node was not CH.

Neeti Jain, Prakriti Trivedi (2012) [11] proposed strategy for CH selection based on residual energy as well as distance of CH from the BS.

Abdul Razaque et al (2016) [41] proposed PEGASIS-LEACH (P-LEACH) protocol, where PEGASIS overcomes limitation of LEACH and uses dynamicity feature of LEACH. Thus advantage of two energy saving protocols are combined. P-LEACH performs well compared to standalone LEACH and PEGASIS.

ZHANG Jingxia et al. (2016) [43] proposed Weighted and intra-cluster multi-hop energy-efficient algorithm for WSN (LEACH-WM). Setup phase of network is same as that of LEACH. But in steady state, it differs.

In steady phase member nodes in the network sends data CH as per time slot in frames. After completion of round, member nodes will now send data packet with their weights. Member having maximum weight will be selected by CH as next hop node and the same is labelled as weight relay (WR).

Weight relay selection process

1. Position of the node obtained before first round
2. Weight function, $W(j,t) = \frac{E(j,t)}{D(j)}$ $E(j,t)$ = Residual energy of node I
   $D(j)$ = distance between node j and BS
3. If W(j,t) is greater than threshold
   Then member node is WR.
   End if

C. Lifetime enhancement with load balancing

Song et al. (2010) [14] proposed AFSO - a routing protocol based on hierarchy. In steady state phase author proposed randomized parallel search algorithm of LEACH mainly for data transmission process.

AFSO optimization algorithm for CH selection [14], it is useful for CH selection i.e. setup phase. Optimization algorithm is executed at BS. Nodes are supposed to transmit location and energy information to BS, may be via CH or direct. In response, BS executes optimization algorithm and selects CH, which should be communicated to all the nodes. It indicates communication overhead involved in the protocol.

1. Steady state phase is same as LEACH, which will be for long duration, compared to setup phase. So no much improvement during that phase.
2. Regarding rounds *r, if it is same as LEACH,*

Peng and LI (2010) [8] have proposed Variable Round-LEACH (VR-LEACH) which is based upon stochastic cluster-head selection algorithm via changing the round time According to the situation of sensor network, increasing lifetime.

VR-LEACH – CH selection

1. Using Eq-1, calculates threshold.
2. SN having energy greater than T(n), can participate in CH selection process.
3. Non-CH has to keep receiver ON to listen advertising message from CH, for setup phase.
4. Non-CH selects cluster based on signal strength of advertisement
5. Cluster formation done.
6. After round time, $T = \lambda \frac{n \mu E}{Ech'}$ n = number of cluster
   μ = length of time slot, E_{ch}' = CH Energy cost in every frame
   λ = constant, E = CH energy in the begin of the round
7. Each round divided into number off frames and each frame divided into time slots according to the number of cluster members.

Non-uniform distribution of CH is solved by VR-LEACH. Changing of time of round based on network situation, lifetime is increased.

Tong and Tang (2010) [35] proposed Balanced LEACH (LEACH-B), where the number of CHs needs to be dominated, and the network needs an optimal CHs amount. Initial selection of CH is same as LEACH protocol.

LEACH-B – Second selection of CH

1. Is CH less than *n*p?*

   Where *p* is the desired percentage of CH and n is the number of total nodes.

2. If no, then sort CH residual energy

   Eliminate nodes from CH set whose residual energy ranks behind *n*p*

3. If yes, then
4. Non-CH selects cluster based on signal strength of advertisement
5. Cluster formation done.
6. After round time, $T = \lambda \frac{n \mu E}{Ech'}$ n = number of cluster

   μ = length of time slot, E_{ch}' = CH Energy cost in every frame

   λ = constant, E = CH energy in the begin of the round

7. Each round divided into number off frames and each frame divided into time slots according to the number of cluster members.

Xiangning and Song (2007) [6] proposed Energy LEACH and Multihop LEACH. Improvement in communication is observed in later due to multi-hop between CH and BS. NOTE – 1, is also valid here, as it follows Rounds in LEACH Multi-hop is standard strategy followed.

Liu et al. (2009) [15] have proposed Energy Aware Routing Protocol (EAP) that uses different state/message to reduce power consumption. State / message are Candidate, Head, Plain, Compete_Msg,Join_Msg , Weight_Msg etc. The operation of EAP is divided into rounds as LEACH, validating NOTE-1. In addition it transmits E_msg where residual energy of node is informed to neighbor node. *Each node* does E_msg transmission, this is obviously overhead with increase in frame size. Compete_Msg, Join_Msg, Weight_Msg are addition to Tx and Rx cycles.

Hou et al. (2009) [16] have proposed Energy and Distance LEACH (EDL) by taking residual energy and distance constraint condition between CH. Proposed algorithms reduces energy loss. NOTE – 1, is also valid here, as it follows Rounds in LEACH. Results are good only if nodes are increased in the area. Obviously, distance between nodes reduces as number of nodes increases for the same area, results in less transmission power and hence prolonged network life.

Xuxing Ding, Fangfang Xie and Qing Wu proposed Master/slave method for energy balanced cluster (EBCMS) [7]. The key idea of the algorithm is that one master CH and two slave CHs are chosen in each cluster. EBCMS selects appropriate CH for data transfer. NOTE – 1, is also valid here, as it follows Rounds in LEACH It keeps track of energy of other nodes as well, which may increase frame size and results in more Tx power.

Bian,Liu and Cho (2008) [3] proposed cluster-chained routing protocol (CCRP). It adopts a more balanced cluster head selection algorithm and an improved data transmission mechanism from the cluster-heads to the base station. ***CCRP*** *protocol* considered, Energy of node for CH selection where E_c is the current remaining energy of the node, E_m is the initial energy of the node. Distance between the neighbor nodes. Energy consideration is valuable consideration, but NOTE-1 still is valid for this protocol.

Master node selects two slave nodes, so selection time as well informing to nodes about slave role consumes power.

Saurav Ghosh et. al (2016) [38] proposed a dominating set based LEACH with Ant Colony Optimization (LEACH-DS-ACO). LEACh being Hierarchical routing protocols (HRP) disseminate data to the BS by assigning energy intensive data communication to CH nodes with high residual energy. Non-CH are involved in local communication, which results in balanced load and energy efficient data routing. Data redundancy being a main drawback of HRP as all nodes gathers data in a round. Author constructs a dominating set (DS) by formulating dominating set formation (DSF) from the deployed nodes.

Nodes are categorized as white node, gray node and dominating set node. Node in respect to sensing range is said to be adjacent to DS node labelled as gray node. White nodes are neither gray or in DS. In first round all nodes have equal energy and are all white nodes. Random selection of a node is done to become first member of DS. In next rounds the white node is selected as the first member of DS having maximum residual energy. Gray nodes are eliminated from the set of white nodes. Now algorithm continuously checks for unvisited node k from gray node set. Threshold values TV(S) will be calculated for all the white neighbours of k node if it has any white neighbours.

$$TV(S) = \left(E_{residual_i}(S) \middle| E_{initial}\right) * \frac{1}{DS} * MAX(1, \#WN) \quad \text{Eq. 8}$$

Where, WN = number of $White\ Neighbours$ of S

$E_{initial}$ = Initial energy,

$E_{residual_i}(S)$ = Residual energy of node S,

DS = dominating set of nodes

Node having values greater than threshold value will be added in the DS set. Set of white and gray nodes are updated. Checking is done till all white nodes are exhausted. The set DS represents the complete dominating set of nodes in the cluster.

Algorithm Dominating Set Formation (DSF)

Input: *Residual Energy* ($E_{residual_i}$) , *Sensing Range* (R_i), *N, Round (r).*
Output: *Dominating Set (DS)*

START DS Formation
Initialize *DS = GRAY_NODES = {β}; WHITE_NODES ← {N};*
if (*r == 1*) **then** *Random selection of a node j ∈ WHITE_NODES.*
else *Select node j ∈ WHITE_NODES having maximum* $E_{residual_i}$
end if
DS = DS ∪ {j};
for all ù ∈ Neighbor (j) **do**
GRAY_NODES = GRAY_NODES ∪ { ù *};*
end for
WHITE_NODES = WHITE_NODES − GRAY_NODES − DS;
while (*WHITE_NODES ≠ β*) **do**
begin
1. *From the set of GRAY nodes select an unvisited node i.*
2. *Check for white neighbors (WN) of i.*
3. ***if*** *white neighbor*
then *Search out the WN of i with max TV*
Include that WN as a member of DS.
Update sets WHITE_NODES, GRAY_NODES and DS.
End if

end while.
return DS.
end DS Formation

D. Optimal CH calculation

Muruganathan (2005) [24] proposed Base-Station Controlled Dynamic Clustering Protocol (BCDCP). This is a centralized routing protocol for enhancing the lifetime of the network. This is achieved by configuring nodes in two modes, sensing and cluster head mode. Responsibilities like formation of cluster, randomized CH selection and analysis of protocol is handled by BS.

BCDCP protocol assumes,

1. Abundance of energy for base station, so effective energy consumption is more.
2. It does not specify aspects of the protocol i.e. how does the base-station gather energy levels of nodes? To achieve this it may require communication of inter-nodes or node-BS, which effectively result in more power consumption of node.
3. Compared to LEACH 40% energy saving is shown but point 2 may reduce this factor effectively.

Do-hyun nam, hong-ki min (2007) [10] proposed Round Robin Cluster Header (RRCH) method where CH are selected in round robin fashion. RRCH further used by Ruchi Sharma Gunjan Jain et. al (2015) [2]. It follows CH selection on round robin fashion. But moment CH changed, some setup time is needed to settle the network. If round robin is also happening at the rate which matches that of LEACH, effective energy saving is less.

It will be best if all nodes are in ring topology, as in that round robin should provide good results.

Davood Izadi and Jemal Abawajy et. al. (2013) [17] suggested type-2 fuzzy based self-configurable cluster head selection (SCCH) approach. It uses fuzzy set of rules to select CH and keeps one backup CH.

SCCH Approach for CH selection

1. Fuzzy set is executed at BS.
2. Nodes are aware of their location.
3. One extra backup CH (BCH), which increases hardware cost.
4. Nothing has been discussed about failure of BCH.

K. Arul Prasath and T. Shankar (2015) [5] proposes a new synchronous transit algorithm named Ridge Method CH Selection (RMCHS). They used ridge method for cluster formation. *Assumptions are:*

1. Location of BS is out of sensor field.
2. BS has an ample energy resource.
3. BS location is known to each and every node on the field.

Process:

1. Each node calculates distance between itself and BS.
2. On similar line *Rn* and member nodes will calculate the distance.
3. Rounding off both the distances for decision making.
4. It checks if both distance are equal.

Hassan EL ALAMI and Abdellah NAJID (2016) [12] have proposed Energy efficient fuzzy logic - cluster head (EEFL-CH), where CH selection is done by BS using fuzzy laws.

1. It uses Fuzzy to select CH.
2. Like LEACH there are always rounds to select CH, but based on fuzzy. So here again NOTE-1 stands valid.

S. M. Hosseinirada, M. Ali Mohammadib, S. K. Basua (2014) [18] proposed Imperialist competitive Algorithm (ICA) - an optimization algorithm inspired by social phenomenon. It considers colonization process as a stage of socio-political evolution.

Ngo et al. (2007) [36] have proposed the Message Passing algorithm (MEPA) - an energy efficient distributed clustering protocol which uses simple and local message- passing rules. Optimal set of CH selection is based on node residual energy and network topology. Normalized residual energy of node is defined as,

$$P_i = \frac{re_j}{\sum_{j \in n(i)} re_j} \quad \text{Eq. 8}$$

Where, re_j = residual energy of node j
N(i) = is the set of neighboring nodes of i
P_i = the normalized preference of node i

Yang et al. (2010) [37] proposed an Optimal Energy Consumption Model (OECM) in which optimal number of CHs are affected by number of SNs, radius of the network, packet length, circuit energy dissipation etc. If number of nodes are constant then CH will be same, this it differs from LEACH. Total energy consumption in each round is,

$E_{total} = E_1 + m\,E_2 + ß\,m\,E_3$ Eq. 9

m = the data collection time when nodes are in the working stage,

ß = Ratio of cluster maintenance time to the data collection time.

Energy consumed in the clustering, working and maintenance phase is E_1, E_2 and E_3.

E. Network Lifetime Enhancement

N. Javaid, M. Waseem, et. al (2013) [22] proposed Away Cluster Heads (ACH). CH selection is based on randomized number generation. Randomly generated number is compared with threshold value. Following two conditions should be met for CH.

1. The value should be less than or equal to the threshold level.
2. Last *1/p* round, node should not be a CH.

K. Padmanabhan,P. Kamalakkannan (2013) [23] proposed Energy Enhanced Base Station Controlled Dynamic Clustering Protocol (EEBDCP), where clusters are divided into sub cluster and CHs are distributed evenly.

Salim E.L. Khediri, Nejah Nasri et.al (2014) [13] proposed Optimization LEACH (O-LEACH) where solutions were proposed to reduce traffic in network.

O-LEACH algorithm

1. Routing process initiated by BS.
2. while
3. If for round r, energy value is > 10% of residual value at each sensor
   Then initiate CH selection
   Form Member nodes.
   Schedule TDMA cycle and sent it to members.
   Initiate transmission phase
   Else launch the process of LEACH
   End if
4. End while

Future work for O-LEACH is implementation on dynamic network.

B.Pitchaimanickam, S.Radhakrishnan (2016) [39] proposed hybrid optimization algorithm i.e. Bacteria Foraging algorithm (BFA) and Particle Swarm Optimization (PSO) Algorithm for cluster formation and identifying CH using LEACH-C as base protocol. The results shows that network life time increased as number of dead nodes reduced. Further extension to this work is applying the quantum behaved PSO with BFA for selecting the suitable cluster head in WSN.

Tang qiang, Wang bingwen, Dai zhicheng et al. (2009) [42] proposed MS-LEACH for prolonging network life time. MS-LEACH has two phases, setup phase and data transmission phase. Setup phase is same as LEACH. In data transmission phase, it calculates critical value of cluster area size ($Q_{critical}$).

$$Q_{critical} = \frac{E_{tx}+\left(\frac{1}{p-1}\right)(E_{rx}+E_{DA})}{\epsilon_{fs}\left[P-1-\frac{1}{\pi}+\frac{(1-p)}{2\pi p}\right]}$$ Eq. 10

E_{tx} = Transmission energy

E_{rx} = Receiver energy

P = *Probability*

E_{DA} = Energy bit/signal

fs = free space

For each CH node, if cluster area size Q is > $Q_{critical}$ (threshold value) then protocol will calculate routing path tree and will broadcast the same.

Extension to this work will be finding the relationship between multi-hop transmissions and single-hop transmissions will be analysed deeply in different protocols.

W.T. Gwavava et al. (2015) [45] proposed Yet Another LEACH (YA-LEACH). It uses centralised cluster formation to ensure optimal clusters, with an addition of an alternative vice-CH (VCH), which is nearby to CH. VCH takes over CH when CH energy reaches to a critical value.

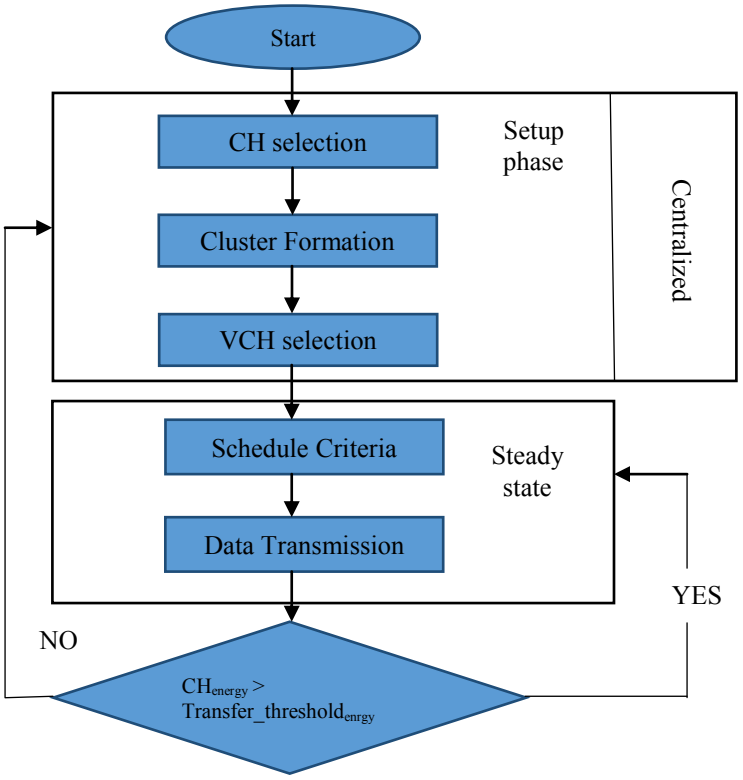

Fig. 5: YA-LEACH flowchart

Prabhat Kumar et al. (2015) [44] proposed modified version of LEACH-CE, by dividing zone into near and far. It's basically distance between nodes and BS. The decision of the same is based on threshold. Based on this information clustering is done, using formula,

$$CLUSTER_{optimal} = \sqrt{\frac{N}{2\pi}} \frac{\epsilon_{fs}}{\epsilon_{mp}} \frac{M}{d_{toBS}^2} \quad \text{Eq. 11}$$

d_{toBS}^2 = average distance from CH to BS.
ϵ_{fs} = Free space energy of an amplifier
ϵ_{mp} = multi path radio model energy of an amplifier
M = Terrain size
N = Number of SN
This protocol is suitable for large area.

F. Orphan node Management

Wassim Jerbi et al (2016) [40] proposed scheme where all the nodes will me in cluster, no possible orphan node. Due to random distribution of nodes in WSN it may happen that SN may not have access to any CH. To reduce this probability Orphan LEACH (O-LEACH) is used.

Case -1: Orphan nodes are less than or equal to member nodes of main CH

If SNs are not member of any cluster, let's label those SNs as Orphan SN (OSN), and doesn't have CH, then a CH member nearby to OSN will act as gateway and will be labeled as CH_G. The way CH allocates numbering to member nodes e.g. M_1, M_2, M_3 and so on. Same way CH_G numbers its member nodes (OSN) as M'_1, M'_2, M'_3 and so on. When M_1 transmits data to CH, exactly in same time slot M'_1 will transmit data to CH_G. So it uses same TDMA slots. So CH_G should have OSN, less than or equal to member nodes of main CH.

Setup phase of O-LEACH

1. Select CH nodes with certain probability(local decision by a node to become a CH)
2. Form Cluster with CH.
3. If OSN exist
   Then
   a. CH reserves two slots for gateway (CH_G). (Slot for gateway and slot for Orphan nodes - compresses and data aggregation)
   b. CH schedules TDMA cycle where SN uses all ranges of the BW channel.
   c. Data transmission should be within stipulated time slot
4. CH forms group and decides member nodes.
5. CH_G of a particular cluster informs CH about list of OSN.
6. The CH allocates TDMA slot based on CH members and OSN.
7. CH and CH_G works in parallel for data aggregation. Allows cluster members and Orphan nodes transmit data simultaneously.

Case -2: Orphan nodes are greater than member nodes of main CH

Setup phase of O-LEACH

1. Select CH nodes with certain probability(local decision by a node to become a CH)
2. Form Cluster with CH.
3. If OSN exist
   Then
   If OSN > member nodes of main CH
   Then
   a. OSN nodes will decide CH_{OSN}, which will aggregate data of OSNs.
   b. CH_G and CH_{OSN} will communicate.
   c. CH reserves two slots for gateway (CH_G).
4. CH forms group and decides member nodes.
5. CH_G of a particular cluster informs CH about CH_{OSN}.
6. The CH allocates TDMA slot based on CH members.
7. CH and CH_{OSN} works in parallel for data aggregation. Allows cluster members and Orphan nodes transmit data simultaneously.

G. Energy efficiency with minimizing routing attacks

S.Ranjeeth Kumar, A.Umamakeswari, (2016) [43] proposed Specification based Secure LEACH Protocol (SSLEACH) that deals with security measure. It handles sinkhole attack. In LEACH there is no CH or non-CH authentication which makes network vulnerable to attacks. Agent process (AP) is executed at node level and periodically transmits agent packet (AGPKT) to BS. This process identifies abnormalities in the transmission of the nodes and BS will get report. BS after identification puts that node into black list and broadcasts to every node.

Specifier ID and node ID is equivalent. Start and end of the event is denoted by System calls. Event queue keeps Process to be processed. Behavioral change of node is marked as an Attribute. These all arguments are used in Specification model.

According to author this work may be extended to HEE, PEGASIS and TEEN. It also should be applied to Internet of things (IoT) environment.

V. ANALYSING 802.15.4 - WPAN

Till this point, LEACH and its variants were focused for analysis. Next part elaborates challenges in ***802.15.4-WPAN [1]*** as this standard is most widely used in wireless communication. While analysing LEACH, reduction in number of rounds r was major consideration.

Following two cases, highlights issues related to CH and normal node.

Case – 1: CH is having problem

When the cluster head has trouble, the distribution of HELLO message is stopped and all member nodes know that they have lost the cluster head. The cluster would be reconfigured in the same way as the cluster formation process.

Issue here is, major time as well as energy wastage, just to know that CH has stopped and again start with new formation of cluster with its head.

Wastage of these two important parameters can be reduced by any means?

Case – 2: If a member node has trouble and unable to communicate,

When node is unable to communicate, then tree route of the cluster would be reconfigured. To understand that node has problem, *message will be transmitted and wait cycle will be executed*.

If problem exist for such few cycles then it is understood that node has problem and network is rearranged.

Point of consideration here is, in totally - network arrangement, sensing node failure – these all activities have to be re-executed which results in consumption of power and time. Question here is,

Power and time wastage can be reduced by any means?

VI. SUMMARY FROM LITERATURE SURVEY

Inference – 1: While doing extension to the base protocol, LEACH protocol itself is largely ignored by not considering timing required for each and every operation performed.

Inference – 2: Every researcher has tried to add some extra element which nothing but node – Access Point (AP) or BS in the network, which may indirectly affect or degrade performance of one of the parameter of QoS.

Few assumptions mad be researchers are highlighted as follows:

- BS has ample power
- all nodes are capable to communicate with BS
- This is required when BS forms CH using Genetic Algorithm, Simulated Annealing or any other optimization technique.

Inference – 3: 802.15.4, for both the cases of CH and non-CH requires power saving protocol.

VII. PROPOUND AN ALGORITHM TO INCREASE ENERGY EFFICIENCY

Following are few points on the issues.

1. Instead of re-arranging nodes or adding multiple CH or handing over CH selection responsibility to BS with various algorithm; try to reduce number of rounds r, by some means. CH selection process will be same as LEACH, but as number of round reduces, QoS will improve.
2. If CH node analyses its power and accordingly, before it fails, can initiate CH selection process.
3. In similar manner normal SN (non-CH), can analyse its power and before it dies out, inform neighbour node and CH to re-arrange network.
4. Prior intimation will reduce time and power, both, for arranging network. It should be surely less than creating new cluster with CH in totality.

A. Energy Model (EM)

Battery power drain and interference - because of link failure between two neighboring node, leads to faulty network and asks for re-arrangement or setting up network, which consumes battery power and blocks data transmission for long duration. Next part looks bit inside of the node for formatting battery power model and also provides steps for hand over mechanism.

Every node has inbuilt micro-controller having in built ADC channels. Due to advancement in the technology manufacturers do provide multiple ADC channels. In node design one can allocate one channel to Battery Health monitoring, where micro-controller will check the battery drain – same way as mobile. Mobile device never alarms at the time of total drain, some marginal battery charge is kept as a backup and the user is alarmed well before total drain of battery.

Let B_{pow} is the power of battery at time t=0, and its fully charged. Battery drain over a period of time is represented by B_i. B_{th} defines threshold level of battery, till appoint it will act as CH, and after that keeping sufficient power for normal operation. Every time slot

$$B_i = \begin{cases} Bpow - Bi & active\ modes \\ Bpow, & Inactive\ node \end{cases} \quad \text{Eq. 12}$$

Update new power after drain i.e. $B_{pow} = B_i$. B_{th} is based on type of node and adjustable by admin person.

In LEACH after startup phase, setup is established and based on timing *r* rounds are executed. *But now setup phase round should not be initiated unless and until B_{th} is reached.*

Let T_r = round time in LEACH protocol

T_{Bth} = Time taken by battery to drain till B_{th} .

$T_r \ll T_{Bth}$

So if, $T_{Bth} = \tau * T_r$, then following activities will be repeated τ times, which may not be the case for energy efficient algorithm.

Case – 1: Node is CH

In this case, even though the activities shown in LEACH are followed it will be $1/\tau$ times.

Case – 2: Node is normal node, no special responsibility like CH.

Let's label this type of SN as faulty SN (FSN) [4].

1. When node senses that power if below threshold value, it can start handover mechanism, before it completely exhaust of energy.
2. Hands off mechanism is also simple as FSN is not DRAINED OUT, has sufficient power to stay in network.
3. Parameters transmitted by FSN will be: hop table, CH address, sink node address.
4. These parameters will help CH to ***re-arrange part of network only.***
5. ***Rearranging process will be fast as dealing with few nodes without FSN – result is less energy consumption.***

VIII. CONCLUSION

In WSN selection CH is very important as it is responsible of keeping network live and transmits data reliably to sink node. Emphasis is given on CH selection aspect. Throughout the total life span of SN, major time involved is data packet routing. So focusing proper data routing with CH selection will lead to energy saving. LEACH protocol being a benchmark, researchers developed improvisation scheme around this protocol.

Paper describes various LEACH variants protocol with their scheme, advantages and disadvantages.

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