OE-LEACH: An Optimized Energy Efficient LEACH Algorithm for WSNs

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***Abstract*— Wireless Sensor Networks (WSNs) are designed by hundreds or thousands of tiny, low cost and multifunctional sensor nodes. Each sensor node has very low battery life. Sensor nodes have finite storage capabilities, transmission and processing range and energy resources are also limited. There are many design issues in WSNs such as mobility, energy consumption, network topology, data aggregation, localization, production cost, security, network size and density etc. Routing protocols provide efficient working of the network, increase network lifetime, responsible for maintaining the routes in the network and perform reliable multi-hop communication under various conditions. LEACH (Low Energy Adaptive Clustering Protocol) is one of the hierarchical protocol in WSNs. LEACH uses TDMA MAC Protocol. During random data distribution, a number of TDMA slots are wasted. Because sensor nodes don't know either they have data to send or not, they continuously listen to the medium and this result in idle listening problem. This paper proposed OE-LEACH (An Optimized Energy Efficient LEACH Algorithm for WSNs) to enhance the performance of the LEACH Protocol, reduce time delay and energy consumption. Network Lifetime and throughput of WSN also increases. The Proposed method is simulated in MATLAB 2010a.**

Keywords*— *Wireless Sensor networks (WSN); Low-Energy Adaptive Clustering Hierarchy (LEACH); TDMA (Time Division Multiple Access); CSMA (Carrier Sense Multiple Access); MAC (Medium Access Control)

I. INTRODUCTION

WSNs consist of sensor devices that communicate wirelessly. Due to the limited battery life of sensor nodes, the energy efficiency management is a crucial issue. Air pollution monitoring, detecting fires in forest, health monitoring, target tracking, environment monitoring, detection of landslides and in battlefield surveillance etc. are the various application for WSNs. Utilizing the energy in efficient way is one of the main challenges for extending the lifetime of the WSN. A lot of work has been done by the researchers to solve this problem [1] [2]. Many energy efficient routing protocols are developed to resolve the issues.

Low Energy Adaptive Clustering Hierarchy (LEACH)[3][4] is a clustering based protocol that uses randomized rotation of cluster heads so that the energy load among the sensor nodes can be evenly distributed. LEACH includes two phases: cluster setup phase and steady state phase (data transmission phase). Cluster heads are chosen first then the clusters are formed in set-up phase. In steady phase, the cluster head aggregates the data from the other non-cluster head nodes [5]. TDMA based MAC protocol is used by the LEACH protocol [6] [7]. Within the cluster, it is the responsibility of the cluster head is to evenly distribute the TDMA slots to all other nodes of the clusters. In real scenarios data distribution may be non-uniform among the nodes and a number of these TDMA slots are wasted. An algorithm OE-LEACH is proposed to use these slots so that energy dissipation can be minimized with in the network. The organization of the paper is as follows: section II discusses about various work done in the related field; section III explains in detail the proposed protocol OE-LEACH; section IV shows the various simulation snapshots of proposed work; section V concludes the paper.

II. RELATED WORK

In order to achieve high energy efficiency and increase the life time of the network, various enhancements related to LEACH protocols are proposed over the years.

A. MR-LEACH (Multihop Routing LEACH)

The network is partitioned into different layers of clusters. To propagate the data in WSNs, cluster heads of different layers communicate with other layers. Upper layer cluster heads act as super cluster heads for the lower layer cluster heads. The base station selects the cluster heads for upper and other respective levels. For transmitting the data to base station, TDMA scheduling is used. This Multihop routing LEACH [8] enhances the lifetime of the WSN.

B. LEACH-SCH (LEACH- Supporting Cluster Heads)

LEACH-SCH [9] improves the network lifetime of the WSNs. It reduces the reclustering overhead during the cluster set-up phase. This method induces another supporting Cluster Head with addition to already selected Cluster Head. After this, instead of choosing one random variable between 0 and 1, two random variable r1 and r2 are chosen for selected Cluster Head and supporting cluster head respectively.

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C. $(LEACH)^2$

$(LEACH)^2$ [10] combines LEACH with a linearly enhanced approach. The entire sensing region is divided into four regions. Sensor nodes choose their cluster head based on received signal strength. This method assumes that all the sensor nodes always have data to send. Data transmission takes place as in traditional LEACH. Network performance is studied in presence of one, two or three sinks. $(LEACH)^2$ reduces the energy dissipation in WSNs.

D. MEDC (Mutual Exclusive Distributive Clustering Protocol)

In this protocol, cluster heads are chosen based on the mutual exclusion principle. MEDC [11] works in iterations same as LEACH. Cluster head is selected that has the maximum residual energy after the iteration. Authors have also described information fusion and various ways of change point detection. This protocol improves the lifetime of the network.

Some common traits are shared by all the descendants of LEACH routing protocols. Still there is a requirement of optimization in existing LEACH protocol so that the slots corresponding to nodes that do not have data to send at its scheduled slot can be used efficiently.

III. OE-LEACH: Proposed Method

OE-LEACH aims to minimize the energy consumption in order to improve the time delay, network stability period and network lifetime of WSNs. There are many situations where the sensor nodes do not have data to send regularly as they may be event driven. In that case, data are available only when they sense the event. So, the sensor nodes need not to listen the channel at all times. Energy is wasted more on idle listening than that dissipated in transmitting and receiving. The proposed method takes advantage of using the slots belong to the node having no data to send. Slots are not allocated to the nodes which have no data to send and free slots are converted into useful slots. This will reduce the idle listening problem. This method will decrease the waiting time for nodes as now sensor nodes can get more than one slot in a frame which means throughput of the network increases. The operation of proposed method works in rounds. Each round has following two phases: Cluster Set-up Phase and Steady State Phase.

A. Cluster Set-up Phase

OE-LEACH divides the work of this phase in two parts which includes cluster head selection and cluster formation.

1) Cluster Head Selection: Depending upon the current energy level, each node advertises its probability of becoming cluster head to the base station. Sensor nodes with higher probabilities are selected as the Cluster Heads. After this, cluster heads broadcast an ADV message (Advertisement message) using the CSMA MAC protocol. This ADV message has two fields: node's ID (number identifying each node uniquely) and distinguishable header having control information. Each non-cluster head node determines its cluster head for this round based on the received signal strength. To balance the energy consumption among nodes, cluster heads change randomly over time. This decision is made by the node picking a random number between 0 and 1. If this number is less than the following threshold value T (n) then the nodes becomes a cluster head for the current round:

$$T(n) = \{p / (1 - p(r \bmod 1/p))\}, \text{ if } n \in G \tag{1}$$

Here, p represents to the cluster head selection probability;
r denotes the current round; and
G is the set of nodes that are not cluster heads in the previous 1/p rounds.

2) Cluster Formation: Each non-Cluster Head node transmits a Join-REQ (join-request) message back to its selected Cluster Head using CSMA MAC protocol, based on receiving signal strength of ADV message. Join-REQ has three fields: Node's ID (number identifying each node uniquely), Cluster Head ID (number identifying each cluster head uniquely) and distinguishable header having control information such as destination and source address. In this way, clusters are formed.

B. Steady State Phase

Cluster Head node receives the data from the non-clusters head nodes. Cluster Head node follows the following steps for data transmission within the cluster:

1) STEP 1: Total data transmission time is divided into frames. Each frame begins with a SYNC1 period, followed by announcement window (ANNC1), SYNC2 period, ANNC2 and ending with a data window. ANNC window is divided into two parts: slot selection window and residual window as shown in Fig. 1. ANNC1 or ANNC2 window is used for advertising for data and reserving data slots.

The slot selection window is further divided into smaller slots as shown in Fig. 2. Each slot number in slot selection window represents corresponding data slot in data window. ANNC1 window size remains fixed for all frames for a particular round. Slot selection window is also divided into equal number of small slots for all frames. ANNC2 window size may vary.

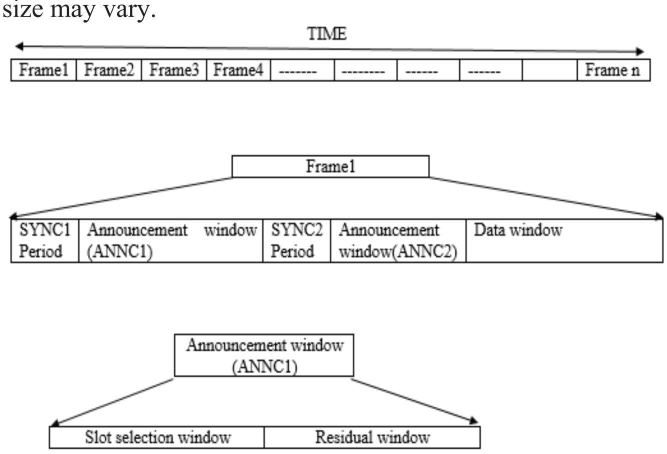

Fig. 1. Frame Structure of Proposed Method

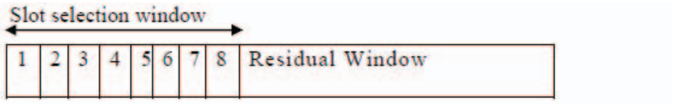

Fig. 2. ANNC1 Window

Adv packets (advertisement Packets) are used by the nodes for requesting for acquiring corresponding data slot. Each adv packet contains ID of the receiver, chosen data slot and amount of data that can be allocated at a time to the cluster member. Cluster Head sends ack packet (acknowledgement) back to the cluster member. Each ack packet have the ID of the cluster member node (to which slot is allocated) and allocated data slot.

2) STEP 2 - SYNC1 Period: In SYNC1 period, cluster member nodes are allowed to select a slot randomly from slot selection window of ANNC1 window and initialize a timer to a value equal to the slot value. In Fig. 3, if A, B, C, D, E, F are the cluster members and all have data to send. Slot Selection Window is divided into 8 parts. They randomly select a slot from window.

3) STEP 3- ANNC1 Window: The transmission of adv and ack packets takes place. When timer reaches to zero, node transmits an adv packet and waits for an ack packet. Other cluster member nodes will hear this transmission and freeze their timers. When the entire adv/ack transmission is over. Then, other cluster member nodes resume their timers again. Successful transmission of adv/ack packets will ensures that all nodes in the cluster are aware of which data are being used. As shown in Fig. 4, Nodes A, B, C, D, E and F select random slots and initialize their timers. Nodes B and D choose the same slot number and their adv packets get collide so these slots remain empty. A, C, F, and E transmitted successfully. The slot numbers 2, 4, 5 and 7 are not used in ANNC1 window.

4) STEP 4- ANNC2 Window: In ANNC2 window, the number of slots in slot selection window is equal to the slots which are not used in ANNC1 window. In SYNC2 Period, the remaining nodes which have data to send and the collided nodes to randomly select a slot from slot selection window of ANNC2 and initialize a timer according equal to their slot value. If the number of collided nodes and remaining nodes are less than or equal to the number of slots (not allocated) then they both are allowed for randomly selection in ANNC2 window otherwise only collided nodes are given permission to select.

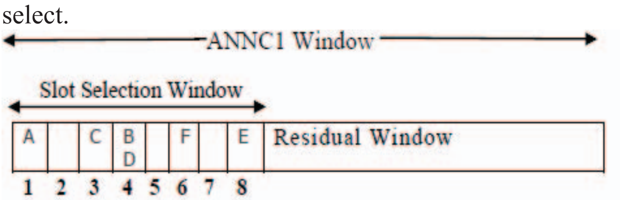

Fig. 3. Selection of slot in ANNC1 Window

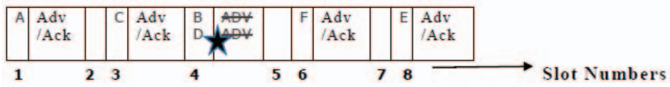

Fig. 4. ANNC1 Window (Transmission of adv/ack Packet)

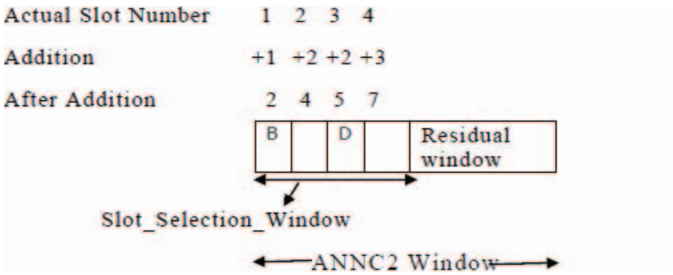

Fig. 5. Selection of slots in ANNC2 Window

As shown in Fig. 5, the slot selection window of ANNC2 window is divided into 4 parts as four slots are empty in ANNC1 window. These slots are numbered in the window as 1,2,3,4 but addition to these numbers is done to represent the empty slots of ANNC1 window. The slots are considered as 2,4,5,7 in ANNC2 Window which represent empty slot of ANNC1 Window.

The same procedure is followed by ANNC2 for transmission of adv/ack packets as in ANNC1 window. Nodes B and D transmitted successfully adv/ack packet as shown in Fig. 6. After this cluster head updates its routing table (Table 1) Cluster head knows which data slots are empty. Before starting of data window, based on the routing table information, the cluster head can allow neighbor nodes of empty slots to extend their data slots either in left or right direction. Rules regarding slots extension are given in step 5.

5) STEP 5: TABLE I after step 4 tells about which slot positions are empty in the frame. Now, Cluster Head decides which neighbor node will extend its slots based on the following rules:

- Neighbor node of empty slot can extend its data slot by one slot according to the empty slot available in left or right direction.
- If the two nodes have common choice for a single slot then the node which has more data to send will occupy that slot. If the data of these two nodes is same then node which have first occurrence in the frame will occupy that slot.
- There may be situation where a single node has two neighbor choices either left or right to extend its slot. Then the node will extend its slot in left directions not in right direction due to time constraints.

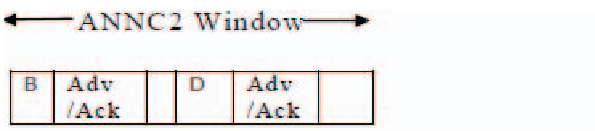

Fig. 6. ANNC2 Window (Transmission of adv/ack packet)

- Directions are chosen by the nodes to extend their slot where maximum neighbor nodes get the empty slots.

Now, it is clear that slot 4 and slot 7 are empty. Nodes D and E can extend their data slots in left directions as shown in TABLE II and TABLE III. All nodes are awake until data window starts. Cluster head has information about the distribution of slots. Now, extension regarding information should be given to the nodes. Format of respective message send by the cluster head to node is shown as Fig. 7. Cluster Head sends **msg** (D, 5, 4) and **msg** (D, 8, 7) to nodes D and E respectively for extending its slot in left direction.

6) STEP 6- DATA WINDOW: All nodes send the data packets to their announced data number in data window as shown in Fig. 8. Nodes are only awake to their respective data slot and go to sleep mode after that. Sensor nodes don't listen to the medium and no idle listening problem. This saves energy of the sensor nodes. Nodes are getting chance to send data more than once in a single frame, the waiting time of the nodes decreases. More data can be sent in less time in proposed method which means throughput of the network increases.

In this way, the cluster head collects the data from all the cluster members and forward the aggregated data to the sink. After a predefined time, the system begins the next round and the whole process is repeated again. The same method procedure repeats for all rounds. Based on all the above steps of Steady Phase, Algorithm 1 is proposed.

Considering BS as the base station, CH is the cluster head, CM are non-cluster head nodes, N_c as the number of nodes collided, N_d represents nodes that have data to send out of CM, N_a is the number of slots not allocated and t is timer.

TABLE I. CLUSTER HEAD ROUTING TABLE

Slot Number	1	2	3	4	5	6	7	8
Node	A	B	C		D	F		E

TABLE II. EXTENSION OF DATA SLOTS BY NEIGHBOR NODES

Slot Number	1	2	3	4	5	6	7	8
Node	A	B	C		D	F		E

TABLE III. ROUTING TABLE AFTER EXTENSION

Slot Number	1	2	3	4	5	6	7	8
Node	A	B	C	C	D	F	E	E

Node's ID	Slot Number	Slot Number Added

Fig. 7. Message Format to inform respective node

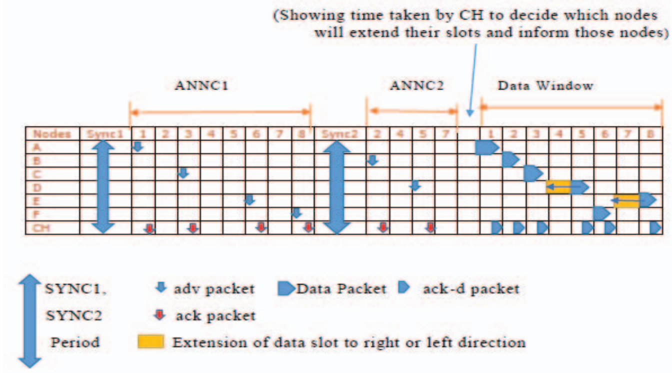

Fig. 8. OE-LEACH Working

Algorithm 1: For Steady State Phase using Proposed Method

Algorithm Steady_Pro_Method (N_d, CH, t)

1. **Begin**
2. Randomly selection of slots by N_d from slot selection window of ANNC1 Window;
3. Each node initializes a timer to a value equal to the slot number;
4. **if** ($t \rightarrow 0$) **then**
5. Send_adv_pkt_to_CH=true;
6. Receive_ack_pkt_by_node=true;
7. Slot number is allocated to N_d;
8. **end if**
9. **if**((N_c=true) || (N_d =true)) **then**
10. Divide the slot selection window of ANNC2 equal to number of slots not used in ANNC1 window;
11. **if**(($N_c + N_d$) <= N_a) **then**
12. Randomly selection of slots by both Nc and N_d from slot selection window;
13. Each node of N_c & N_d initializes a timer to a value equal to the slot number;
14. **if**($t \rightarrow 0$) **then**
15. Send_adv_pkt_to_CH=true;
16. Receive_ack_pkt_by_node=true;
17. Slot number is allocated to the node;
18. **end if**
19. **else**
20. Randomly selection of slot by N_c only from slot selection window;
21. Each node in N_c initializes a timer to a value equal to the slot number;
22. **if**($t \rightarrow 0$) **then**
23. Send_adv_pkt_to_CH=true;
24. Receive_ack_pkt_by_node=true;
25. Slot number is allocated to N_c;
26. **end if**
27. **end if**
28. **end if**
29. If any slot remains empty and neighbor node has data to send then
30. Extension rules are applied by CH as discussed in Step 5;
31. CH informs the corresponding node;
32. N_d send data in the data window at their selected slot numbers;
33. **End**

IV. SIMULATION OF PROPOSED WORK

The proposed work simulates a network of sensor nodes in MATLAB 2010a. These nodes form a WSN. The network consists of clusters of sensor nodes. The nodes are randomly deployed within area of 100m X 100m. The base station is located at coordinate (50, 0) of the deployment area. The population of nodes for this simulation is 100 (i.e. n=100). Simulation parameters for the proposed work are given in TABLE IV.

Fig. 9 shows a WSN with some sensor nodes and a base station. All sensor nodes are shown in triangle shape and base station with green color star shape at coordinate (50, 0). Proposed method works in rounds. Total number of rounds for experiments is 5000. At the start of simulation every node has energy 0.5J. Yellow circle sensor nodes are denoting cluster heads and these cluster heads are connected to base station through red dotted lines. In Proposed Method, first node dies at 1839 round. Dead node is shown with black color in Fig. 10. No data slot is allocated to dead node. It means node does not have energy to stay in the network. Stability period (The time interval between the start of the network operation and the death of the first sensor node is called stability period) is high for OE-LEACH than that of traditional LEACH. The output window is showing round number for first dead node in Fig. 11. Instability period (it is the time interval between the death of first node and the death of the last sensor node) starts after 1839 round. Nodes perform data transmission from cluster head to base station in network and when the energy becomes zero that particular node does not respond and die. Number of dead node starts increasing after instability period. Number of dead nodes are 15 after 3000 rounds. Number of cluster head is also decreasing due to the effect of increasing dead node (black color nodes are dead nodes). After 3750 rounds, the number of cluster heads is 1 or 2 only and number of dead nodes starts increasing. Because nodes don't have enough energy to reside in the network. When all the sensor nodes don't have energy to be a cluster head then no data transmission takes place in the network. Sensor nodes die when no energy is left. This situation occurs after 4300 rounds and remains same up to 5000 rounds depicted in Fig. 12. It shows that no any node have tendency to become the cluster head. So, no data transmission takes place. More than 90% nodes have dead.

TABLE IV. SIMULATION PARAMETERS

Parameters	Values
Network Size	100 X 100
Number of nodes	100
Initial Energy	0.5J
P_d	0.1
Data Aggregation Energy Cost	50pj/bit j
Packet Size	4000 bit
Transmitter Electronics	50 nJ/bit
Receiver Electronics	50 nJ/bit
Transmit amplifier	100 pJ/bit /m^2
Number of Rounds	1 to 5000

Fig. 13 shows that OE-LEACH has greater stability time as compared to LEACH. The first node of OE-LEACH is dead after approximately 1839 rounds whereas the first node of LEACH is dead after approximately 600 rounds. The OE-LEACH provides the better stability time. The last node in traditional LEACH is dead after approximately 2200 round. While in OE- LEACH, after 4300 rounds, network does not perform any transmission. The network lifetime (the time interval between the start of the network operation and the death of the last sensor node is called network lifetime) of OE-LEACH is greater than traditional LEACH as depicted in Fig. 14.

After becoming a cluster head, the node needs to perform the additional functions of cluster heads. A higher number of cluster heads causes more network energy consumption. OE-LEACH has an efficient number of cluster heads. There is more certainty in the selection of cluster heads in OE-LEACH as compared to traditional LEACH. The numbers of cluster heads selected in each round by using proposed method are shown in Fig. 15. Higher throughput is achieved due to longer network lifetime of OE-LEACH. Throughput of the network is shown in Fig. 16. This shows number of packets sent to base station in proposed method (OE-LEACH).

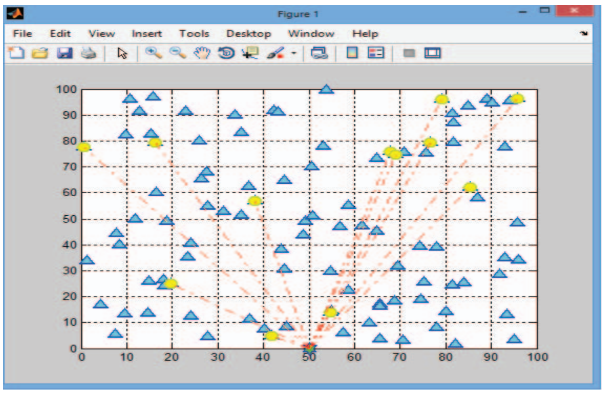

Fig. 9. Simulation of network with base station, cluster head and non-cluster member

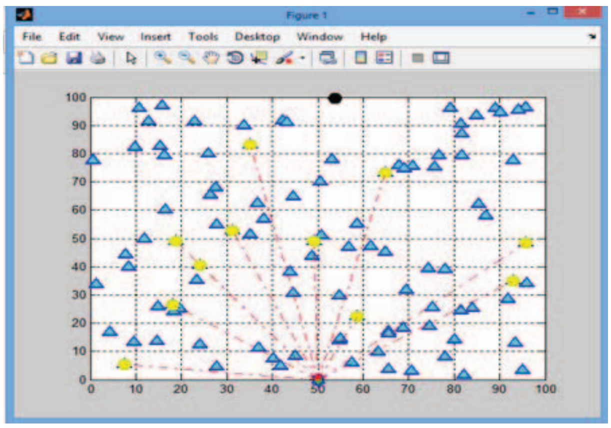

Fig. 10. Simulation of network indicating dead node at round 1839

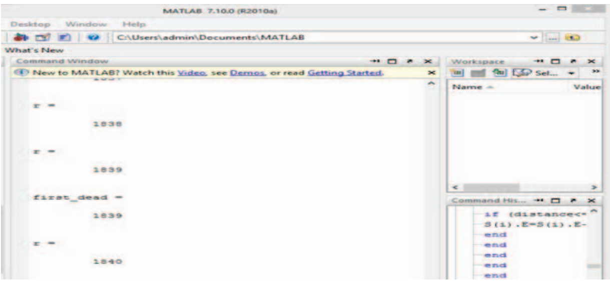

Fig. 11. Output window displaying round number for first dead node.

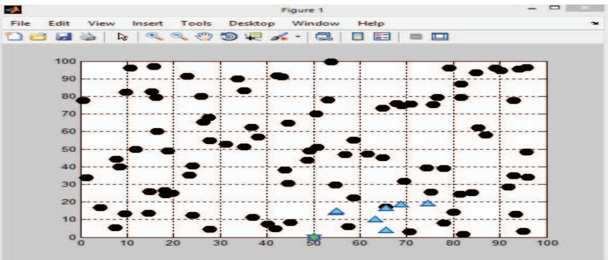

Fig. 12. Network dead after 5000 rounds

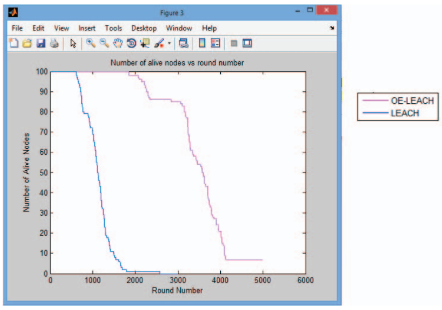

Fig. 13. Total number of alive nodes in each round

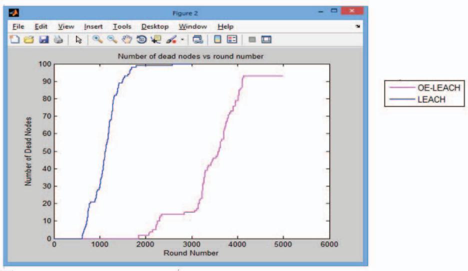

Fig. 14. Total number of dead nodes in each round

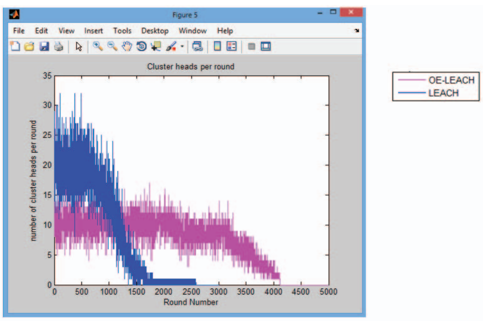

Fig. 15. Cluster Heads in each round

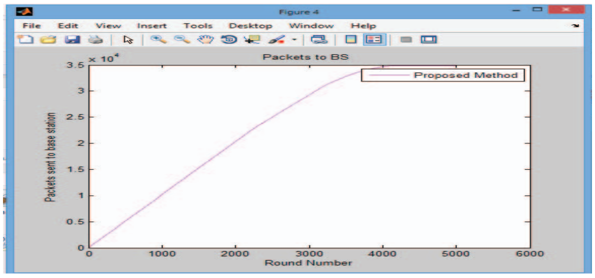

Fig. 16. Throughput of the Proposed Method (OE-LEACH)

V. CONCLUSION

In this paper, a more optimized energy efficient routing scheme for WSNs is proposed. More focus is presented on enhancement of steady phase of LEACH Method. Integrity of OE-LEACH is checked with the help of simulation work. The simulation work shows improvement in terms of stability period, network lifetime and throughput of the network. The most important extension of proposed method would be to mobile networks. In the future work, the node and BS mobility will be considered to route the data to BS.

REFERENCES

[1] N. Tuah, M. Ismail and AR. Haron, “Energy consumption and lifetime analysis for heterogeneous Wireless Sensor Network,” IEEE TENCON Spring Conference, pp. 188–93, 2013.

[2] A. Di Marco, O. Gemikonakli and L. Mostarda “Implementing adaptation and reconfiguration strategies in heterogeneous WSN,” IEEE 27th International Conference on Advanced Information Networking and Applications, pp.477–483, 2013.

[3] N. Ramanathan, M. Yarvis, J. Chhabra, N. Kushalnagar L. Krishnamurthy and D. Estrin, “A Stream-Oriented Power Management Protocol for Low Duty Cycle Sensor Network Applications,” IEEE Workshop on Embedded Networked Sensors, pp. 53–62, May 2005.

[4] K. Akkaya and M. Younis, “Energy-Aware Routing of Delay-Constrained Data in Wireless Sensor Networks,” Journal of Communication Systems, special issue on QoS support and service differentiation in wireless networks, vol. 17, pp. 663-687,2004.

[5] S. Gambhir and N. Fatima, “Op-LEACH: An Optimized LEACH Method for Busty Traffic in WSNs,” Fourth International Conference on Advanced Computing and Communication Technologies, pp. 222-229, 2014.

[6] D. Wu, G. Y. Wang. and X. L. Li., “Distributed TDMA Scheduling Protocol Based on Conflict-Free for Wireless Sensor Networks,” ICISS, pp. 876–879, October 2010.

[7] P. K. Pal and P. Chatterjee, “A Survey on TDMA-based MAC Protocols for Wireless Sensor Network,” IJETAE, vol. 4, issue 6, pp. 219-230, June 2014.

[8] M. O. Farooq, A. B. Dogar A and G. A. Shah, “MR-LEACH: multi-hop routing with low energy adaptive clustering hierarchy,” Fourth International Conference on Sensor Technologies and Applications, IEEE, pp. 262–268, 2010.

[9] A. Solanki and N. B. Patel, “LEACH-SCH, An Innovative Routing Protocol for Wireless Sensor Network,” ICCCNT, pp.1-5, 2013.

[10] K. Khan, M. Sajid, S. Mahmood and Z. A. Khan, “(LEACH)^2: Combining LEACH with Linearly Enhanced Approach for Cluster Handling in WSNs,” International Conference on Advanced Information Networking and Applications, IEEE 2015.

[11] Y. Singh and U. Chugh, “Clustering, Information Fusion and Event Detection in Wireless Sensor Networks: A Review,” Second International Conference on Computing for Sustainable Global Development (INDIACom), IEEE, pp. 566 – 571, 2015.