International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-04, Issue-05, Aug 2018

A Performance Evaluation of Routing Algorithms for Wireless Sensor Networks under Energy Harvesting Nodes Deployment

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Abstract **A wireless sensor network (WSN) is considered as a collection of battery constrained sensor nodes working collaboratively using wireless communication. The area is regaining momentum, as a variety of Internet of Things (IoT) applications consider WSNs to collect the sensors data from the application specific field. The energy-efficiency of routing algorithm in WSN is critical for achieving a long-life reliable network. Many routing algorithms have been proposed for improving the WSN lifetime. The energy heterogeneity scenarios (e.g., few nodes with better batteries/line-powered) have also been exploited for network lifetime improvement in WSNs. The consideration of energy–harvesting nodes in WSN routing decision is another approach, where few energy-harvesting nodes are deployed to reduce the energy burden on battery powered nodes in the WSN. The placement of energy harvesting node is another important criteria; however, the deterministic placement of nodes is generally not available in many applications. This paper analyzes the performance of WSN routing algorithms with inducing few solar energy harvesting nodes in the network. As the solar energy harvesting capabilities of a node are time-varying and affected by the environmental conditions, a simplified energy-harvesting model is considered. The simulation results show that inducing few energy harvesting nodes in WSN can improve the performance of routing algorithms in terms of network stability period.**

Keywords — Wireless sensor networks, Routing protocols, Energy heterogeneity, Node placement and Energy harvesting.

I. INTRODUCTION

Due to the limited energy resources and problems associated with replacement of embedded batteries, it is difficult to achieve the WSNs with long life. WSN life is the key factor and the network Performance degrades with the death of sensor nodes. The energy harvesting technology can be used to solve the problem of dissipation of battery. By using this technology sensor network can use the environmental energy and collect the energy from node's surrounding, such as from solar, vibration and wind energy. This collected energy generally stored into secondary storages (e.g. batteries) for further usage. Management of energy harvesting system is presented in [1].

Several hierarchical routing algorithms have been proposed for improving the network stability period. LEACH [2] is a homogeneous protocol which is proposed by Heinzelman. LEACH assign one type of probability function for all the nodes to become cluster head. LEACH_C [3] and PAGASIS [4] are also type of homogeneous routing protocols. Clustering technique and radio model is important for improvement of WSNs is discussed in [5-10]. These algorithms work well with battery-driven sensor network but not suitable for network with energy harvesting nodes. To extend the stability period of networks, Theimo Voigt introduced a clustering routing protocol that is sLEACH [11] protocol. All nodes are solar-powered in this network and use battery power as secondary supply, and when the nodes in WSNs loss their battery energy, the WSNs will end at last. Some routings are designed for heterogeneous energy nodes like SEP [12] that have two type of nodes and both type of nodes have different weighted probability to become cluster-head. For understanding the concept of some energy heterogeneity protocols is discussed in [13-14].

Based on the LEACH and SEP, this work proposes an analysis of deterministic placement of nodes and analyzes the stability period of WSNs routing algorithm with inducing few solar energy harvesting nodes in the network.

The rest of this work is arranged as follows: In Section II, we introduce system models used for the analysis. In

 DOI : 10.18231/2454-9150.2018.0658

ISSN : 2454-9150 Vol-04, Issue-05, Aug 2018

Section III, we present Methodology for placing the node in the network field. In section IV, Energy harvesting analysis for homogeneous WSNs routing algorithm is shown. In section V, Result of energy harvesting analysis for homogeneous WSNs routing algorithm is shown. In section VI, Energy harvesting analysis for heterogeneous WSNs routing algorithm is shown. In section VII, Result of energy harvesting analysis for heterogeneous WSNs routing algorithm is shown. Section VIII concludes the paper.

II. System Model

A. Network Model

A simplified energy-harvesting model (Figure 3) and a fixed base station with unlimited power supply are considered. A network has N sensor nodes, they form clusters with q nodes and from a cluster one of node being selected as cluster head. The algorithm operation is divided into rounds and round is further divided into set-up phase (including the election of cluster head) and steady phase (data transmission).

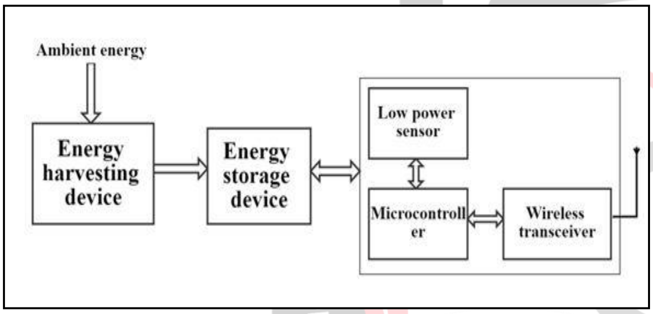

Fig. 1. Hardware architecture of Harvesting Sensor.

B. RADIO MODEL

Distance threshold value is

$$d_o = \sqrt{(E_{fsl} / E_{mpl})}$$

The energy dissipation in the transmission is given as:

$$E_T(l,d) = E_{elect} * l + E_{fsl} * l * d^2 \quad ; d < d_o \qquad (1)$$

$$E_T(l,d) = E_{elect} * l + E_{mpl} * l * d^4 \; ; d \geq d_o \qquad (2)$$

The receiver electronic energy is given as:

$$E_R = E_{elect} * l \qquad (3)$$

In figure 2, l is the no. of bits for transmission data. Distance d, is free space energy dissipation is calculated within a cluster and the multi-path fading is used for calculating the energy from a cluster head to base station.

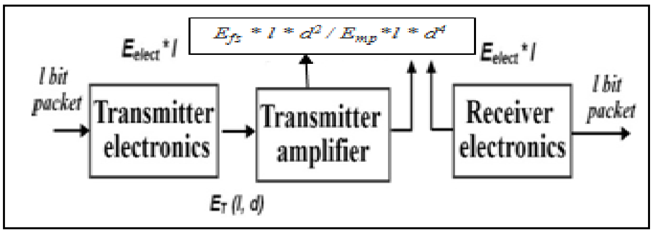

Fig. 2. Wireless Radio Model

TABLE I. Radio Model Parameters Value

S.No.	Parameters	Value
1.	Network size	100m x 100m
2.	No. of sensor nodes *(N)*	100
3.	Base station location	Centre of the field
4.	Normal node's initial energy *(E_o)*	0.5J
5.	Advanced node's extra initial energy *(a)*	1 or Eo *(1+a)
6.	Energy in Transmit /Receive electronics *(E_{elect})*	50 nJ/bit
7.	Energy in Transmit amplifier in free space *(E_{fsl})*	10 pJ/bit/m2
8.	Energy in Transmit amplifier in multipath *(E_{mpl})*	0.0013pJ/bit/m4
9.	Energy in Data aggregation	5 nJ/bit/signal
10.	Packet length *(l)*	4000 bits
11.	Harvesting Energy of a node (upper limit)	0.05J/hr

C. ENERGY HARVESTING MODEL

Most commonly used energy prediction model is Exponential weighted moving average (EWMA). Power management in energy harvesting sensor networks [15] had been introduced by Aman Kansal. DPSO-based clustering routing algorithm for energy harvesting WSNs [16], DC-LEACH [17] and ECO-LEACH [18] are also use the EWMA model for energy forecasting.

Based on [15], we derived a simplified solar energy harvesting model. The energy of the i^{th} node at the beginning of the rth round E(i,cR) can be described as:

$$E(i, cR) = \min(E_{resi}(i, cR-1) + E_{har}(i, cR-1), E\_capacity)) - eEe(i, cR) \qquad (4)$$

s = mod (cR, 24) and h=0.05/3 J/hr

$$E_{har}(i,cR-1) = \begin{cases} 0 & 0 < s < 7 \\ h/3 * (s-7) & 7 < s < 10 \\ h & 10 < s < 15 \\ h/3 * (18 - s) & 15 < s < 18 \\ 0 & 18 < s < 24 \end{cases} \qquad (5)$$

Where E_{resi} (i,cR-1) and E_{har} (i,cR-1) are the residual energy at the starting of the r^{th} round and the harvested energy during the $(cR-1)^{th}$ round of the i^{th} node respectively. eEe (i, cR) is the energy consumed by node i^{th} processing data in round r^{th}.

 DOI : 10.18231/2454-9150.2018.0658

International Journal for Research in Engineering Application & Management (IJREAM)
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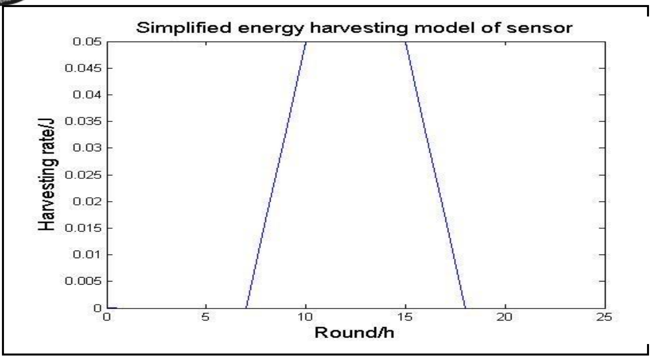


Fig. 3. Simplified Energy Harvesting Model

III. METHODOLOGY

Deterministic placement [19] of node on the basis of different scenario:

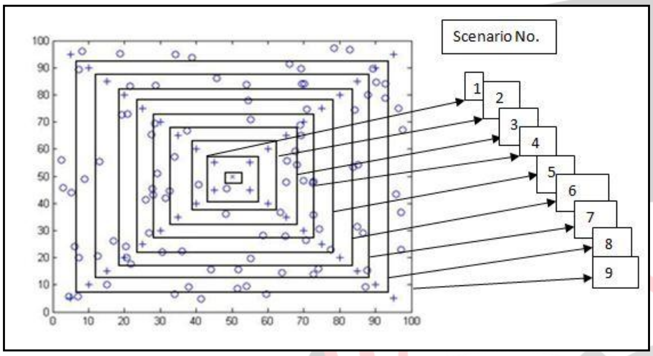


Fig. 4. Placement of 4 nodes in the field (9 different scenarios)

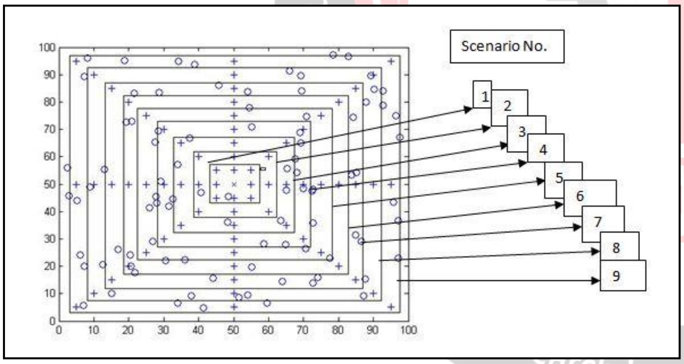


Fig. 5. Placement of 8 nodes in the field (9 different scenarios)

TABLE II. COORDINATES FOR PLACEMENT NODES (NODE NO.1-4 NODES) IN DIFFERENT SCENARIOS

Scenario No.	Coordinates of node			
	Node_1c	***Node_2c***	***Node_3c***	***Node_4c***
1.	(45,45)	(55,45)	(45,55)	(55,55)
2.	(40,40)	(60,40)	(40,60)	(60,60)
3.	(35,35)	(65,35)	(35,65)	(65,65)
4.	(30,30)	(70,30)	(30,70)	(70,70)
5.	(25,25)	(75,25)	(25,75)	(75,75)
6.	(20,20)	(80,20)	(20,80)	(80,80)
7.	(15,15)	(85,15)	(15,85)	(85,85)
8.	(10,10)	(90,10)	(10,90)	(90,90)
9.	(5,5)	(95,5)	(5,95)	(95,95)

TABLE III. COORDINATES FOR PLACEMENT NODES (NODE NO. 5-8 NODES) IN DIFFERENT SCENARIOS

Scenario No.	Coordinates of node			
	Node_5c	***Node_6c***	***Node_7c***	***Node_8c***
1.	(45,50)	(50,45)	(55,50)	(50,55)
2.	(40,50)	(50,40)	(60,50)	(50,50)
3.	(35,50)	(50,35)	(65,50)	(50,65)
4.	(30,50)	(50,30)	(70,50)	(50,70)
5.	(25,50)	(50,25)	(75,50)	(50,75)
6.	(20,50)	(50,20)	(80,50)	(50,80)
7.	(15,50)	(50,15)	(85,50)	(50,85)
8.	(10,50)	(50,10)	(90,50)	(50,90)
9.	(5,50)	(50,5)	(95,50)	(50,95)

TABLE IV. DIFFERENT CASE FOR ANALYSIS IN ROUTING PROTOCOL AFTER PLACING NODE IN FIELD

Case No.	Concept
I.	Best scenario of node placement without considering Energy harvesting.
II.	Best scenario of node placement analysis with Energy harvesting consideration.
III.	Best scenario of node placement analysis with Energy harvesting consideration with change in threshold function.

Figure 3 and 4, represents 4 and 8 nodes placement in network field respectively with 9 different scenarios. Table III and IV shows coordinates for placement of nodes in different scenarios. In 4 nodes placement, firstly nodes is placed near to base station and coordinates of node_1c, node_2c, node_3c and node_4c are (45, 45), (55, 45), (45, 55) and (55, 55) respectively considered as scenario number 1. We placed 4 nodes and its co-ordinates are given in Table III which is placed in the field.

In 8 nodes placement, firstly nodes is placed near to base station and coordinates of node_1c, node_2c, node_3c and node_4c are (45, 45), (55, 45), (45, 55) and (55, 55) shows in Table III that is shown in Table III and node_5c, node_6c, node_7c and node_8c are (45, 50), (50, 45), (55, 50) and (50, 55) is shown in Table IV respectively and is considered as scenario number 1. This is same as for all other placement of 8 nodes and is considered in Table III and Table IV.

Placement of nodes in the field with 9 different scenarios and algorithm runs 9 times for different placement of nodes and then find the best placement of nodes in the field that increases the stability of network. Table V shows the case that is consider for analysis, firstly it finds the best

 DOI : 10.18231/2454-9150.2018.0658

placement of nodes with good stability and then show the difference of different algorithm results.

IV. Energy Harvesting Analysis In Routing Algorithm For Homogeneous WSNs (LEACH)

A. Basic Algorithm (Concept)

LEACH has been considered as the base algorithm for analyzing the effect of node placement under harvesting energy. In LEACH, a node becomes a cluster head in the current round if the random number selected by the node is less than the threshold. The threshold function is given by:

$$Th(nr) = \begin{cases} \dfrac{Popt}{1 - Popt * \left[cR * mod\left(\frac{1}{Popt}\right)\right]} & , i \in Grp \\ 0 & , otherwise \end{cases} \quad (6)$$

P_{opt} is the optimal probability to become cluster head. G_{rp} is the set of nodes that have not been become cluster heads with in the last $(1/P_{opt})$ rounds of the epoch and cR represent the current round. Nodes other then the cluster head nodes join the cluster considering the signal strength of the cluster heads advertisement message. Each member node is assigned a time slot by its cluster head node for data communication. The cluster head aggregates the data collected from the member nodes before sending it to base station. After a certain time period, the complete process is repeated.

B. Modified Algorithm (Concept)

Normal nodes are randomly placed and some of these normal nodes (Energy harvesting node for case number III) are deterministically placed by giving their coordinates they are placed in the network field.

New threshold function (eq. 8) for being a cluster heads is based on [20].

$$h_1(i) = \frac{(E_{resi}(i,cR-1) + E_{har}(i,cR-1))}{E_{resi}(i,cR-1)} \quad (7)$$

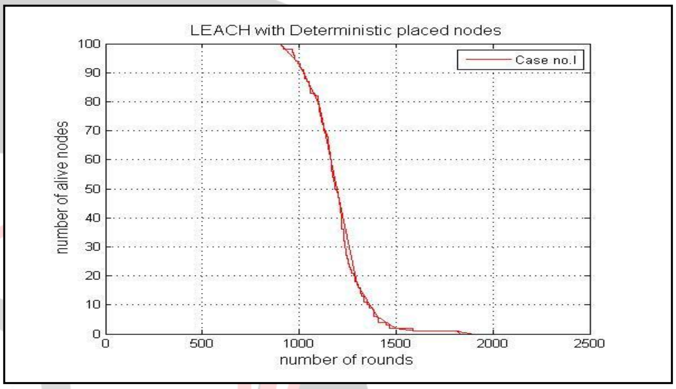
$$N\_Th(i) = \begin{cases} \dfrac{Popt}{1 - Popt * \left[cR * mod\left(\frac{1}{Popt}\right)\right]} * h1(i) & , i \in Grp \\ 0 & , otherwise \end{cases} \quad (8)$$

V. Result Of Energy Harvesting Analysis In Routing Algorithm For Homogeneous WSNs (LEACH)

A. LEACH with 4 node placement (b1=5)

TABLE V. NODE PLACEMENT ANALYSIS WITHOUT CONSIDERING ENERGY HARVESTING

Scena-rio No.	First_Dead (in Round)	Tenth_Dead (in Round)	All_Dead (in Round)	No. of Alive Node	No. of Dead Node
1.	836	1008	1718	0	100
2.	880	1002	1742	0	100
3.	833	1016	2015	0	100
4.	784	1012	1993	0	100
5.	773	1030	1845	0	100
6.	773	1025	1999	0	100
7.	805	1022	2259	0	100
8.	849	1015	1584	0	100
9.	910	1020	1826	0	100



Stability period of LEACH without considering energy harvesting

Figure 6 shows stability period of LEACH (4 nodes placement) without considering energy harvesting for best scenarios number is 9 for case number I having good stability period then other nodes placement.

TABLE VI. NODE PLACEMENT ANALYSIS WITH ENERGY HARVESTING CONSIDERATION WITHOUT CHANGING THRESHOLD FUNCTION

Scena-rio No.	First_Dead (in Round)	Tenth_Dead (in Round)	All_Dead (in Round)	No. of Alive Node	No. of Dead Node
1.	836	1019	0	4	96
2.	880	1064	0	4	96
3.	888	1031	0	4	96
4.	900	1047	0	4	96
5.	910	1060	0	4	96
6.	910	1060	0	4	96
7.	910	1062	0	4	96
8.	910	1048	0	4	96
9.	910	1056	0	4	96

 DOI : 10.18231/2454-9150.2018.0658

ISSN : 2454-9150 Vol-04, Issue-05, Aug 2018

Fig. 6. Stability period of LEACH with and without energy harvesting consideration without changing threshold function

Scena-rio No.	First_ Dead (in Round)	Tenth_ Dead (in Round)	All_Dead (in Round)	No. of Alive Node	No. of Dead Node
1.	865	1003	1957	0	100
2.	890	1006	1650	0	100
3.	834	1013	1854	0	100
4.	790	988	2348	0	100
5.	767	1006	1721	0	100
6.	787	1029	2096	0	100
7.	795	1017	1983	0	100
8.	848	1014	1665	0	100
9.	895	1028	2195	0	100

Figure 7 shows comparison between stability period of LEACH (4 nodes placement) with and without energy harvesting. We consider without change threshold function and find best scenarios number i.e. 7. There we consider case number II which is having good stability period and is also considered tenth dead node for best positioning.

Scena-rio No.	First_ Dead (in Round)	Tenth_ Dead (in Round)	All_Dead (in Round)	No. of Alive Node	No. of Dead Node
1.	844	1016	0	4	96
2.	887	1045	0	4	96
3.	900	1042	0	4	96
4	906	1053	0	4	96
5.	910	1055	0	4	96
6.	910	1066	0	4	96
7.	910	1058	0	4	96
8.	910	1058	0	4	96
9.	910	1052	0	4	96

TABLE VII. NODE PLACEMENT ANALYSIS WITH ENERGY HARVESTING CONSIDERATION WITH CHANGING THRESHOLD FUNCTION

TABLE VIII. BEST SCANARIOS OF LEACH WITH 4 NODE PLACEMENT

Ca-se No.	Scenario No.	First_ Dead (in Round)	Tenth_ Dead (in Round)	All_ Dead (in Round)	No. of Alive Node	No. of Dead Node
I.	9.	910	1020	1826	0	100
II.	7.	910	1062	0	4	96
III.	6.	910	1066	0	4	96

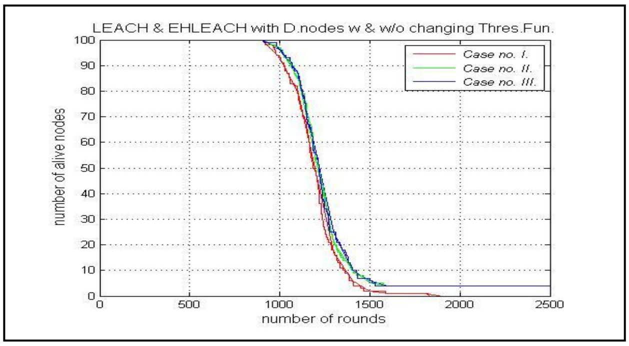


Figure 8 shows comparison between stability period of three best scenarios for case number I, II and III with 4 node placement in LEACH (4 nodes placement). The best scenarios number for node placement is 9, 7and 6 for case number I, II and III respectively. They are having good stability period and are also consider the tenth dead node for finding best nodes placement that is shown in Table V, VI and VII.

Fig. 7. Stability period of three best scenarios for case number I, II and III with 4 node placement in LEACH

B. *LEACH with 8 node placement (b1=10)*

TABLE IX. NODE PLACEMENT ANALYSIS WITHOUT CONSIDERING ENERGY HARVESTING

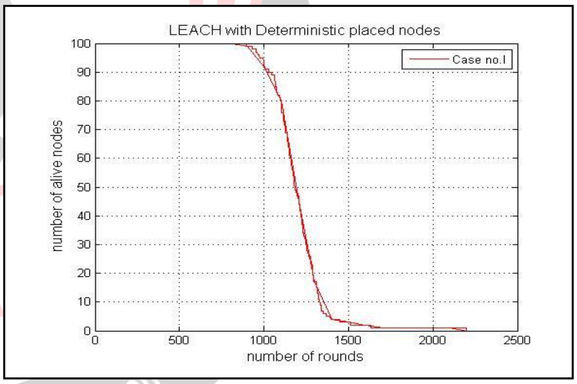


Fig. 8. Stability period of LEACH without considering energy harvesting

Figure 9 shows stability period of LEACH (8 nodes placement) without considering energy harvesting. The best scenarios number is 9 for case number I. This is having good stability period then other nodes placement.

TABLE X. NODE PLACEMENT ANALYSIS WITH ENERGY HARVESTING CONSIDERATION WITHOUT CHANGING THRESHOLD FUNCTION

Scena-rio No.	First_ Dead (in Round)	Tenth_ Dead (in Round)	All_Dead (in Round)	No. of Alive Node	No. of Dead Node
1.	865	1048	0	8	92

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2.	890	1079	0	8	92
3.	890	1068	0	8	92
4.	896	1076	0	8	92
5.	914	1083	0	8	92
6.	926	1096	0	8	92
7.	933	1099	0	8	92
8.	933	1089	0	8	92
9.	921	1098	0	8	92

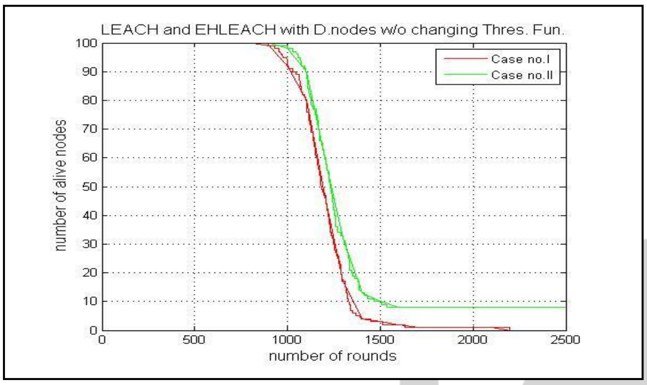

Fig. 9. Stability period of LEACH with and without energy harvesting consideration without changing threshold function

Figure 10 shows comparison between stability period of LEACH (8 nodes placement) with and without energy harvesting. Here we are not changing threshold function and find best scenario number i.e. 7 for case number II, which is having good stability period and is also considered tenth dead node for best placement.

TABLE XI. NODE PLACEMENT ANALYSIS WITH ENERGY HARVESTING CONSIDERATION WITH CHANGING THRESHOLD FUNCTION

Scena-rio No.	First_ Dead (in Round)	Tenth_ Dead (in Round)	All_Dead (in Round)	No. of Alive Node	No. of Dead Node
1.	870	1075	0	8	92
2.	884	1065	0	8	92
3.	890	1064	0	8	92
4.	891	1079	0	8	92
5.	911	1078	0	8	92
6.	931	1089	0	8	92
7.	936	1083	0	8	92
8.	941	1093	0	8	92
9.	933	1085	0	8	92

TABLE XII. BEST SCANARIOS OF LEACH WITH 8 NODE PLACEMENT

Ca-se No.	Scenario No.	First_ Dead (in Round)	Tenth_ Dead (in Round)	All_ Dead (in Round)	No. of Alive Node	No. of Dead Node
I.	9.	895	1028	2195	0	100
II.	7.	933	1099	0	8	92
III.	8.	941	1093	0	8	92

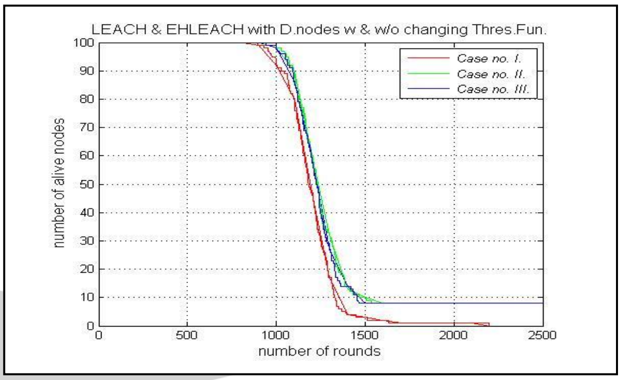

Fig. 10. Stability period of three best scenarios for case number I, II and III with 8 node placement in LEACH

Figure 11 shows comparison between stability period of three best scenarios for case number I, II and III with (8 node placement) in LEACH. The best scenarios number for node placement is 9, 7 and 8 for case number I, II and III respectively. They are having good stability period also consider the tenth dead node for finding best nodes placement that is shown in Table IX, X and XI.

VI. Energy Harvesting Analysis In Routing Algorithm For Hetero-geous WSN (SEP)

A. *Basic Algorithm (Concept)*

SEP considers LEACH like clustering approach with improved cluster head selection mechanism to cater energy heterogeneity. SEP has been considered as the base algorithm. SEP considers weighted optimal probability based cluster head selection mechanism for normal and advanced nodes. In SEP with node placement, the weighted probability of normal P_{nr} and advanced P_{ad} are given by:

$$P_{nr} = \frac{(1+ad')}{(1+ad'*m')} * Popt \qquad (9)$$

$$P_{ad} = \frac{1}{(1+ad'*m')} * Popt \qquad (10)$$

The threshold functions for the normal nodes (Th_{nr}) and advanced nodes (Th_{ad}) are given by:

$$Th_{nr} = \begin{cases} \frac{Pnr}{1-Pnr*[cR*mod(1/Pnr)]}, & i \in Grp_{nr} \\ 0, & otherwise \end{cases} \qquad (11)$$

$$Th_{ad} = \begin{cases} \frac{Pad}{1-Pad*[cR*mod(1/Pad)]}, & i \in Grp_{ad} \\ 0, & otherwise \end{cases} \qquad (12)$$

 DOI : 10.18231/2454-9150.2018.0658

ISSN : 2454-9150 Vol-04, Issue-05, Aug 2018

Grp_{nr} and Grp_{ad} are the set of nodes that have not become cluster head within the last $(1/Pnr)$ and $(1/Pad)$ rounds of the epoch respectively and cR represent the current round. In transmission phase, the cluster head communicate with the base station through one-hop method directly.

B. Modified Algorithm (Concept)

Normal nodes are randomly placed and advanced nodes (Energy harvesting node for case number III) are deterministically placed by giving their coordinates they are placed in the network field. Threshold function (eq.13), harvesting energy of a node (eq.14) and new threshold function with harvesting energy consideration (eq.15) for being a Cluster heads for advance node:

$$T\_P_{ad}=Th_{ad}=\begin{cases}\frac{Pad}{1-Pad*[cR*mod(1/Pad)]} & ,i\in Grp_{ad}\\ 0 & ,otherwise\end{cases} \quad (13)$$

$$h_z(i)=\frac{(E_{resi}(i,cR-1)+E_{har}(i,cR-1))}{E_{resi}(i,cR-1)} \quad (14)$$

$$N\_Th_{ad}=\begin{cases}T\_Pad*h2(i) & ,i\in Grp_{ad}\\ 0 & ,otherwise\end{cases} \quad (15)$$

VII. Result Of Energy Harvesting Analysis In Routing Algorithm For Heterogeous WSN (SEP)

A. SEP with 4 nodes placement (b1=1)

TABLE XIII. NODE PLACEMENT ANALYSIS WITHOUT CONSIDERING ENERGY HARVESTING

Scena-rio No.	First_ Dead (in Round)	Tenth_ Dead (in Round)	All_Dead (in Round)	No. of Alive Node	No. of Dead Node
1.	960	1107	3306	0	100
2.	996	1103	3225	0	100
3.	996	1092	2661	0	100
4.	970	1109	2544	0	100
5.	921	1092	2677	0	100
6.	918	1108	2439	0	100
7.	954	1106	2138	0	100
8.	996	1095	2078	0	100
9.	996	1093	1952	0	100

Figure 12 shows stability period of SEP (4 nodes placement) without considering energy harvesting. The best scenarios number is 2 for case number I which is having good stability period. It is also consider tenth dead node for best placement.

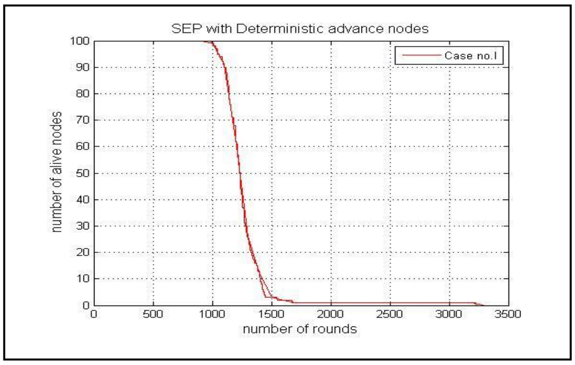

Fig. 11. Stability period of SEP without considering energy harvesting

TABLE XIV. NODE PLACEMENT ANALYSIS WITH ENERGY HARVESTING CONSIDERATION WITHOUT CHANGING THRESHOLD FUNCTION

Scena-rio No.	First_ Dead (in Round)	Tenth_ Dead (in Round)	All_Dead (in Round)	No. of Alive Node	No. of Dead Node
1.	960	1108	0	4	96
2.	996	1114	0	4	96
3.	996	1114	0	4	96
4.	1000	1114	0	4	96
5.	1007	1133	0	4	96
6.	1004	1124	0	4	96
7.	996	1135	0	4	96
8.	996	1106	0	4	96
9.	996	1094	0	4	96

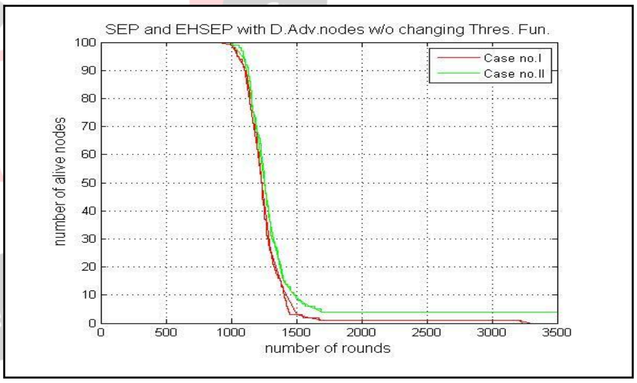

Fig. 12. Stability period of SEP with and without energy harvesting consideration without changing threshold function

Figure 13 shows comparison between stability period of SEP (8 nodes placement) with and without energy harvesting. Here we don't change threshold function for best scenarios number 5 for case number II. It is having good stability period then other nodes placement.

 DOI : 10.18231/2454-9150.2018.0658

TABLE XV. NODE PLACEMENT ANALYSIS WITH ENERGY HARVESTING CONSIDERATION WITH CHANGING THRESHOLD FUNCTION

Scena-rio No.	First_ Dead (in Round)	Tenth_ Dead (in Round)	All_Dead (in Round)	No. of Alive Node	No. of Dead Node
1.	961	1086	0	4	96
2.	1007	1087	0	4	96
3.	1007	1102	0	4	96
4.	1007	1117	0	4	96
5.	1019	1127	0	4	96
6.	1007	1125	0	4	96
7.	1007	1126	0	4	96
8.	1007	1106	0	4	96
9.	1007	1100	0	4	96

TABLE XVI. BEST SCANARIOS OF SEP WITH 4 NODE PLACEMENT

Ca-se No.	Scenari o No.	First_ Dead (in Round)	Tenth_ Dead (in Round)	All_ Dead (in Round)	No. of Alive Node	No. of Dead Node
I.	2.	996	1103	3225	0	100
II.	5.	1007	1133	0	4	96
III.	5.	1019	1127	0	4	96

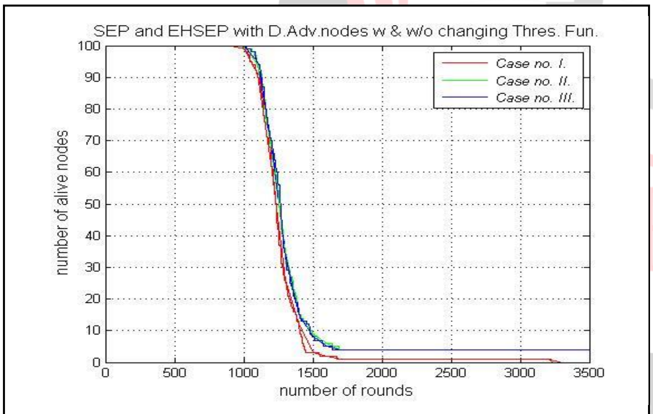

Fig. 13. Stability period of three best scenarios for case number I, II and III with 4 node placement in SEP

Figure 14 shows comparison between stability period of three best scenarios for case number I, II and III with (4 node placement) in SEP. The best scenarios number for node placement is 2, 5 and 5 for case number I, II and III respectively. They are having good stability period and is also considered the tenth dead node for best nodes placement that is shown in Table XIII, XIV and XV.

B. SEP with 8 nodes placement (b1=1)

TABLE XVII. NODE PLACEMENT ANALYSIS WITH ENERGY HARVESTING CONSIDERATION WITHOUT CHANGING THRESHOLD FUNCTION

Scena-rio No.	First_ Dead (in Round)	Tenth_ Dead (in Round)	All_Dead (in Round)	No. of Alive Node	No. of Dead Node
1.	1071	1157	3120	0	100
2.	1097	1176	2022	0	100
3.	1091	1164	3379	0	100
4.	1025	1165	2489	0	100
5.	977	1175	2655	0	100
6.	960	1180	2647	0	100
7.	971	1164	2095	0	100
8.	1025	1167	1723	0	100
9.	1103	1158	1942	0	100

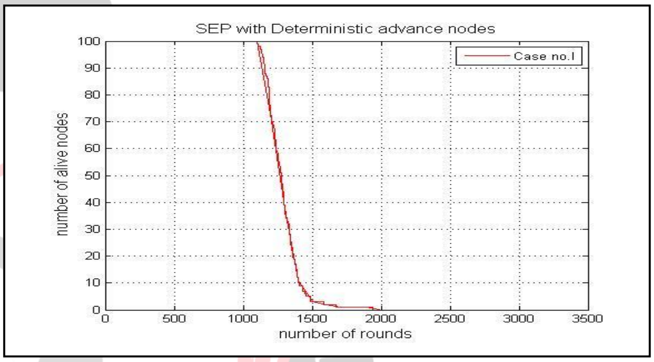

Fig. 14. Stability period of SEP without considering energy harvesting

Figure 15 Figure 15 shows stability period of SEP (8 nodes placement) without considering energy harvesting. The best scenarios number is 9 for case number I having good stability period then other nodes placement.

TABLE XVIII. PLACEMENT ANALYSIS WITH ENERGY HARVESTING CONSIDERATION WITHOUT CHANGING THRESHOLD FUNCTION

Scena-rio No.	First_ Dead (in Round)	Tenth_ Dead (in Round)	All_Dead (in Round)	No. of Alive Node	No. of Dead Node
1.	1071	1157	0	8	92
2.	1097	1176	0	8	92
3.	1110	1167	0	8	92
4.	1134	1180	0	8	92
5.	1126	1192	0	8	92
6.	1116	1189	0	8	92
7.	1113	1181	0	8	92
8.	1109	1171	0	8	92
9.	1106	1157	0	8	92

DOI : 10.18231/2454-9150.2018.0658

Figure 16 shows comparison between stability period of SEP (8 nodes placement) with and without energy harvesting. Here we don't consider any changing in threshold function and find best scenarios number i.e. 4 for case number II. It is having good stability period then other nodes placement.

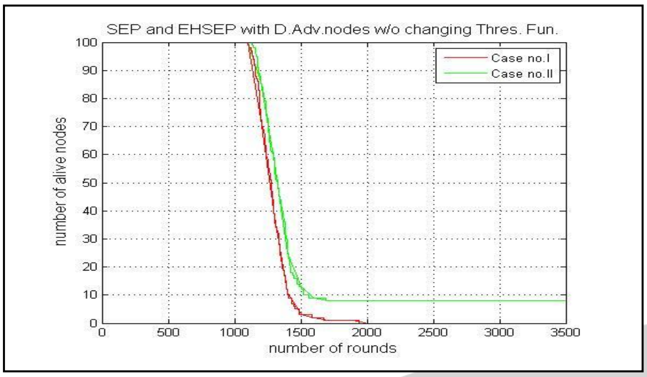

Fig. 15. Stability period of SEP with and without energy harvesting consideration without changing threshold function

TABLE XIX. NODE PLACEMENT ANALYSIS WITH ENERGY HARVESTING CONSIDERATION WITH CHANGING THRESHOLD FUNCTION

Scenario No.	First_ Dead (in Round)	Tenth_ Dead (in Round)	All_Dead (in Round)	No. of Alive Node	No. of Dead Node
1.	1071	1157	0	8	92
2.	1097	1175	0	8	92
3.	1117	1175	0	8	92
4.	1142	1183	0	8	92
5.	1136	1189	0	8	92
6.	1124	1193	0	8	92
7.	1115	1184	0	8	92
8.	1109	1172	0	8	92
9.	1109	1162	0	8	92

TABLE XX. THREE BEST SCENARIO FOR PLACING 8 NODES IN FIELD FOR SEP

Case No.	Scenario No.	First_ Dead (in Round)	Tenth_ Dead (in Round)	All_ Dead (in Round)	No. of Alive Node	No. of Dead Node
I.	9.	1103	1158	1942	0	100
II.	4.	1134	1180	0	8	92
III.	4.	1142	1183	0	8	92

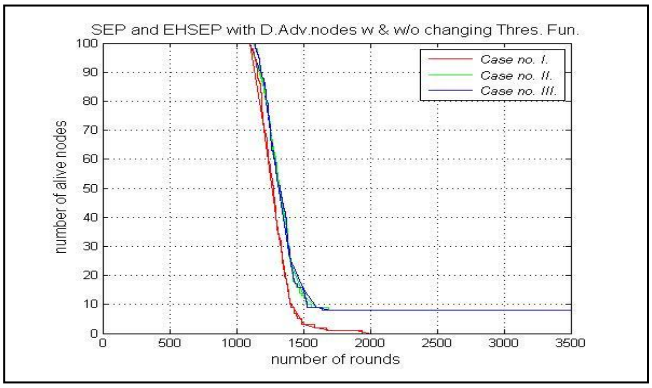

Fig. 16. Stability period of three best scenarios for case number I, II and III with 8 node placement in SEP

Figure 17 shows comparison between stability period of three best scenarios for case number I, II and III with (8 node placement) in SEP. The best scenarios number for node placement is 9, 4 and 4 for case number I, II and III respectively. It is having good stability period and which find best nodes placement that is shown in Table XVII, XVIII and XIX.

VIII. Conclusion

This paper analyzes the effect of node placement in routing algorithm for energy homogeneous and heterogeneous WSN with and without considering the harvesting energy. The MATLAB simulation results showed that the node placement find the best location to place the normal nodes in homogeneous network and advance node in heterogeneous network with and without considering the harvesting energy that increase the stability period. The proposed improved cluster head selection method based on the analysis results, shows better energy efficiency in terms of improved stability period under different node placement scenarios.

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