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A Novel Algorithm for Optimum Balancing Energy Consumption LEACH Protocol Using Numerical Simulation Technique

Er. Avadhesh Kumar Maurya[1], Prof. (Dr.) Vishwa Nath Maurya[2]
and Diwinder Kaur Arora[3],

[1]Assistant Professor,
Department of Electronics & Communication Engineering
Lucknow Institute of Technology, U.P. Technical University, Lucknow-226002,
U.P., India, avadheshmaurya09@gmail.com

[2] Professor & Principal,
Shekhawati Engineering College, Rajasthan Technical University, India
prof.drvnmaurya@gmail.com, prof_vnmaurya@yahoo.in

[3] Inspector of Police,
Group Centre, Central Reserve Police Force, Lucknow-226002, U.P.
Ministry of Home Affairs, Govt. of India
hkdkarora@rediffmail.com, diwi.kaur1992@gmail.com

Abstract In this paper we have explored an optimization algorithm using Matlab for balancing energy consumption LEACH protocol to prolong the lifetime of network. In wireless sensor network (WSN), each node has limited energy resources and the lifetime of network is one of the most critical issues in WSNS. Because LEACH protocol has some defects including indefinite and unevenly distributed cluster heads. By studying the energy consumption of nodes and cluster heads on data acquisition and transmission, we propose Balancing Energy Consumption LEACH (BEC-LEACH) protocol to prolong the lifetime of the network. The protocol proposed in the present paper aims to study the clustering algorithm and take geographical location and remaining energy of nodes as the leading feature for cluster heads selection. The simulation results explored in this paper show that BEC-LEACH algorithm can more effectively balance the energy consumption of nodes and prolong the lifetime of network compared with LEACH.

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1 Introduction

A wireless sensor network (WSN) node is equipped with a radio transceiver or other wireless communication devices, a tiny microcontroller (CPU, storage, embedded operating system, etc.), the sensing unit (A/D conversion module) and battery [1]. The energy consumption and the lifetime of nodes are the most critical issues in WSNS. According to the network structure, routing in WSNs can be divided into flat-based routing, hierarchical- based routing, and location-based routing. Nodes grouped together to form a cluster in hierarchical routing, the cluster head（CH） acts as the leader collects and aggregates the data from their respective clusters and send the data to base station (BS). Hierarchical routing is the most desirable routing for prolong the life time of wireless sensor network [1-2]. Several noteworthy researchers [1, 2…10] contributed to explore in related field.

2 Related Previous Work

The most well-known hierarchical routing protocols are LEACH, HEED, TEEN, PEGASIS [4 & 6] etc. The LEACH is the most representative routing protocols among these protocols, whose purpose is to balance the energy consumption of all nodes and prolong the lifetime of network. The sensor nodes are grouped together to form a cluster or clusters. LEACH protocol chooses cluster head from high energy nodes. [8].

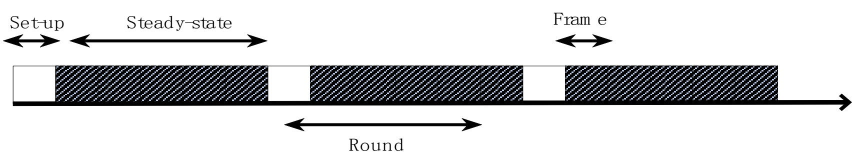

Figure 1: Operation of the LEACH protocol

The Operation of LEACH protocol is divided into two steps. set-up phase and steady-state phase, as shown in figure 1. In the LEACH protocol， each round has a set-up and steady-state phase. In set-up phase cluster heads are randomly chosen and normal nodes choose the closest cluster to join. In the steady-state phase, Cluster heads collect the data from nodes and send the data to the BS. Set-up phase and steady-state phase are divided into multiple sub-phases. That is: advertising phase, cluster set-up phase, Schedule Creation Phase and data transmission phase [4]. The flow chart of LEACH protocol is shown in figure 2.

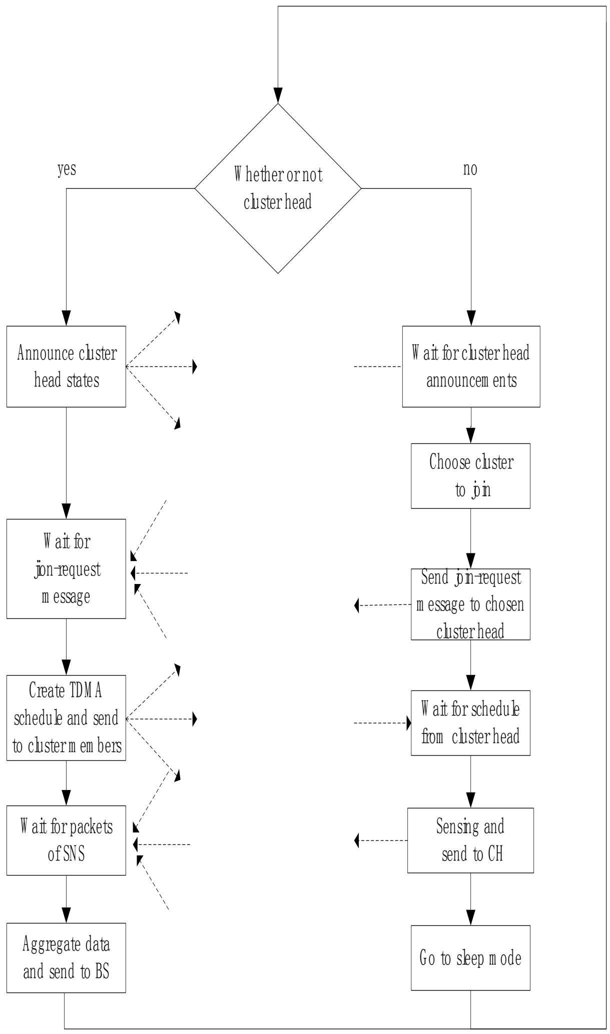

Figure 2: Process of the LEACH protocol

2.1 Phases Description

In the advertising phase, each node selects a random number between 0 and 1, the node becomes the cluster head if the randomly number is less than T (n) in the current round. T (n) is calculated as shown in equation 1.

$$T(n) = \begin{cases} \dfrac{p}{1 - p \times (r \bmod \frac{1}{p})} & if\ n \in G \\ 0 & otherwise \end{cases} \tag{1}$$

where n is the total number of nodes, P is the predetermined percentage of cluster heads r is the current round, and G is the set of nodes that have not been elected as cluster heads in the last 1/P rounds.

2.2 Drawbacks of LEACH

Serving as the most representative hierarchical routing protocol in WSN, the LEACH still has some drawbacks as described below:

- LEACH assumes that network is small size and all nodes can communicate with each other, which is not always true for large-scale network. [1]
- LEACH randomly selects cluster-head, the probability of all nodes elected as cluster head is equal, which would consume unnecessary energy if one round cluster heads are generated in a small region.
- The number of cluster heads is uncertain in LEACH [9], which will consume a large amount of energy when the number of cluster heads is too many or too few because of the base station being usually far away from the network.
- LEACH conducts cluster head selection in each round which need all nodes broadcast their messages and geographical location, which will significantly increase energy consumption.
- LEACH assumes that all nodes are uniformly distributed and each node has the same initial energy, however it is often impossible in actual operation.

2.3 Advancements of LEACH

Since LEACH is defective, much works and many investments have been done to improve LEACH protocol, such as S-LEACH [6], GS-LEACH [3], LEACH-C. LEACH-C is the most representative protocol proposed by Heinzelman [5], which require all nodes to broadcast their own position and energy to the base station in set-up phase, base station selects cluster heads depending on the remaining energy.

Although it prolong the lifetime of the low-energy nodes, the number of cluster heads is still indefinite, the drawback of irrational distribution cluster heads still exists. Based on the above, we propose BEC-LEACH protocol through studying the energy consumption of nodes and cluster heads on data reception and transmission, we propose a novel clustering algorithm which takes geographical location and remaining energy of nodes as the main factor for cluster heads selection.

3 Novel Optimization Algorithm

In routing protocol, to transmit n-bit message along the distance d, the energy consumption of cluster heads and nodes is given by:

$$E_{Tx}(n,d) = E_{Tx-mp}(n,d) + E_{Tx-elec}(n) = \begin{cases} n \times E_{elec} + n \times \varepsilon_{mp} \times d^4 & d \geq d_0 \\ n \times E_{elec} + n \times \varepsilon_{fs} \times d^2 & d < d_0 \end{cases} \tag{2}$$

where E_{elec} denotes radio electronics transmission/reception energy which depends on factors such as modulation, digital coding, filtering, and spreading of the signal, E_{mp} denotes the amount of energy consumption of multipath fading, E_{fs} denotes the amount of energy consumption of free space.

To receive n-bit message， the energy consumption of cluster heads and nodes is shown in equation 3.

$$E_{Rx}(n) = E_{Rx-elec}(n) = nE_{elec} \tag{3}$$

The up expression of equation 2 is an energy consumption value spent by transmission of electronic device and the down expression is the value by transmission amplifier. If the distance is less than a threshold d_o which is shown in equation 4, the free space (fs) model is used, whatever, the multipath (mp) model is used.

$$d_0 = \frac{\sqrt{\varepsilon_{fs}}}{\sqrt{\varepsilon_{mp}}} \tag{4}$$

We assume that the number of nodes in network is M, and all nodes placed randomly within L*L meter area. The number of cluster heads is assumed to be K, so the average number of members of each cluster is M/K-1. The energy consumption of each cluster head in each round of collection and transmission is as follows:

$$E_{CH} = nE_{Elec}(x)(\frac{M}{K}-1) + nE_{bit}\frac{M}{K} + \frac{n}{\partial}(E_{\mathrm{elec}} + \varepsilon_{\mathrm{mp}} \times \mathrm{d}_{tobs}^{4}) \qquad (5)$$

where E_{bit} denotes the energy consumption of cluster head in receiving one-bit message, d_{tobs} denotes the distance from each node to the base station, ∂ denotes the fusion rate of data.

The energy consumption of each node is computed by:

$$E_{no-CH} = \mathrm{n} \times E_{elec} + \mathrm{n} \times \varepsilon_{\mathrm{fs}} \times \mathrm{d}_{\mathrm{to}CH}^{2} \qquad (6)$$

Through (5) and (6), we can obtain the energy consumption of each cluster in one round as shown in (7).

$$E_{\mathrm{cluster}} = E_{CH} + (\frac{M}{K}-1) \times E_{\mathrm{no\text{-}CH}} \qquad (7)$$

The energy consumption of all nodes and cluster heads in one round is given by:

$$\begin{aligned} E_{\mathrm{total}} &= \mathrm{K} \times E_{\mathrm{cluster}} = K(E_{\mathrm{CH}} + (\frac{M}{K}-1) \times E_{\mathrm{no\text{-}CH}}) \\ &= \mathrm{n} \times (2\mathrm{M} \times E_{\mathrm{elec}} + (\frac{1}{\partial}-1) \times \mathrm{K} \times E_{\mathrm{elec}} + \frac{K}{\partial} \times \varepsilon_{mp} \times \mathrm{d}_{tobs}^{4} + \mathrm{M} \times \varepsilon_{\mathrm{fs}} \times \mathrm{d}_{toCH}^{2} + \mathrm{M} \times E_{\mathrm{bit}}) \end{aligned} \qquad (8)$$

Compare to other parameters in equation 8, $(\frac{1}{\partial}-1) \times \mathrm{K} \times \mathrm{E}_{\mathrm{elec}}$ is so small that it can be ignored, so Equation 8 can be simplified to equation 9.

$$E_{\mathrm{total}} == \mathrm{n} \times (2\mathrm{M} \times \mathrm{E}_{\mathrm{elec}} + \mathrm{K} \times \varepsilon_{mp} \times \mathrm{d}_{tobs}^{4} + \mathrm{M} \times \varepsilon_{\mathrm{fs}} \times \mathrm{d}_{toCH}^{2} + \mathrm{M} \times \mathrm{E}_{\mathrm{bit}}) \qquad (9)$$

Since M nodes placed irregularly within a L*L meter area, we assume that each cluster is a circle with the radius of $\frac{\sqrt{\pi}}{2}$, and the area of each cluster is $\frac{L \times L}{K}$, the expected distance between all points and the centre of the circle is shown in equation 10.

$$E(\mathrm{d}) = \iint (\mathrm{x}^2 + \mathrm{y}^2)\rho(\mathrm{x},\mathrm{y})\mathrm{dxdy} = \iint r^2 \rho(\mathrm{r},\theta)\mathrm{rdrd}\theta \qquad (10)$$

In this way, the average distance from all nodes to the cluster head is as follows:

$$E(d^2_{toCH})=\rho\int_0^{2\pi}\int_{r=0}^{\frac{L}{\sqrt{\pi K}}} r^3 dr d\theta=\frac{\rho L^4}{2\pi K^2}=\frac{L^2}{2\pi K} \tag{11}$$

In wireless sensor networks, all nodes are far away from the base station because of it usually being arranged in complex environment. We assume that the optimum number of cluster heads is 4. The two distribution models of clusters are shown in Figure 3.

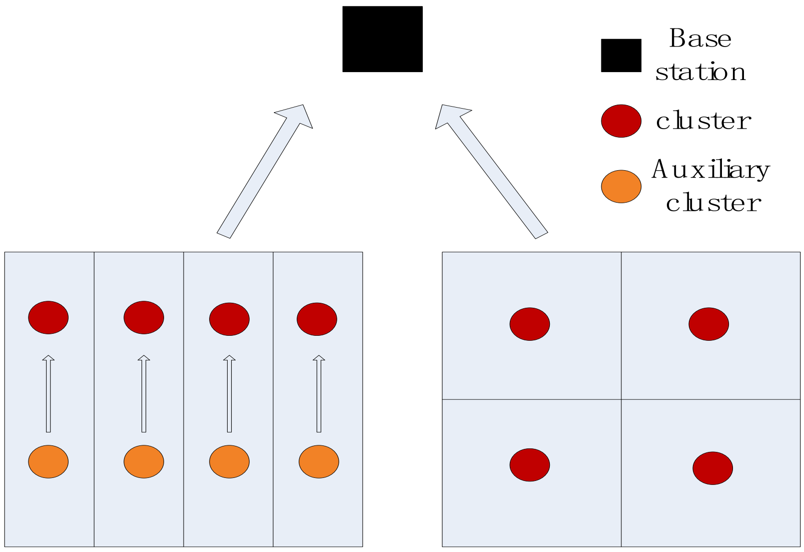

Figure 3: Two distribution models of clusters

Base station is far away from all nodes and cluster heads, the energy consumption in the process of cluster heads transmitting data to base station is usually much greater than that of nodes transmitting data to cluster heads. The distance between nodes and cluster heads in the left model of Figure 3 is longer than that of the right model. However, the cluster head of left model is much closer to base station, and the distance between nodes and cluster heads can be shorten by the use of the auxiliary cluster head. The energy consumption of the left model is less than that of the right model in real situation. The expected distance between all nodes and cluster heads is shown in equation 12.

$$E(d_{toCH}^2) = \frac{L^2}{4} + \frac{L^2}{4K^2} \tag{12}$$

The optimal numbers of cluster-head nodes of this paper is calculated as:

$$K_{opt} = \sqrt[3]{\frac{ML^2 d_0}{2d_{toBS}^4}} \tag{13}$$

4 Principle of BEC-LEACH

The nodes are non-uniform distribution in network, so taking the center of gravity of the network can get more accurate numerical than geometric center. Let (X_i ,Y_i) represent the coordinates of each node. The average horizontal coordinate of all nodes is as follows:

$$X_0 = \frac{\sum_{i=1}^{M} X_i}{M} \tag{14}$$

The average Vertical coordinate of all nodes is shown in equation 15.

$$Y_0 = \frac{\sum_{i=1}^{M} Y_i}{M} \tag{15}$$

The distance from Nodes to the center of gravity is as follows:

$$d = \sqrt{(X_i - X_0)^2 + (Y_i - Y_0)^2} \tag{16}$$

BEC-LEACH chooses cluster heads based on the remaining energy of nodes, the distance from the center of gravity to node and the distance from node to BS. We propose a data model of nodes, which is as shown in equation 17.

$$CH - E = a * e + b/d1 + c/d2 \tag{17}$$

where e is the remaining energy of nodes, d1 is the distance from s node to the center of gravity and d2 is the distance from a node to the base station.

In the set-up phase, all nodes broadcast information, which causes useless duplication of information and leads to “Information Collision” and “Broadcast Storm”

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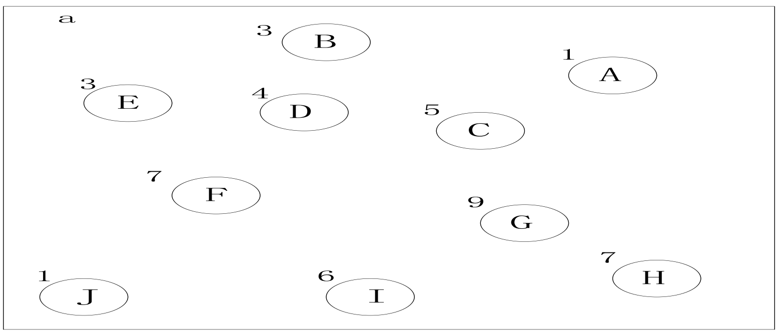
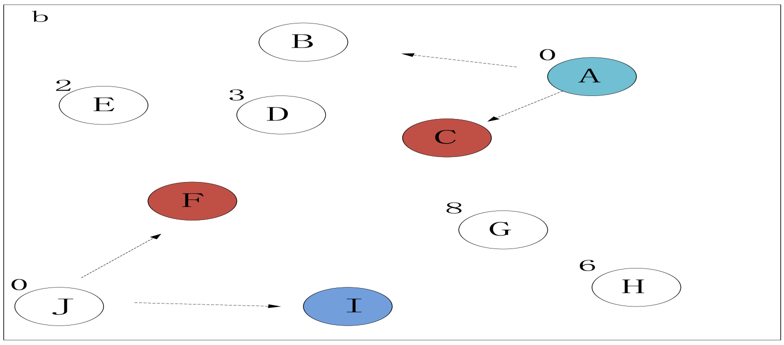
phenomenon [11]. Based on this (?), we use the "reciprocal mechanism". Each node generates a random digital in the initial (?), the initial digital starts decreasing reciprocal, when countdown (?) to zero, it starts compare the CH-E value (?) with around nodes and the specific process is as follows:

(i) At the beginning**,** *t*he information from base station is broadcast to the whole networks, each node computes it coordinates (?) by the information they received.
(ii) Each node calculates their own CH **-** E value according to their own energy and geographical location.
(iii) In the advertising phase, each node generates a random number from 1 to 20, and starts to countdown.
(iv) When one node countdown to zero (?), it sends energy comparison requirement to around nodes (?). The node which has higher energy becomes the temporary cluster head while the node which is closest to the center of gravity becomes auxiliary cluster head.
(v) All nodes countdown (?) simultaneously till the smallest of them reaches zero, the current temporary cluster heads become cluster heads, while auxiliary cluster head is decided to become auxiliary cluster head or normal node depends on the position of the cluster head.
(vi) Cluster head broadcast messages to the surroundings, and nodes select the closest cluster head to join.

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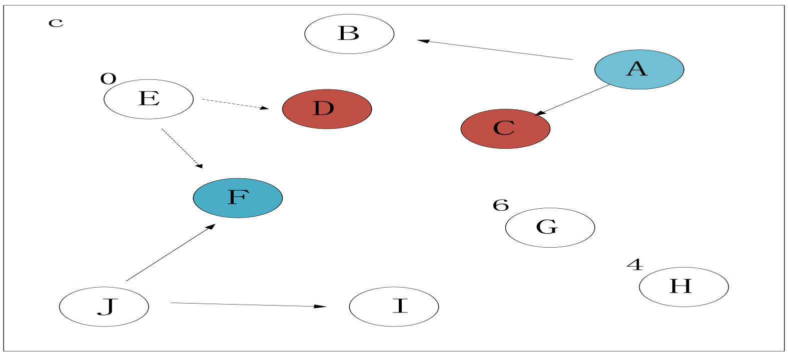
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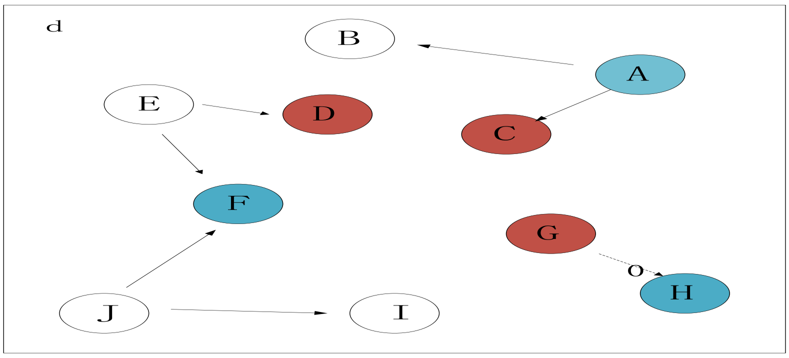
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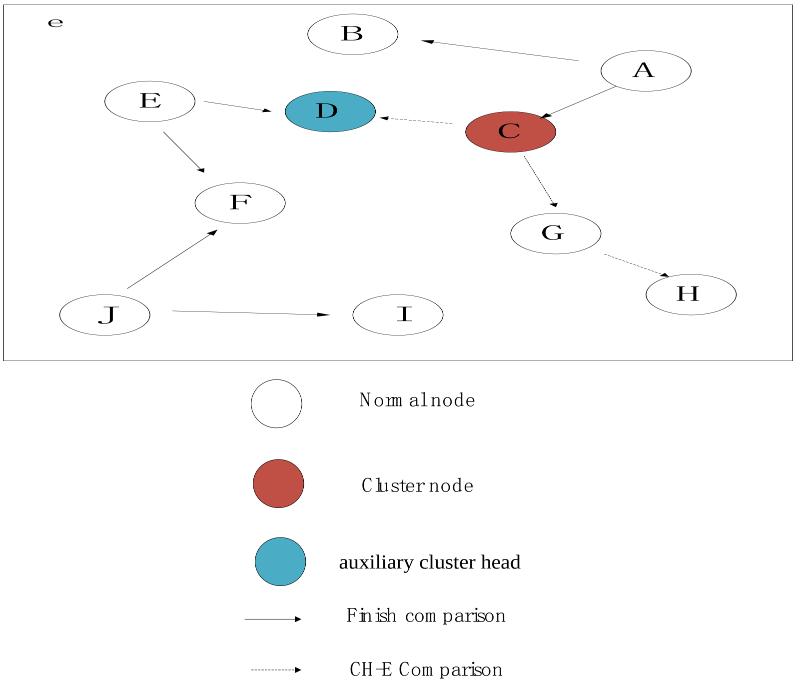

Figure 4:.Process of choose cluster head

The choosing step is shown in figure 4. As shown in (a) and (b), each node generates a random number, and then begin to countdown. The node A firstly countdown to zero begin searching **(?)** for the around nodes to compare the value of CH-E, A finds the nearest node C, B and compare with each other (?). After the comparison, the node C which has the highest CH-E value is elected as the temporary cluster head, and A is elected to be the auxiliary cluster head. All nodes countdown simultaneously till the smallest of them reaches zero. As it (?) is shown in (d), it (?) generates temporary cluster heads D, C, G and three auxiliary cluster heads. At last, the node C which has highest CH-E value becomes cluster head, and D becomes auxiliary cluster head. If node C is not far away from the center of gravity, node D becomes normal node.

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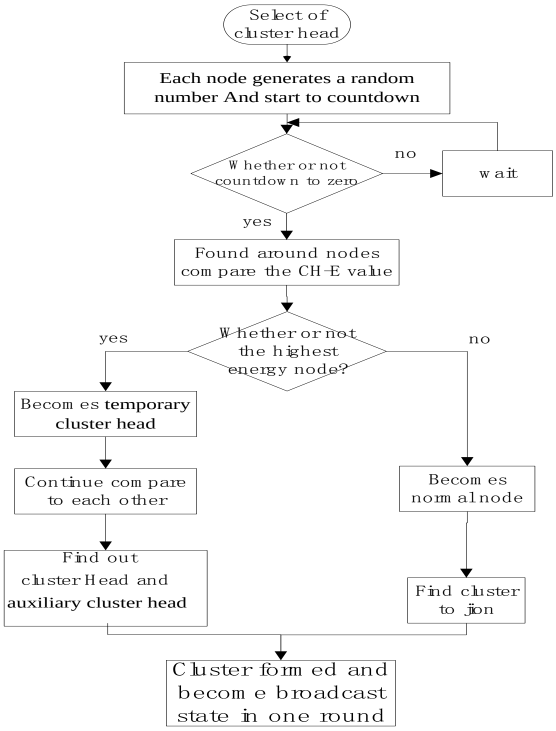

Figure 5: Process of the BEC-LEACH protocol

In order to reduce energy consumption in the process of cluster head selection, after the data transmission phase, we calculate the CH-E value of the cluster head in every area. If its energy value is greater than the average value of networks, the node is still selected to the cluster head of this area in the next round.

5 Simulated Outcomes

In this section, we mainly use simulations to analyze and to evaluate the performance of the algorithm. This paper uses Matlab to simulate the method. Then, we have focused our key attention for a comparative analysis between the results with LEACH and BEC-LEACH in order to verify the improved algorithm proposed in this paper.

5.1 Simulation Setup

The simulation modeled a network of 100 nodes placed randomly within a 100×100 meter area. The communication energy parameters (?) are set as follows: E_{elec} is

50nJ/bit, E_{fs} is 10 pJ/bit/m^2, E_{mp} is 0.0013 pJ/bit/m^4, E_{da} is 5nJ/bit/signal and the location of BS is (50,175).Apply energy parameters to Equation 13, we can concluded that the best number of cluster heads is 4.

5.2 Simulations and Comparative Analysis

In this section, we focus our attention to evaluate performance of BEC-LEACH comparing to LEACH algorithm in terms of network lifetime. In order to serve our key objective here, we have drawn two graphs for node dead and energy consumption in LEACH and BEC-LEACH respectively in Figures 6-7.

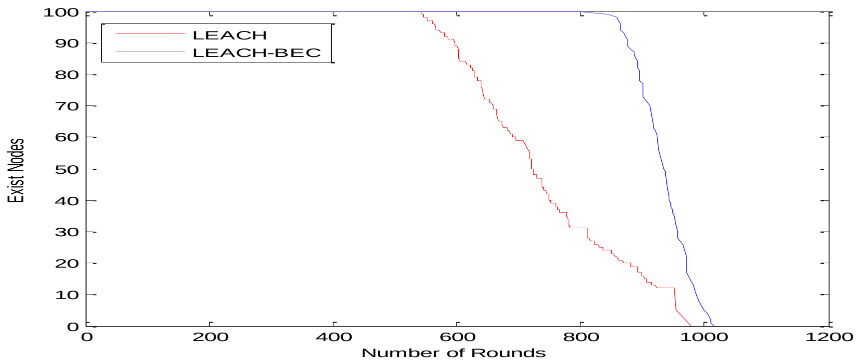

Figure 6: Graph of node dead in LEACH and BEC-LEACH

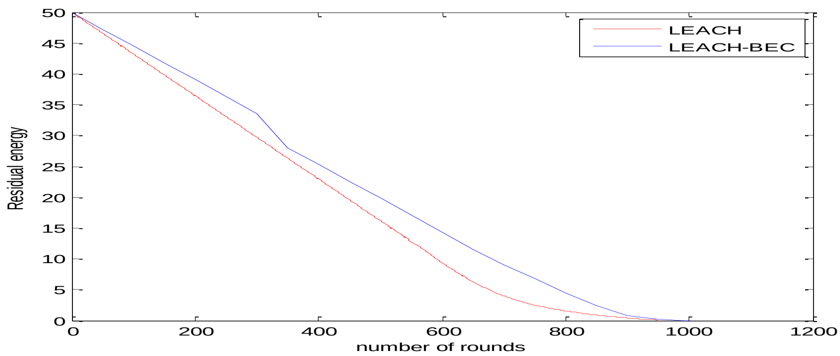

Figure 7: Graph of energy consumption in LEACH and BEC-LEACH

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Figure 6 illustrates the performance of BEC-LEACH comparing to LEACH algorithm in terms of network lifetime. As it is clear from Figure 6 that sensor network performs longer with BEC-LEACH in comparison to LEACH, the first node of BEC-LEACH dies later by 54.3%, the network has a 31.3% delay at time when the half number of nodes dead and the network lifetime decreased by 20%-30%. This power saving is due to: BEC-LEACH can save energy in the process of cluster transmit data to BS. Figure 7 shows the remaining energy in each round of BEC-LEACH and LEACH, after 200 rounds the amount of consume energy in LEACH is 13.7 J and in BEC-LEACH is 9.7 J, after 500 rounds he (?) amount of consume energy in LEACH is more than 35 J when in BEC-LEACH is 31.7J. Overall from each of these two graphs it is clear that in BEC- LEACH nodes survive longer than in LEACH. Thus BEC-LEACH prolong network lifetime than LEACH.

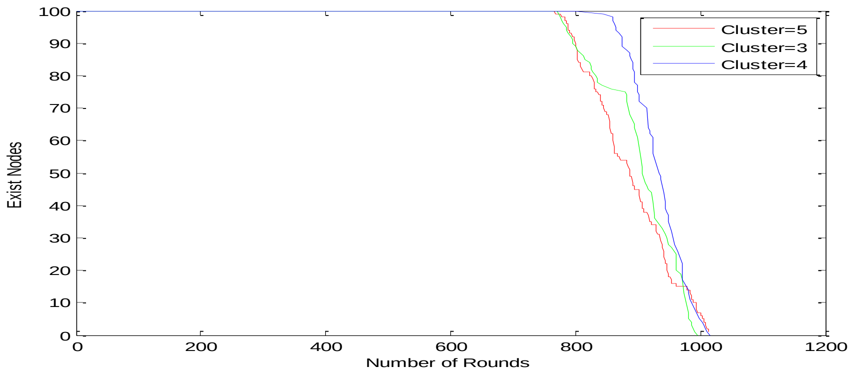

Figure 8: The energy consumption of varying number cluster head

We use simulations to inspect the optimal numbers of cluster heads. As shown in Figure 8. The first node dead after 800 rounds when the number of cluster heads is 4, however Therefore, it is clearly shown that when the number of cluster heads is 5 the half number of cluster heads and the last node dead later than the number of cluster heads is 3 and 5.

6 Conclusions

In this paper, an optimization algorithm for balancing energy consumption to prolong the lifetime of network has been presented. Numerical simulation technique has been applied to analyze and evaluate the performance of the proposed novel algorithm using Matlab. Then, to verify the improved algorithm proposed in this paper, a comparative analysis has been done between the results with LEACH and BEC-LEACH. Wireless sensor networks would balance the energy consumption significantly by using hierarchical routing, especially when LEACH stochastically chooses nodes as cluster heads to reduce the energy consumption. However, in LEACH the number of cluster heads is not clear and the cluster heads are distributed unevenly. In order to deal with these problems, a further protocol BEC-LEACH is discussed in this paper. By analyzing the manner and amount of energy used by nodes and cluster heads, in this paper we put out a better way to select cluster heads and we take geographical location and the remaining energy of nodes as an important factor to select cluster heads. If the node is far away from the center of network, an auxiliary node should be added to help collect data. Simulation results show that BEC-LEACH is more energy-efficient than LEACH with greater network lifetime. In this protocol, nodes would exist longer and energy consumption is slower. At the same time, the number of cluster heads chosen by BEC-LEACH is the best. Therefore, it is believed that BEC-LEACH would balance the energy consumption of network as well as make it live longer. Finally, we expect that the proposed novel algorithm in this paper would be useful for researchers in the related field.

Acknowledgments

Dr. V. N. Maurya; corresponding author of the present paper has served as founder Director of Vision Institute of Technology, Aligarh (U.P. Technical University, Lucknow (India) and as Principal/Director at Shekhawati Engineering College (Rajasthan Technical University, Kota) after having vast experience in the field of Technical and Management Institutions in the cadre of Professor & Dean Academics such as at Institute of Engineering & Technology, Sitapur, UP, India; Haryana College of Technology & Management (Kuruchhetra University, Kuruchhetra) and Singhania University, Rajasthan. During his tenure as the Director, Vision Institute of Technology, Aligarh (Uttar Pradesh Technical University, Lucknow) and as the Principal, Shekhawati Engineering College (Rajasthan Technical University, Kota); massive expansion of infrastructure, research facilities, laboratories upgradation/augmentation and other relevant facilities and services for B.Tech./M.Tech./MBA academic programmes in different branches had taken place to accommodate and facilitate the campus students. He is the Chief Editor of Editorial Board of American Journal of Modeling and Optimization; Science and Education Publishing, New York, USA and Statistics, Optimization and Information Computing; International Academic Press, Hong Kong and Advisory Editor of World Research Journal of Mathematics; Bioinfo Publications, Pune, India and Member of Editorial and Reviewer Board of over 50 Indian and Foreign International leading journals published in USA, Italy, Hong Kong, Austria, Germany, U.K., Algeria, Nigeria and other European and African countries. He has been associated with leading Indian Universities-U. P. Technical University, Lucknow during 2005-06 and Chhatrapati Shahu Ji Maharaj University, Kanpur for three terms during 2000-2004 for significant contribution of his supervision as Head

Examiner of Central Evaluation for Theory Examinations of UG (B.Tech./B.Pharm.) and PG (MA/M.Sc.) programmes.

Dr. Maurya was born on 15^{th} July 1974 in District Basti of Uttar Pradesh in India and he possesses an outstanding and meritorious academic record. He earned his M.Sc. (1996) with First Division and Ph.D. Degree (2000) in Mathematics & Statistics with specialization in Operations Research from Dr. Ram Manohar Lohia Avadh University, Faizabad, UP, India and thereafter he accomplished another two years Master's Professional Degree-MBA with First Division (B^+ Grade) with specialization in Computer Science from NU, California, USA in 2003. He did Ph.D. on topic titled "A study of use of stochastic processes in some queueing models" under supervision of Prof. (Dr.) S.N. Singh, Ph.D. (BHU). He started his teaching career as Lecturer in 1996 to teach post-graduate courses MBA, MCA and M.Sc. and later he was appointed as Professor & Head, Department of Applied Sciences and Engineering at Singhania University, Rajasthan in the year 2004. Since then, Prof. V. N. Maurya has rendered his services as Professor & Head/Dean as well as keen Researcher for Post-Doctoral research and he has devoted his entire scientific and professional career in teaching at various premier technical institutions of the country such as at Haryana College of Technology & Management, Kaithal (Kuruchhetra University, Kuruchhetra); Institute of Engineering & Technology, Sitapur and United College of Engineering & Research, Allahabad. During the last 17 years of his professional career, Prof. V. N. Maurya has authored three textbooks and published more than 55 scientific and academic research papers including 25 research papers as Principal Author based on his Post-Doctoral work and D.Sc. Thesis in Indian and Foreign leading International Journals in the field of Mathematical and Management Sciences, Industrial Engineering & Technology. He is an approved Supervisor of UGC recognized various Indian Universities for Research Programs leading to M. Phil. & Ph.D. such as Shridhar University, Pilani (Rajasthan), Singhania University, Rajasthan and CMJ University, Sillong, Meghalaya and JJT University Jhunjhunu, Rajasthan and U.P. Technical University Lucknow etc. and since last 7 years, he is actively engaged as Research Supervisor of M. Phil. & Ph.D. Scholars in wide fields of Operations Research, Optimization Techniques, Statistical Inference, Applied Mathematics, Operations Management and Computer Science. He has guided as Principal Supervisor and Co-Supervisor to several Research Scholars of M. Phil. and Ph.D. Most of his published research papers in India, USA, Algeria, Nigeria, Malaysia and other European and African countries are recognized as innovative contributions in the field of Applied Mathematics and Statistics including Operations Research. By virtue of his innovative research contribution to many mathematical, statistical, computer science and industrial engineering related areas basic as well as application oriented, Prof. V. N. Maurya is known as one of the Indian leading experts in Applied Mathematics, Statistics and Operational Research.

Apart from this, Prof. Maurya is also on active role of Fellow/Senior/Life Member of various reputed National and International professional bodies of India and abroad including Operations Research Society of India, Kolkata; Indian Society for Technical Education, New Delhi; Indian Association for Productivity, Quality & Reliability, Kolkata; Indian Society for Congress Association, Kolkata; International

Indian Statistical Association, Kolkata; All India Management Association, New Delhi; Rajasthan Ganita Parishad, Ajmer and International Association of Computer Science & Information Technology, Singapore and many more.

Diwinder Kaur Arora; co-author of the present paper accomplished MBA Degree with specialization in Human Resources from Pondicherry Central University, Pondicherry and she graduated with B.Sc. (Medical/ZBC Group) Degree in 1987 from Kanpur University, Kanpur, India and did two years Diploma also from Government Polytechnic College, Amethi, U.P. throughout in First Division. She has vast experience of more than 22 years of general administration and management as Police Officer in Central Reserve Police Force, Ministry of Home Affairs, Govt. of India. She was selected as Assistant Sub-Inspector (Non-Gazetted Officer) in 1991 and after successful completion of her services she was promoted as Sub-Inspector in 2004 and since 2012 she is working in the grade of Inspector of Police at Group Centre, Central Reserve Police Force, Lucknow, U.P. Apart from this, she has published more than 15 research papers in Indian and Foreign International journals of repute in the field of Management, Computer Science & Information Technology and Physical Sciences such as in World of Sciences Journal, Engineers Press Publishing Group, Vienna, Austria; International Journal of Engineering Research and Technology, Engineering Science & Research Support Academy (ESRSA), Vadodara, India; International Journal of Electronics Communication and Electrical Engineering, Algeria; International Journal of Information Technology & Operations Management, Academic and Scientific Publisher, New York, USA; International Open Journal of Operations Research, Academic and Scientific Publisher, New York, USA.

Er. Avadhesh Kumar Maurya; principal author of the paper is having an outstanding academic record and accomplished his M.Tech. Degree with specialization in Digital Communication Engineering from Uttarakhand Technical University, Dehradun, UK and he was graduated with B.Tech. Degree in Electronics and Communication Engineering from Rajasthan Technical University, Kota (Rajasthan). He is recipient of four First Divisions in his Student career with flying colors. Since last one year, Er. A. K. Maurya is serving as Assistant Professor in Department of Electronics and Communication Engineering at Lucknow Institute of Technology, U.P. Technical University, Lucknow. Prior to assuming the post of Assistant Professor at Lucknow Institute of Technology, U.P., he served as a Network Engineer for two years in National Informatics Centre, Department of Information Technology, Govt. of India with collaboration of HCL Co. He has worked on some projects such as Movable Target Shooter using Ultrasonic Radar and Hartley Oscillator. Apart from this, he has got industrial training in Door Darshan Kendra, Lucknow, U.P. in the field of TV Program Generation and Broadcasting of different channels for partial fulfilment of his Degree and published also over 18 research papers in various Indian and Foreign International journals of repute in the field of Electronics & Communication Engineering, Computer Science & Information Technology and Physical Sciences such as in International Journal of Electronics Communication and Electrical Engineering, Algeria; World of Sciences Journal, Engineers Press Publishing Group, Vienna, Austria; International Journal of Information Technology & Operations Management, Academic and Scientific Publisher, New York, USA; International Journal of Mathematical Modeling and Applied Computing, Academic and Scientific Publisher, New York, USA; International Journal of Engineering Research and Technology, Engineering Science & Research Support Academy (ESRSA), Vadodara, India; International Journal of Software Engineering & Computing, Serials Publications, New Delhi, India and many more.

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