Hierarchical Energy Harvesting Aware Adaptive Fuzzy Routing with Data Compression for Energy Harvesting WSN

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Abstract: In present scenario of the world moving towards the smart systems. Smart systems and applications are developed using sensor nodes for data collection, data aggregation and decision making process. Wireless sensor nodes are configured in the physical environment for communications between the devices and the user. The number of limitations affecting the performance of wireless sensor based application. The various factors affecting the performance of the WSN based applications, one the major factor is energy efficiency of the sensors. Sensor nodes are battery powered devices and the sensors are dropping their energy during the transmissions. So we need a solution to overcome the energy efficiency issue of WSN based applications. In this paper, we proposed a methodology called Hierarchical energy harvesting adaptive fuzzy routing algorithm with uniform data quality compression to manage the energy efficiency of the sensor nodes. It uses a new energy management framework and allocating the energy budget to sensors and reduces the consumption of each node. The existing energy harvesting approaches only concentrate on find the best path and forward the data to base station. The performance evaluation shows the effective use of proposed method in WSN based applications.

Keywords: Energy harvesting, Adaptive Routing, Data Quality, WSN, Applications.

1. INTRODUCTION

Wireless Sensor Networks (WSNs) are constructed and configured using the N number of sensor nodes. It is self configured, battery powered and infrastructureless devices. These sensor nodes are used to monitor the environment then collect and aggregate the data from the environment. A sensor node consist of three elements, i) Sensing Element ii) Processing Elements iii) Wireless Communication Element. The sensor nodes communicating with each other in the network and collecting the data from the neighbor nodes, it would be transmitted to the sink or base station. Sensor nodes are operated by battery power and each sensor node has global identification to know the place of the sensor. Data transmission between the sensor nodes and to the sink is very expensive because transmitting one bit of data is equal to the processing more than thousands of operations in a sensor node. So it is mandatory to reduce consumption of sensor nodes in a network. Data collection is an important part of sensor node in WSN. This data collection is made by the sensor nodes in three possible ways. One is data collection through the individual sensor nodes to sink, secondly, data collection through the network based sensor nodes, and finally, data collection through the sensor nodes of mobile sink. The sink is act as an intermediate between the sensor nodes and the user. According to these strategies, the network based sensor node data collection is suitable for reducing the energy consumption between the nodes. The sensor nodes are arranged in the form clusters or any type of network structure. They are sensing the environment and collecting the data from the neighbor nodes in the network.

There are previous studies elevates EH-WSN applications are implementing the technique called sensing subsystem, the findings illustrate that, it is difficult to send data directly to the sink node. In our proposed methodology, the networking based subsystem is implemented for data collection and aggregation. Data aggregation means to collect the various data from the node sin the network and checking the uniqueness of the data then it forwarded to sink. This kind of data transmission is called the hierarchical approach or sometimes referred as hierarchical based network approach. This can be classified into four types; i) Clustering approach ii) Chain based approach iii) Tree based approach iv) Hybrid approach. We focus the problem of increase the network lifetime through the energy harvesting based WSN.

The proposed system follows cluster based network approach defines sensor nodes are grouped and/or formed as clusters. A single node is selected as a head node based on the node parameters among the nodes and it is act as a representative of all other nodes. It is called cluster head. The CH sensing the environment and received the data from all other nodes and process the data and send it to the base station or sink node. We propose adaptive data quality with energy harvesting aware algorithm for enhance the quality of the applications and improve the performance of the applications with less energy usage.

Our contribution is to address the problem of increase the network lifetime and improve the quality of the WSN based applications.

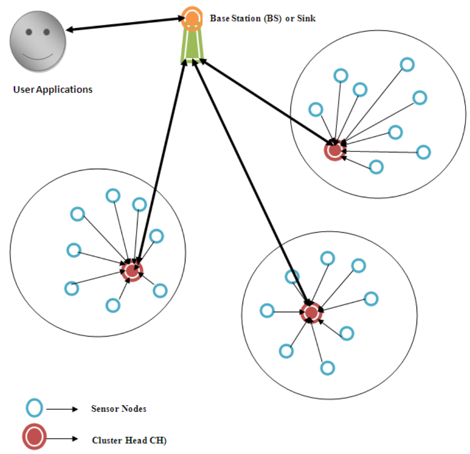

Figure 1. Clustering based Approach

This paper is organised in section 2 describe about the review of the literature related to the problem of prolong the network lifetime through energy harvesting of the nodes. The proposed methodology describes in section 3, the simulation results and performance analysis of the proposed method is described in section 4, and finally, conclusion is presents in section 5.

2. RELATED WORK

At present wireless sensor network is place the wise role in all aspects of technology development. To implement the WSN based applications in the environment for monitoring, data collection and decision making processes. The researchers concentrate on the various techniques and methodologies involved in wireless sensor network routing and increase the network lifespan. So this section analyzes the energy efficient and energy harvesting routing methodologies of wireless sensor network based applications.

Nabil Ali Alrajeh et al [5]. (2013) introduce a secure protocol for energy harvesting based WSN. This protocol is designed like cross layer based information exchange between the nodes. All the nodes are directly communicate with cluster head so the energy consumption of each is node is reduced. The data transmission is done through the two-hop neighboring mechanism and this secure transmission follows the cross layer design with network parameters. Initially all the nodes are actively involved in the network processes but in the idle state, the nodes are received the energy from the environment and it is converted into harvested energy. Compare with LEACH and HEED, it is more efficient to increase the network lifetime. But the shortfall of this method is, not possible to get the packet acknowledgement for each transaction so the packet delivery ratio is not achievable in this approach.

Selahattin Kosunalp et al [6]. (2016) deal the energy issue of the sensor nodes. All the sensor nodes are battery powered and it is not possible to retain the energy when they are involved in network operations. Node selection plays a vital role in route discovery from source to destination. The author proposed a new energy prediction algorithm for selection of high energy nodes. This algorithm predicts the energy level of the node based on the history of the transmission. Along with this algorithm a Q-Learning approach is implemented to increase the performance of the optimum use of energy among the sensor nodes. Finally observed that, to manage energy level intelligently in sensor nodes is more important but the above Q-Learning approach is not sufficient.

Chin-Feng Lai et al [7]. (2017) defines that the routing protocols are decided the energy utilization of the sensor nodes. The sensor nodes plays various roles in WSN based IoT applications like storage, processing or computing and energy management. Author proposed a new routing protocol energy-efficient centroid based routing protocol (EECRP) to maintain the network lifetime and less energy consumption of sensor nodes. It consists of three parts. First, the sensor nodes are organised in the cluster formation. Second, the cluster head is chosen based on centroid based approach, that is, the nearest node of the base station. Third, the CH collects the data, processing it and finally communicates to base station with less energy consumption. During the comparative study of EECRP with LEACH and GEEC, it supposes to fail in multi-hop transmission of data packets in the WSN.

Xuecai Bao and Guanqun Ding et al [8]. (2016), proposed a new routing algorithm for maximizing the network performance in energy harvesting wireless sensor network. The routing techniques and methodologies for energy efficient networks are not to fit for energy harvesting WSN. The main objective is to analyze the factors affecting the energy harvesting WSN and to find the best route discovery. This can be achieved using proposed heuristic algorithm. It implements three operations between the sensor nodes. Firstly, find the residual energy of each and every sensor nodes in a WSN. Secondly, select the sensor nodes based on the high residual energy availability. Finally, the node is communicated based on the less link cost between the nodes and the optimal path is established. However, when the more sensor nodes added in EH-WSN, the average energy consumption of each sensor nodes will reduce and has more energy to serve information transmission.

Yunquan Dong et al [9]. (2016) find the use of energy in the sensor nodes. Energy harvesting technologies plays a vital role in the maximization of network lifetime and achieves the sustainability in the EH-WSN. Author proposes a new energy aware routing protocol for distance-and-energy-aware routing with energy reservation (DEARER). Using this approach, the high energy arrival rate of node is selected as a Cluster Head (CH). The CH is act as a intermediate between the sink and sensor nodes. Also, DEARER permits non-Cluster Head nodes to reserve a place of the harvested energy for further use. In doing so, DEARER selects “enabler” nodes as CH nodes and provides them with more energy, thereby mitigating the energy shortage events at CH nodes. Apart from these, the DEARER protocol point out that, the reservation ration is constant over time. So this leads to be further improvement of network energy efficiency.

Thien D. Nguyen et al [2]. (2017) considered that the energy harvesting to be one of the key aspects of WSN based IoT applications. Energy harvesting techniques could remove the needs of node replacement in the network due to energy efficiency. Author encourages moving the energy-aware techniques to energy harvesting aware routing development in the WSN. Author proposes a new routing algorithm EHARA, which is further enhanced by integrating a new parameter called ‘extra backoff’. The proposed algorithm improves the lifetime of sensor nodes as well as the quality-of-service (QoS) under variable traffic load and energy availability conditions. The shortcomings are present in this new approach of energy harvesting aware approach that is, the global information is unable to adapt to variations in sensor nodes’ energy levels. Here do not consider the actual amount of harvested energy accumulated during the harvesting period. Use constant rates of replenishment for all sensor nodes in the network. Thus, they cannot deal with the stochastic characteristics of the ambient energy sources.

Varying from the above reviews of different existing EH routing protocols and algorithms for WSN based applications, to address the two major aspects of performance issues in WSN, i) Select the optimal less energy usage path based on the residual energy. ii) Improve the quality of WSN applications with the implementation of energy harvesting techniques. To overcome the limitations of existing methodologies, a new proposed approach called a hierarchical based adaptive routing scheme is introduced to find the optimized energy efficient route and assure the quality of data collection and transmission to applications.

3. SYSTEM MODEL

At present to design of WSN based applications is challenging task. Theoretical evaluations cannot be adequate for many cases to prevent and predict the crash of sensor networks. The design complexity of WSNs rises with growing applications and their requirements. The network lifetime and minimum error margin of data transmission is largely depends on the energy consumption of the nodes. Consequently, different methods have been proposed to reduce the energy consumption of the wireless sensor network. Designing wireless sensor networks has many problems from this point of view.

Energy harvesting is a promising solution to overcome the problem of large energy consumption and network stability. Therefore, we propose a clustering oriented approach called Energy Harvesting based hierarchical approach of adaptive routing with uniform data quality assignment to prolong the network lifetime and stability of the network. The main advantage of clustering is the expansion of sensor networks in terms of scalability of performance. In addition, the clustering approach offers many secondary benefits. It ensures reliability and avoids one-point failure through its localized solutions.

A. Network Model

The elements of our system model consist of collection of sensor nodes. The sensor nodes are supposed to be placed in the unstructured manner according to the energy perspective. The sensor node performs three mandatory activities, which means sensing the data, processing the data and communicates the data. In all three functions, data communication in most cases it is a high energy consuming activity. Because of this, our network model fully addresses the issue of energy consumption.

The following conclusions have been made about the testbed.

- The sensor node formation is done in randomly.
- Sensor nodes and the base station are fixed (static).
- The distance between the sensors is defined based on the signal strength.
- Data aggregation is done through the Cluster Head (CH).

Each senor nodes are represented as s and wireless sensor network consist of n number of sensors (s_1, s_2, s_3, …., s_n). All the sensor nodes are transmitting their data s(i) to the cluster head (CH) and the sensor nodes energy consumption is represented as (Es_1, Es_2, Es_3, …., Es_n). The CH act as an intermediate between the sensor nodes and base station. It performs data aggregation, integration and communicates to base station so it needs more energy to stable the network and active. A cluster head handles two types of messages, one is internal messages and other is external messages. Whose internal messages are nothing but own messages of the cluster head and the external messages are defined as the neighbor nodes data collected by the cluster head. A vast data handling situation occurs in this type approach, it may fail the quality of data transmission between the cluster head and base station.

Data transmission is an important factor for energy consumption in WSNs. Here, we focus on reducing the number of bits transmitting from cluster head to base station through the data compression method.

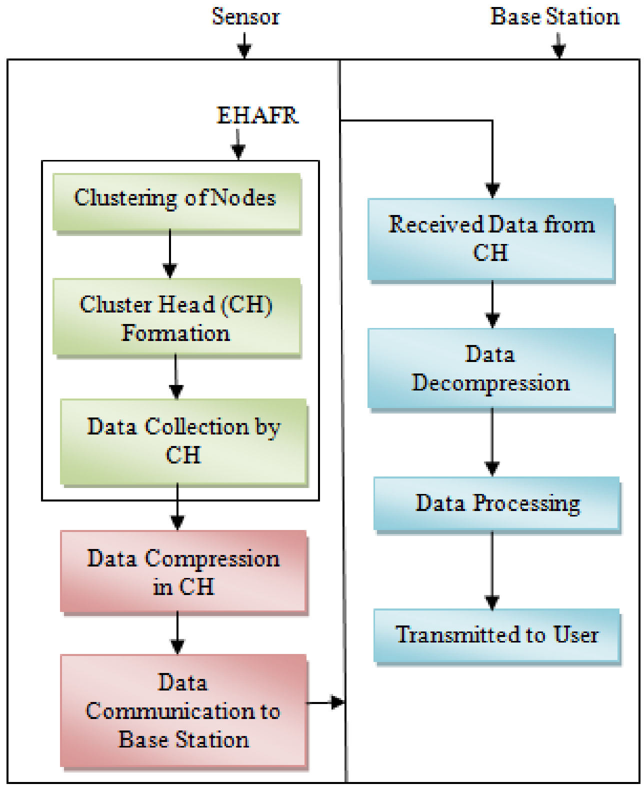

Figure 2. Proposed Framework

Due to the flat network approach there is a vast number of communication from sensor node to sink or base station. It will create the overburden to base station and fast exhaustion of the battery. In our proposed hierarchical network model differs from the existing methods, which focus on the energy harvesting type of WSNs. A data collection is made through the special node which reduces the number of messages sent to base station and this improves the energy efficiency of the network.

4. THE PROPOSED ALGORITHM – EHAFRA

Each node is capable of being powered by a battery with energy harvesting. So the energy levels of each sensor nodes are not the same in the network because it is unmanned sensor environment with geographically distributed.

A. Cluster Formation and CH Selection

Initially the sensor nodes are placed and the distance between the each sensor node is measured. In our proposed approach, the base station or sink send the beacon frame to all the sensor nodes. Through this frame, the base station receives the information about the configuration of the network and can also identify the list of eligible nodes available in the network sorted by signal strength. The collection of temporal cluster heads is elected according to the signal strength in the network.

The base station generates the gateway value 'G' is calculated and forwarded to rest of the sensor nodes. Each and every sensor nodes calculated the energy value and it compared with the received gateway value. If the energy value is greater than the gateway value, then the nodes is selected as a cluster head and all other nodes are treated as normal node. The proposed method follows three major key variables,

- **Calculate the Residual Energy**

This variable represents each and every node calculates its own energy level and it is represented as 'El'. After completing the transmission its energy level is reduces and the remaining energy is measured. 'Et' required energy per transaction, 'El' initial energy level of the node and 'Er' residual energy of the node.

$$Er = El - Et \quad (1)$$

➢ **Node Degree measured**

According to this criterion, the total number of neighbors located at a 2-hop distance from cluster head (CH) and measured like,

Node Degree = (Total 2-hop-Nb nodes) / (Nodes) (2)

➢ **Betweeness Centrality of the CH.**

Using this adaptive method, the betweeness centrality is of nodes to CH is calculated using distributed mechanism. Once the CH receives the updates from its neighbors then it calculates the betweeness centrality of each and every node.

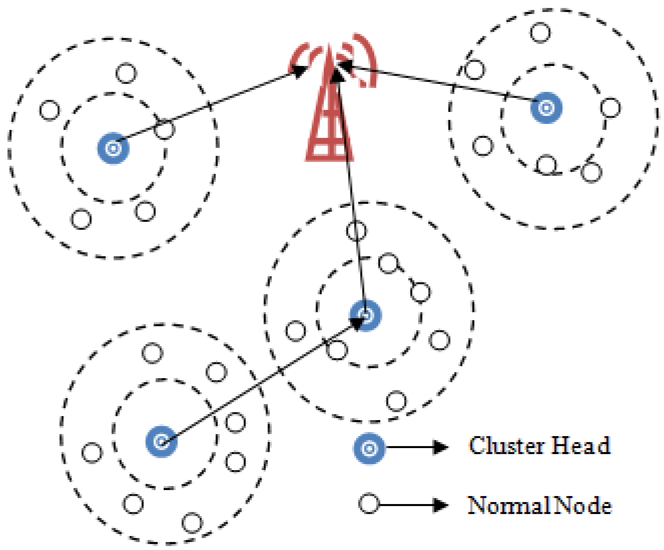

Figure 3. 2-Hop Clustered WSN

The fuzzy process maps each smooth input value to a set of respective fuzzy member functions for each temporary cluster head over three parameters. The output variable indicates the possibility of a temporary cluster head becoming a cluster head.

Now, each and every sensor nodes are prepares themselves become a member of a cluster and it is joined with the nearest cluster head. After the cluster formation, the required data is generated and sensed by the members those who are joined in the cluster formation. The cluster head is the Incharge to collect and integrate the data from their members. After the aggregation is over, the cluster head made the compression process to reduce the overload and energy consumption of the cluster head. Finally, the CH communicates to base station or sink and transmit the data.

B. Algorithm: Energy Harvesting Adaptive Fuzzy Routing (EHAFR)

Step 1: Begin

Step 2: S ← Set of Sensor Nodes, $S_1, S_2, S_3, \ldots, S_n$

Step 3: Status (S[x]) ← M, x=1, 2, …, N.

Step 4: Tch ← Number of Tentative CHs.

Step 5: CH ← Set of Temporary Cluster Heads | Tch[x], x=1, 2, …, T selected from S.

Step 6: S ← S – CH.

Step 7: Chance[y] ← Probability of CH[y] to become a Cluster Head, y=1, 2, ….., T.

Step 8: For every Tentative Cluster Head Tch[y], y=1, 2, …, T.

Step 9: Calculate Chance [y] using fuzzy if-then mapping rules.

Step 10: Broadcast Advertisement (Chance[y]) to all its 1-hop and 2-hop neighbours.

Step 11: While (timer).

Step 12: If (Advertisement from any CH[x] & (Chance[y] < Chance[x])).

Step 13: Add CH[y] to S.

Step 14: CH← CH- {CH[y]}.

Step 15: End if.

Step 16: Else.

Step 17: Status (CH[y]) ← H.

Step 18: Broadcast Advertisement (Status (CH[y])) to all its 1-hop and 2-hop neighbours.

Step 19: End else.

Step 20: End While.

Step 21: End For.

Step 22: For every sensor node S[x].

Step 23: If Advertisement(Status(CH[z])) received form exactly one Cluster Head CH[z].

Step 24: Add S[i] to CH[k].

Step 25: End if

C. Data Compression in CH

Data compression is nothing but to reduce the number of data transmitted from cluster head to sink. Usually, the data compression technique is classified into three categories according to the recoverability of original data in the destination part.

1. Lossy Compression Standard.
2. Lossless Compression standard.
3. Unrecoverable Compression Standard.

In lossy compression, some features of the original content are lost after performing the decompression. In lossless compression, the original content is accurately received after performing decompression. The unrecoverable compression defines that not possible to recover the input value of compressed data.

In our proposed approach, the lossless compression algorithm is used called adaptive UDQ arithmetic coding algorithm.

The adaptive UDQ concentrate on three basic aspects during the encoding process called the next symbol to be encoded, the interval and the probability. The encoder divides the current interval into sub-spaces, each representing a portion of the current interval proportional to the probability of that index in the current space. Any space that corresponds to the actual symbol next to the symbol becomes the space used in the next step.

When all symbols are encoded, the resulting space clearly identifies the sequence of symbols it has created. Anyone using the same end space and model can reconstruct the code line that must have entered the encoder at that final interval. However, there is no need to transmit the final break; It is necessary to transmit only a portion of that space. In particular, it is only necessary to transmit enough fractions so that all fractions beginning with those digits fall into the final interval; this will guarantee that the resulting code is a prefix.

For example, note that arithmetic encoding can be implemented by changing the base or radix if the symbols have equal probabilities. In general, arithmetic (and range) encoding can be interpreted as a general transformation of radix. For example, we can see any sequence of symbols:

'DADASD'

Assume that the symbols involved form a sorted set, and that each symbol in the sorted set represents a continuous integer A = 0, B = 1, C = 2, D = 3, and so on. This results in the following frequencies and cumulative frequencies:

Table 1. Frequency of Symbol

Symbol	Frequency of occurrence	Cumulative frequency
S	1	0
A	2	1
D	3	3

The overall frequency of an object is the sum of all the frequencies preceding the item. In other words, the cumulative frequency is the total number of frequencies that are running.

5. PERFORMANCE EVALUATION

The performance of the proposed system is evaluated under the scenario of the networks consist of 100 nodes, 200 nodes, 300 nodes, 400 nodes and 500 nodes distributed randomly in the area of 100m x 100m. The base station (50 m, 150 m) is positioned. The initial energy of all nodes takes the value of 0.5 J. This value is commonly used in the literature because it provides sufficient energy to quickly see the effect of application mechanisms. Each node sends a 2000 bit message per round to its cluster head. P is set to 0.05; about 5% of the nodes in a round are cluster heads.

The proposed EHAFRA reduces energy efficiency and takes into account potential parameters for a cluster head election, where 2-hop coverage is provided for each cluster head communication. The results demonstrate that the EHAFRA makes WSN longer to operate than other approaches. The following parameters are used to compare the proposed approach and the existing one.

i) Network Lifetime

The time interval from the start of the operation to the death of the last living node. It is a combination of the stability phase and the instability phase.

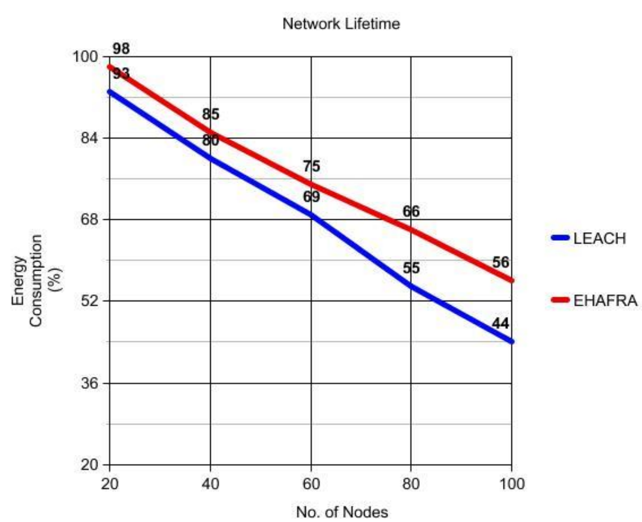

Figure 4. Network Lifetime

The result shows the efficient use of energy in the network and network lifetime is illustrated.

ii) No. of CHs per round: -

This Immediate action reflects the number of nodes. This will send the data directly to the base station.

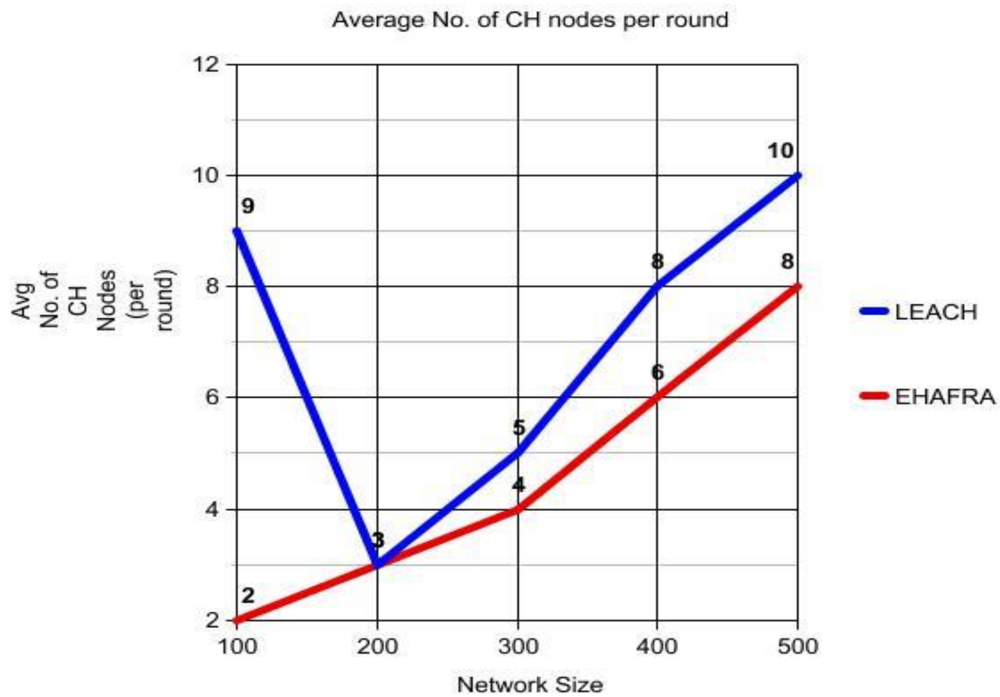

Figure 5. Average No. of CH nodes per round

The results show that EHAFRA outperformed LEACH for most of the cases. EHAFRA showed better scalability in more than 90% of the networks under test. This is because EHAFRA uses a larger number of CHs that cover the network.

6. CONCLUSION

In this paper, we have focus on two things, that is, prolong the network lifetime and quality of data transmission between the nodes and the base station. This can be achieved through the energy harvesting based wireless sensor network. Here, we propose an hierarchical energy harvesting adaptive fuzzy routing algorithm, referred as EHAFRA, to address the fuzzy based cluster head selection and also introduce the UDQ data compression technique to reduce the amount of data transmission between the CH and base station. The results declared that the proposed system improves the network lifetime and achieve the quality requirements of the network.

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DOI: https://doi.org/10.15379/ijmst.v10i5.3552