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Energy Efficient Hierarchical and Distributed Clustering Algorithm for Efficient Formation of Clusters in Wireless Sensor Network

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ABSTRACT

Wireless sensor networks are network of sensor nodes with a set of processors and small memory unit embedded in it. Unfailing routing of packets from sensor nodes to its base station is the most significant function for these networks. The conservative routing protocols cannot be applied here due to its battery powered nodes. To provision energy efficiency, nodes are frequently clustered in to non-overlapping clusters. A distributed clustering methodology, the energy efficient hierarchical distributed clustering algorithm (EHDCA) has been proposed. It is a well-distributed clustering mechanism and the cluster head selection is based on residual energy, communication cost and the distance to the base station. The main characteristic feature of the proposed methodology is the cluster head selection is carried out in just few steps. The performances of the proposed clustering methodology have been compared with LEACH. Its hierarchical nature shall be effectively employed for reduction in total energy consumption and backbone energy consumption. The energy efficiency and overall network lifetime shall be greatly improved.

Keywords: Wireless sensor network (WSN), distributed clustering algorithm, coverage based clustering, energy efficiency, network lifetime.

1. INTRODUCTION

When a quantity of sensor nodes in WSN is drained, their functioning is stopped thereby causing progressive deconstruction of the network. Hence the protocol should be so designed, that minimum energy should be consumed during sensing, processing and communication. Three layers of protocol stack involved in the functioning of wireless sensor network are the physical, data link and network layers. The physical and data link layers deals with energy awareness, wireless communication hardware, duty cycle issues, sensor system partitioning and energy aware protocols. The network layer finds the energy-efficient route and reliably transmits the data from sensor nodes to the base station. Since wireless sensor nodes are power-constrained devices, long-haul transmissions should be kept to minimum in order to expand the network lifetime. Thus, direct communications between nodes and the base station are not intensely encouraged. An effective methodology to perk up efficiency is by arranging the network into several clusters, with each cluster electing one node as its leader or cluster head [1-5]. The aggregated data will then be transmitted to the base station directly or by multi-hop fashion by the cluster head. In such an arrangement, only cluster heads are required to transmit the data over longer distances. The remaining nodes will need to do only short-distance transmission. Clustering mechanism is basically classified into centralized, distributed and hybrid clustering. Hierarchical methodology could be employed for all these clustering mechanisms. When energy efficiency is a major criterion during clustering, hierarchical methodology could be more effective. The cluster heads all over the wireless sensor network will be divided into different levels (hierarchy or tier). First level cluster heads will transfer the aggregated data to the second level cluster heads. The second level cluster heads will transmit the data to third level cluster heads. The cluster head at the final level only will be forwarding all the data to the base station. By following this hierarchical approach, energy wastage can be avoided to a larger extent. This paper gives a profound description about energy-efficient hierarchical distributed clustering algorithm (EHDCA) for efficient formation of clusters in wireless sensor network.

The rest of this paper has been organized as follows. The existing hierarchical clustering methodologies have been discussed in section 2. The limitations of the existing methodologies have been described in section 3. Section 4 elaborates the features of the proposed methodology. The basic concept of the proposed methodology has been discussed in section 5. Section 6 describes the performance evaluation of the proposed methodology and finally the last section gives the conclusion.

2. HIERARCHICAL CLUSTERING METHODOLOGIES

The major hierarchical clustering algorithms for wireless sensor network are LEACH, Threshold sensitive Energy Efficient Network (TEEN) and Scaling Hierarchical Power Efficient Routing (SHPER). The initial stage of TEEN protocol is the formation of clusters. In this mechanism, every cluster member nodes becomes a cluster head for a particular time interval referred as cluster period as formulated by (Manjeshwar and Agarwal 2001). Dionisis et al (2008) proposed SHPER protocol which includes base station and sensor nodes which are arbitrarily dispersed over a restricted region of attention. The base station and all the nodes are found to be stationary. The end users can access the data from the base station, which is situated far away from the sensing field. Every cluster nodes are grouped together into separate clusters. Within every cluster, one node is elected to be the cluster head [6-8]. The cluster head election in SHPER is purely based on residual energy. The cluster heads that are nearer to the base station, which could correspond with the base station with rational power utilization, is considered to be the highest level cluster head. Similarly, the cluster head which is located far away from the base station is considered to be the lowest level cluster head. The operation of SHPER protocol includes two main phases namely the initialization phase and steady state phase. During the initialization phase, the base station decides which node should be a cluster head. The nodes other than the cluster head becomes member nodes. Each cluster head along with some cluster nodes are grouped together to form a specific cluster. The base station sends the ID of each cluster heads which are newly elected. Additionally, each sensor node decides the cluster to which it belongs and informs its cluster head on being the member of that cluster. The cluster head informs the member nodes regarding the time when they have to transmit. Accordingly, data is collected by the cluster head and aggregated, further being transmitted to the base station during the steady state phase.

3. LIMITATIONS OF THE EXISTING METHODOLOGIES

LEACH protocol is less-effective when periodic transmissions are unnecessary, thus causing useless power consumption. The election of cluster head is based on priority, and hence there is a possibility that the weaker nodes to be drained, when they are elected as cluster heads as frequently as the stronger nodes. Moreover, the protocol is based on the suppositions that every nodes start with identical energy capacity in every election round and all the nodes can transmit with sufficient power to the base station if needed. However, in several cases these assumptions are found to be unrealistic. TEEN protocol has been developed for reactive networks so as to take action for abrupt changes in the sensed attributes. TEEN is appropriate for time critical applications, but not suitable for applications where periodic reports are required. In case of SHPER, the election of cluster head is purely based on the base station. Hence unnecessary transmissions occur between the base station and cluster heads. Also the base station should keep track on the sensor nodes in order to decide which node has the highest residual energy, thereby causing increased power consumption.

4. FEATURES OF THE PROPOSED EHDCA METHODOLOGY

In the existing techniques, the election of cluster heads and cluster nodes are entirely done by the base station. Hence they are prone to additional power consumption. The proposed work mainly considers that the cluster head to be completely responsible for all the process including the election of new cluster heads and member nodes. The cluster head calculates the power consumed by the nodes, which normally depends on the available power at the nodes, and the distance between nodes and the cluster head.

Two different thresholds are employed namely hard threshold and soft threshold to reduce the number of transmissions during data aggregation. Generally, hard threshold is the smallest possible values of an attribute to activate a sensor node to switch on its transmitter and transmit the data to the cluster head. Soft threshold is a little change in the value of the sensed attribute that activates the node to switch on its transmitter and transmit the data. The former tries to diminish the number of transmission by letting the nodes to transmit only when the sensed attribute is ahead of a critical value. Similarly, soft threshold additionally trims down the number of transmissions when there is small or no change in the value of sensed attribute. For each cluster change, the values of both the thresholds could be altered, facilitating the user to manage the trade-off between energy efficiency and data accuracy. The nodes transmit the sensed data to the cluster head. The distinctive feature of this method is that, the residual energy is transmitted along with the sensed data by the nodes to the cluster head. The cluster head only transmits the aggregated data to the base station. Figure 1 shows the hierarchical clustering architecture of the proposed EHDCA methodology. Every process such as initialization, formation of clusters, election of cluster heads and monitoring the residual energy is done exclusively by the cluster head. Store and forward technique is followed at the cluster head, so that the sensed attribute along with the residual energy is collected from the cluster nodes, stored at the cluster head and further the aggregated data alone is forwarded to the base station. Since the BS has no direct link with the cluster nodes, unnecessary transmissions are avoided thereby minimizing enormous energy consumption.

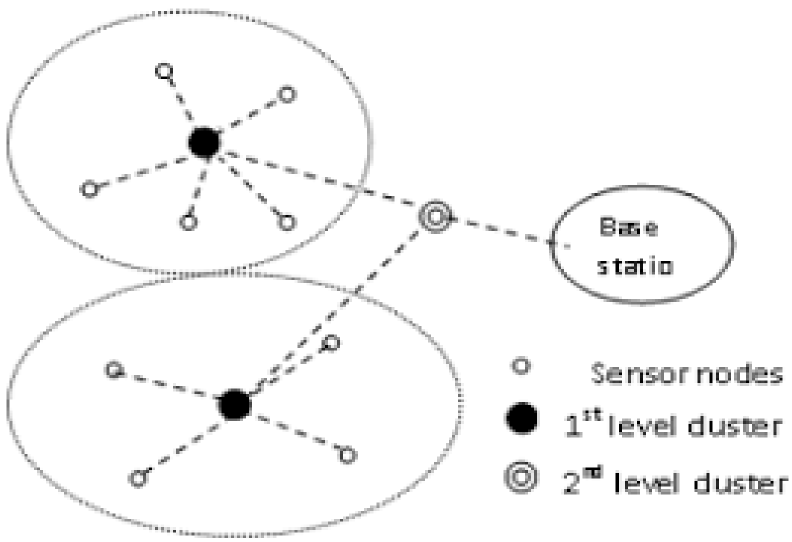

Figure 1: Hierarchical clustering Architecture of EHDCA

5. BASIC CONCEPT OF THE PROPOSED METHODOLOGY

As described in the preceding sections, the cluster nodes need to be evenly distributed over the entire network for reducing energy utilization. In the proposed EHDCA methodology, the redundant formation of cluster heads is greatly avoided. The proposed EHDCA methodology incorporates set-up phase and steady state phase. Figure 2 depicts the timeline concept of the proposed methodology.

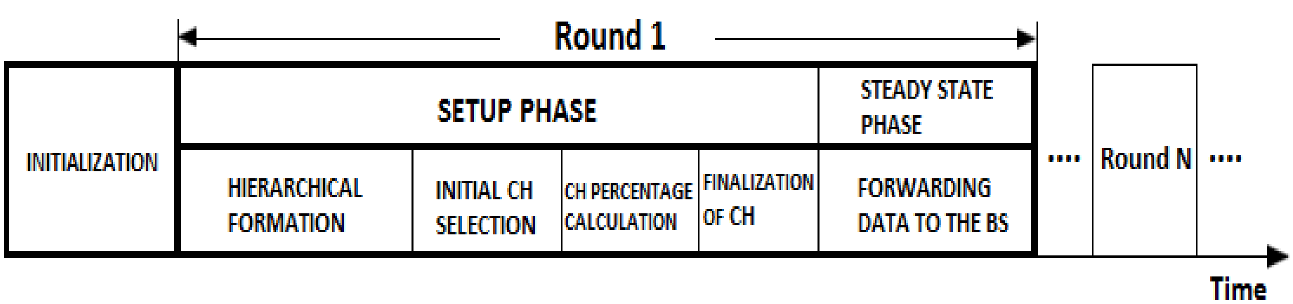

Figure 2: Timeline of the proposed Methodology

The Set-up Phase

The chief actions during the set-up phase are the hierarchical layer formation, election of candidate nodes, initial selection of cluster heads, calculating the percentage of cluster heads, scheduling at each cluster, finding cluster head for CH-to-CH data transmission and finalization of the CH. During set-up phase, every node initially decides whether it could become a candidate node for the current round. An advertisement message has been used to elect the CHs. Every candidate nodes broadcast an advertisement message within its transmission limit. The advertisement range is twice the maximum distance to cover other levels. This choice is based on the available strength of the signal of the advertisement message. When all the nodes have decided their respective clusters, the sensor nodes start transmitting its data to their suitable cluster head. The cluster head on receiving all the messages from the sensor nodes that would like to be incorporated in the cluster, and based on the number of sensor nodes contained in the cluster, the cluster head creates a schedule and allocates every node with a time slot for data transmission. For this sole reason, every cluster head makes use of two-way handshake technique containing messages like Request (REQ) and Acknowledgement (ACK). Each and every cluster head broadcasts a REQ message within its own advertisement range. When the cluster head receives this REQ message, it transmits an ACK message back to the cluster head that has transmitted the REQ message. The node that transmitted REQ message on receiving the ACK message, it chooses this cluster head which transmitted the ACK message as the next successive hop. If the cluster head could not find the upward cluster head it decides the base station as the next hop.

The Steady-State Phase

In EHDCA, the steady state phase is similar to other cluster-based schemes. The main activities done in this phase are sensing and transmission of the sensed data. Each sensor node performs sensing operation and transmits the data to its respective cluster head during its assigned time schedule. When every data has been received, the cluster head carries out data aggregation in order to further reduce the amount of data for communication. Each cluster head finally transmits the aggregated data to the base station along the CH-to-CH routing path which has been constructed during the set-up phase. After every data has been transmitted, the network returns back to set-up phase again and the next successive round begins by electing fresh candidate nodes.

6. PERFORMANCE EVALUATION

The performance of the proposed EHDCA clustering methodology has been evaluated through simulations for 30 wireless sensor nodes and the results have been compared with LEACH. All the simulations have been carried out using NS-2. The sensor nodes are considered to be immobile (stationary) with uniform initial energy level of 1 Joule. The sensor nodes are thoroughly prepared with every possible power control capabilities. The base station has sufficient energy and energy scarcity does not occur at any cost.

Table 1: Simulated values for Energy consumption

Number of Rounds		100	500	1000	1500	2000	2500	3000
Energy Consumption (Joules)	LEACH	0.220	0.180	0.170	0.140	0.160	0.115	0.135
	EHDCA	0.150	0.125	0.095	0.100	0.095	0.090	0.070

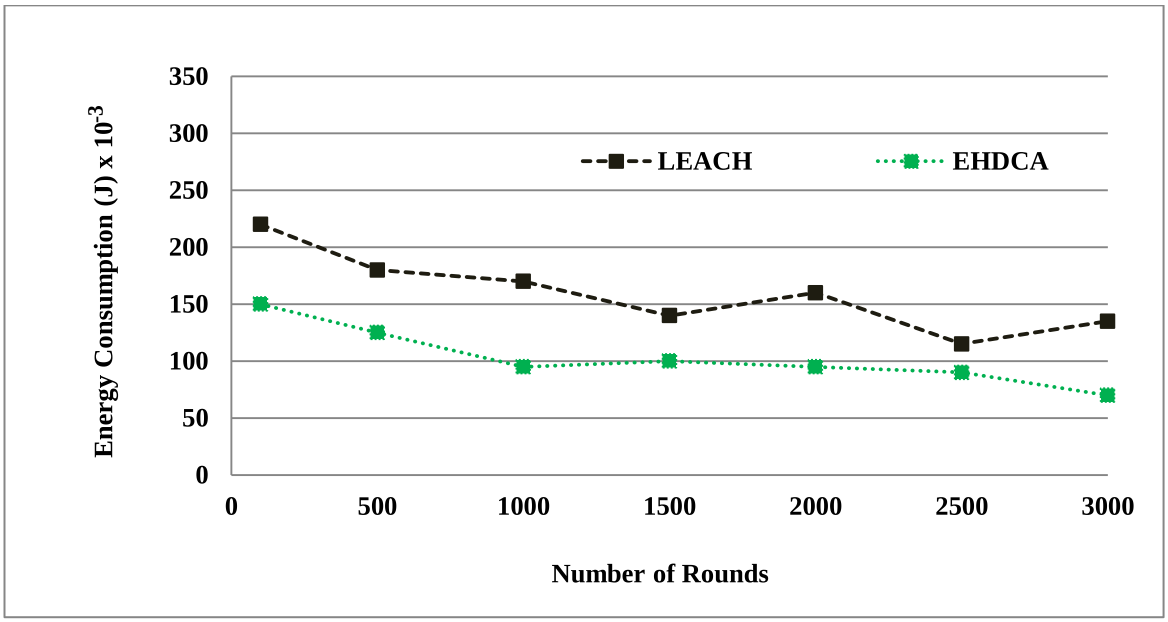

Figure 3: Total energy consumption in LEACH and EHDCA

Figure 3 shows the total energy consumption for each round for both LEACH and EHDCA. Initially at 100 rounds, the total energy consumption is 0.22 Joules and 0.15 Joules for LEACH and EHDCA respectively. Similarly for 3000 rounds, the energy consumption is 0.135 Joules and 0.07 Joules for LEACH and EHDCA respectively. The average energy consumption is 0.160 Joules for LEACH and 0.104 Joules for EHDCA. EHDCA shows 35% reduced energy consumption when compared to LEACH. This is because, the proposed EHDCA methodology reduces needless creation of cluster heads and utilizes the CH-to-CH routing path, and thereby unnecessary energy utilization is avoided.

Table 2: Simulated values for Lifetime comparison

Number of Rounds		100	500	1000	1500	2000	2500	3000
% Lifetime	LEACH	90	53	40	20	4	2	1
	EHDCA	95	70	62	46	28	23	19

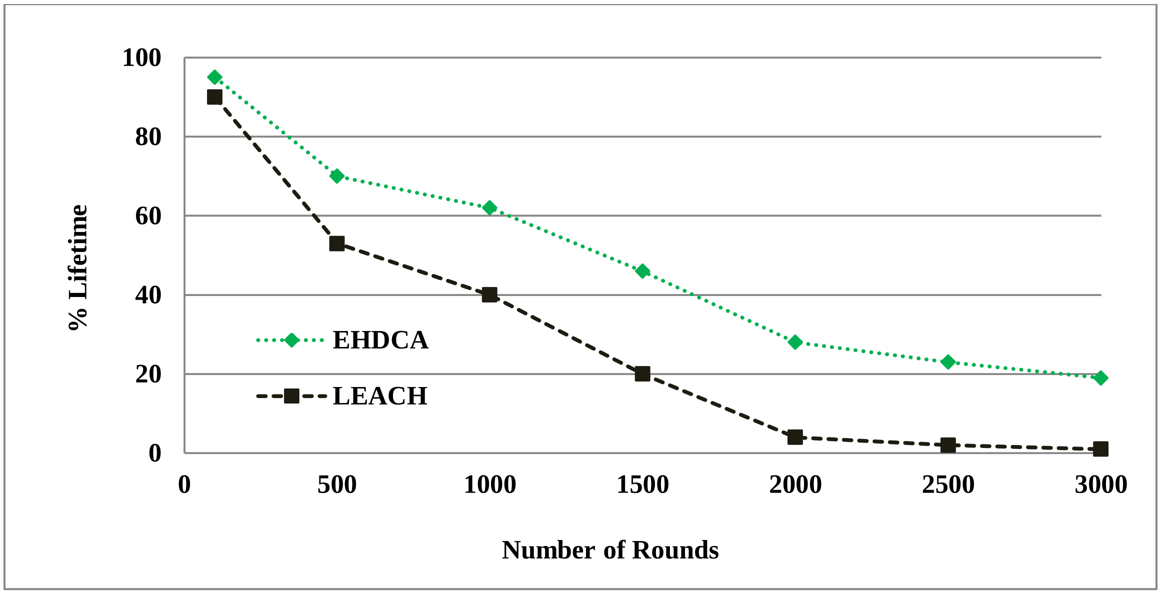

Figure 4: Percentage Lifetime in LEACH and EHDCA

Figure 4 shows the percentage lifetime for particular number of rounds for both LEACH and EHDCA. Initially in 100 rounds, the percentage lifetime of LEACH is 90% and that of EHDCA is 95%. Similarly in 3000 rounds, the percentage lifetimes of LEACH and EHDCA are 1% and 19% respectively. At an average, EHDCA shows 19% improvement in lifetime when compared to LEACH. This clearly shows that the proposed EHDCA methodology has enhanced lifetime when compared to LEACH, because of the hierarchical concepts employed in the proposed methodology. Figure 5 shows the percentage backbone energy consumption against number of rounds for both LEACH and EHDCA. The backbone energy consumption is lesser in EHDCA when compared to LEACH for all the successive rounds. The average percentage backbone energy consumption in LEACH and EHDCA is 23.57% and 14.71% respectively. EHDCA shows 37.59% reduced backbone energy consumption when compared to LEACH. This is mainly because LEACH uses random CH selection mechanism and direct forwarding of data to the BS by the cluster head. But EHDCA employs hierarchical method for cluster formation and the aggregated data is not directly forwarded to the base station. Thus, it could be clearly seen that the proposed methodology is highly efficient in terms of backbone energy consumption when compared to LEACH.

Table 3: Simulated values for Backbone energy comparison

Number of Rounds		**100**	**500**	**1000**	**1500**	**2000**	**2500**	**3000**
% Backbone Energy	**LEACH**	30	27	25	24	22	20	17
	EHDCA	20	19	15	14	12	11	12

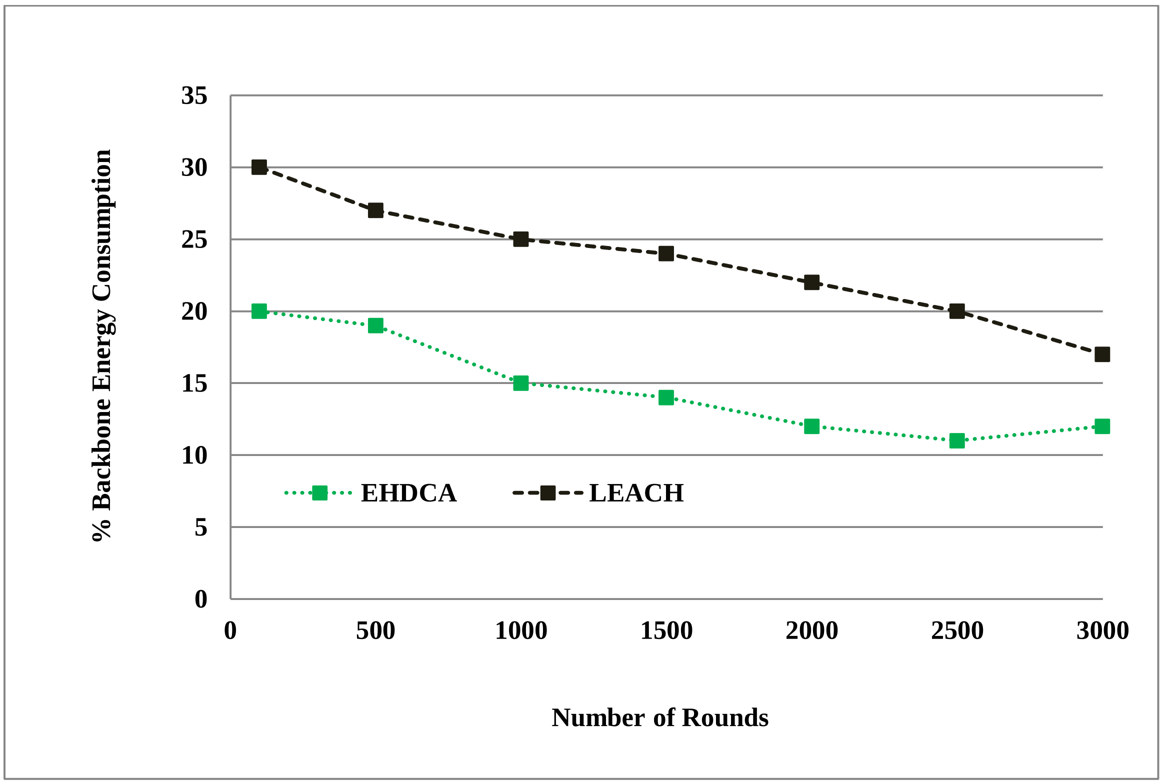

Figure 5: Backbone Energy Consumption in LEACH and EHDCA

Figure 6 shows the energy efficiency comparison of both ECDCA and LEACH. Initially in 100 rounds, the energy efficiency is 42% and 69% for LEACH and EHDCA respectively. Similarly in 3000 rounds, the energy efficiency is 20% and 49% respectively for LEACH and EHDCA. Throughout the process, the energy efficiency is better in EHDCA when compared to LEACH.

Table 4: Simulated values for Energy efficiency comparison

Number of Rounds		100	500	1000	1500	2000	2500	3000
% Energy Efficiency	LEACH	42	45	43	46	38	27	20
	EHDCA	69	67	64	67	61	55	49

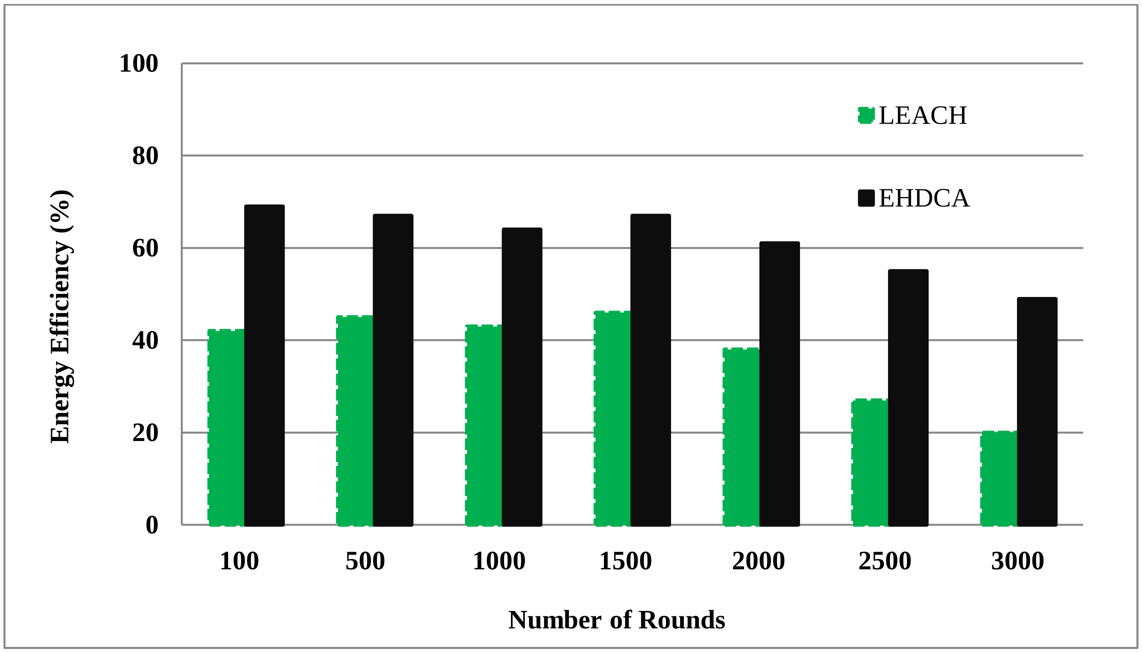

Figure 6: Energy Efficiency Comparison in LEACH and EHDCA

Thus, it could be clearly understood that the proposed EHDCA mechanism is a well-distributed and energy-efficient clustering mechanism, and could be employed for effective clustering of sensor nodes in wireless sensor network.

7. CONCLUSION

This paper is concerned with the proposal of EHDCA methodology for static wireless sensor network. This methodology employs hierarchical architecture for cluster formation. The peculiar feature of this technique, compared to the existing techniques is that the election of cluster head, cluster nodes and monitoring of residual energy is purely done by the cluster head. Since base station does not involve in these processes, unnecessary energy wastage for long distances communication is avoided, thereby reducing energy usage to much extent. Simulation results clearly show that the proposed EHDCA methodology depicts an excellent reduction in backbone energy consumption and total energy consumption. Nevertheless, the energy efficiency in EHDCA is improved to a great extent. It is noted that the first node death and final node death are greatly delayed, thereby the overall lifetime of the wireless sensor network is improved by the proposed EHDCA methodology.

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