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Improving WSN Longevity through Adaptive Node Distribution and Heterogeneity Considerations

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Abstract— In recent years, numerous routing protocols have been introduced to improve various aspects of Wireless Sensor Networks (WSNs), including network lifetime, node deployment efficiency, energy consumption, latency, robustness, fault tolerance, and overall reliability. Among these, extending the network's operational lifetime while addressing energy constraints remains a critical objective. Various cluster-based routing protocols have been developed as enhancements to traditional methods such as direct transmission, multi-hop routing, static clustering, and minimum energy transmission schemes. Among these, the Low-Energy Adaptive Clustering Hierarchy (LEACH) stands out as one of the most widely adopted protocols for WSNs.

In this study, we focus on enhancing the LEACH protocol by incorporating new features suitable for both homogeneous and heterogeneous network environments. We propose Hand-LEACH Phase-1, which introduces an efficient cluster head selection mechanism and variable transmission power levels tailored for homogeneous settings. However, energy-saving strategies designed for homogeneous networks are generally ineffective in heterogeneous scenarios, where nodes have varying energy capacities. To address this, we examine the Stable Election Protocol (SEP), a well-known heterogeneous routing protocol that employs weighted probabilities based on residual energy to elect cluster heads.

Building upon this, we introduce Hand-LEACH Phase-2, which employs differentiated communication strategies between cluster heads (CHs) and the sink for advanced and normal nodes in heterogeneous environments. Simulation results demonstrate that the proposed Hand-LEACH protocol offers improved energy efficiency and significantly extends the network lifetime compared to the original LEACH protocol in both homogeneous and heterogeneous network configurations.

Keywords-- Data aggregation, Dynamic cluster head rotation, Heterogeneous system, Leach Protocol, WSN.

1. Introduction

In a direct communication protocol, each sensor node transmits its sensed data directly to the base station. While this approach is simple, it becomes highly energy-intensive when the base station is located at a significant distance, as each node must expend substantial transmission power. To address this limitation, a second conventional approach, the minimum-energy routing protocol, has been proposed. In this method, data is forwarded through multiple intermediate nodes en-route to the base station. Consequently, each sensor node not only performs sensing tasks but also functions as a router, forwarding data from other nodes. These routing protocols primarily differ in the strategy used for selecting optimal transmission paths.

Cluster-based routing protocols can be broadly categorized into two classes: those designed for homogeneous environments and those tailored for heterogeneous environments. Among the earliest and most well-known protocols is the Low-Energy Adaptive Clustering Hierarchy (LEACH). LEACH assigns an equal probability to each node for becoming a cluster head (CH), which works effectively in homogeneous networks where all nodes possess identical capabilities and energy levels. However, in heterogeneous networks, where sensor nodes may have varying energy reserves and capabilities, LEACH becomes inefficient.

To overcome this limitation, the Stable Election Protocol (SEP) was introduced to prolong the network lifetime by incorporating a percentage of high-energy (heterogeneous) nodes. In heterogeneous WSNs, sensor nodes may differ in sensing range, computational power, and residual energy. SEP improves network stability by employing a weighted cluster head selection scheme based on the residual energy of nodes, ensuring that nodes with higher energy are more likely to become cluster heads. This approach leads to a more balanced energy consumption across the network and extends its overall operational lifetime.

A significant challenge in WSNs is the efficient handling and transmission of large volumes of data, which, if not managed properly, can lead to rapid depletion of energy resources. To address this, routing protocols must minimize overhead and employ effective data aggregation techniques to conserve energy.

In this context, the HAND-LEACH (Heterogeneous distribution of node Adaptive Cluster Head) protocol has been proposed to enhance the performance of LEACH in both homogeneous and heterogeneous environments. HAND-LEACH introduces the concept of threshold-based data aggregation to reduce power consumption and employs dynamic cluster head rotation to distribute energy usage evenly among sensor nodes. The protocol is structured in two phases. In Phase-1, the network is assumed to be homogeneous, with all nodes having equal energy levels. However, as nodes begin to deplete their energy and some eventually fail, the network becomes heterogeneous. In Phase-2, the protocol adapts to the heterogeneous environment by dynamically selecting cluster heads based on the remaining energy of nodes. This approach ensures continued stability and efficient energy utilization. Additionally, HAND-LEACH assumes that all nodes are static, simplifying the clustering and communication processes.

1.1 Need of HAND LEACH:

HAND LEACH is the proposed protocol to use the LEACH protocol for the longer time in the field by increasing its efficiency. It tries to improve some of the drawbacks of LEACH protocol in WSN.

- LEACH assumes that most of the WSN fields are homogeneous system, but in real-world situation, it is very difficult to find homogeneous system for a long time or till the network exists. Therefore, it is very essential to cover both homogeneous and heterogeneous environment situation while creating the protocol.
- LEACH assumes that all cluster heads pay the same energy cost, which is not possible. The cluster head in the WSN consumes different amount of energy depending upon the distance between n cluster head to base station and the amount of data it is transmitting. Therefore, calculation for the energy consumptions is wrong. Death model is incorrect.
- Compression may not be as cheap as claimed because it is unclear how much savings are from compression assumptions and how much from adaptive clustering. There is not any threshold decided for compression of sensed data.
- LEACH gives adaptive clustering mechanism which deals very efficiently with energy conservations. However, LEACH doesn't take account of residual energy of a node. To address this, a novel technique as efficient cluster head selection is proposed.
- LEACH uses same amplification energy for both kinds of transmissions i.e. cluster head to base station and CM to CH. To address this, multi amplified power levels are introduced. This is how much of the energy wasted in cluster head formation process can be saved. Moreover, control overhead is also limited.
- LEACH does not determine optimal number of cluster heads in simulation, before implementation. Round durations never specified or explained in LEACH protocol.

2. Related Work:

Heinzelman, et.al. [10] proposed LEACH-centralized (LEACH-C), a protocol that uses a centralized clustering algorithm and the same steady-state protocol as LEACH.

O. Younis, et.al [1] proposed HEED (Hybrid Energy-Efficient Distributed clustering), which periodically select cluster heads according to a hybrid of the node residual energy and a secondary parameter, such as node proximity to its neighbors or node degree.

T. N. Qureshi et. al., [2] Wireless Sensor Networks (WSNs) contain numerous sensor nodes having limited power resource, which report sensed data to the Base Station (BS) that requires high energy usage. Many routing protocols have been proposed in this regard achieving energy efficiency in heterogeneous scenarios. However, every protocol is not suitable for heterogeneous WSNs. Efficiency of protocol degrades while changing the heterogeneity parameters. In this paper, we first test Distributed Energy-Efficient Clustering (DEEC), Developed DEEC (DDEEC), Enhanced DEEC (EDEEC) and Threshold DEEC (TDEEC) under several different scenarios containing high level heterogeneity to low level heterogeneity. We observe thoroughly regarding the performance based on stability period, network life time and throughput. EDEEC and TDEEC perform better in all heterogeneous scenarios containing variable heterogeneity in terms of life time, however TDEEC is best of all for the stability period of the network. However, the performance of DEEC and DDEEC is highly effected by changing the heterogeneity parameters of the network.

G. Smaragdakis, I. Matta, A. Bestavros proposed SEP (Stable Election Protocol) [9] in which every sensor node in a heterogeneous two-level hierarchical network independently elects itself as a cluster head based on its initial energy relative to that of other nodes.

Li Qing et.al. [11] Proposed DEEC (Distributed energy efficient Clustering) algorithm in which cluster head is selected on the basis of probability of ratio of residual energy and average energy of the network. Simulations show that its performance is better than other protocols.

Md. Solaiman Ali, et.al [4] proposed ALEACH (Advanced LEACH) a new technique to select the cluster heads in every round which depends both on current state probability and general probability.

Sajjanhar et al. [5] proposed a Distributive Energy Efficient Adaptive Clustering (DEEAC) Protocol, which is having spatio-temporal variations in data reporting rates across different regions. DEEAC selects a node to be a cluster head depending upon its hotness value and residual energy.

B. Elbhiri et al [6], proposed SDEEC (Stochastic Distributed Energy-Efficient Clustering (SDEEC) SDEEC introduces a balanced and dynamic method where the cluster head election probability is more efficient. Moreover, it uses a stochastic scheme detection to extend the network lifetime. Simulation results show that this protocol performs better than the Stable Election Protocol (SEP) and the Distributed Energy- Efficient Clustering (DEEC) in terms of network lifetime.

Inbo Sim, et.al [7] proposed ECS (Energy efficient Cluster header Selection) algorithm which selects CH by utilizing only its information to extend network lifetime and minimize additional overheads in energy limited sensor networks.

Ma Chaw Mon Thein, et.al [8] proposed a modification of the LEACH's stochastic cluster-head selection algorithm by considering the additional parameters, the residual energy of a node relative to the residual energy of the network for adapting clusters and rotating cluster head positions to evenly distribute the energy load among all the nodes. We

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have proposed an approach called threshold distributed energy efficient clustering (TDEEC) algorithm whose main aim is to increase the energy efficiency and stability of the heterogeneous wireless sensor networks.

3. Methodology:

LEACH, which is a WSN protocol for homogeneous systems, is not suitable for heterogeneous systems. Putting few heterogeneous nodes in a Wireless Sensor Network is an effective way to increase the network's stability and lifetime. The energy saving schemes used for homogeneous WSNs does not work efficiently when used for heterogeneous WSNs. Thus, a new energy efficient clustering protocol should be designed for them. Heterogeneous WSNs are very much useful in real deployments because they are more close to real life situations.

We can divide heterogeneous WSN system mainly in three parts.

1) Computational heterogeneity
2) Link heterogeneity
3) Energy heterogeneity

3.1 Computational heterogeneity:

In this type of system, some of the nodes have more energy than the other normal nodes. The heterogeneous nodes can provide some benefits such as complex data processing and long term storage with the use powerful computational resources. We are going to use this approach in HAND LEACH Phase 2.

3.2 Link heterogeneity:

Here, some of the heterogeneous nodes have higher bandwidth and longer distance network transceiver than the normal nodes. It can provide more reliable data transmission.

3.3 Energy heterogeneity:

This system has some of the heterogeneous nodes that are line powered or their batteries are replaceable.

For our protocol, Computational heterogeneity is the best suitable. Because in HAND LEACH, we are trying to increase the lifetime of the network. By distributing powerful calculations to advance nodes, we can increase the network lifetime. Link heterogeneity is dealing with the quality and reliability of packets whereas; Energy heterogeneity can be implemented in practical situations. We are not considering Link and Energy heterogeneity from the algorithm point of view.

A. Proposed work:

In this section we present Hand Phase 2 protocol. Here we assume that after couple of rounds of homogeneous system, system will be no longer homogeneous. This is possible because of data transmission is not always same from all the nodes. Nodes which are nearer to the base station, they have to pass more data compared to the nodes which are far away. This is the reason we assume that, the nodes at a far end from the base station have more energy and are considered as advance nodes. Nodes which are near to the base station are normal nodes with lesser energy than advanced node.

Our protocol is extension of SEP. It follows the hybrid approach i.e. direct transmission as well as transmission via cluster head. Depending on Energy of nodes, we can divide all the nodes in advanced nodes with more energy than normal nodes. For Hand Phase2 setup, we will put advance nodes in the corner for direct transmission and normal nodes in-between through cluster head transmission.

At the end of Hand Phase 1, we assume that the nodes are placed randomly and with different amount of energies in all. So we can divide the nodes based on their energies: zone 0, Head zone 1, and Head zone 2.

We assume that the advance nodes are having fraction of more energy than the normal nodes. Total m numbers of nodes out of n are having α time more energy than normal nodes. We refer these nodes as advance nodes and (1-m) ×n are normal nodes.

Nodes in zone 0 have less energy and they are deployed near to the base station. These nodes will directly transmit the data to the sink. Nodes in Zone 1,2 have α times more energy than nodes in zone 0.

Where 0 is Normal node, + is special energy activated node and x is BS

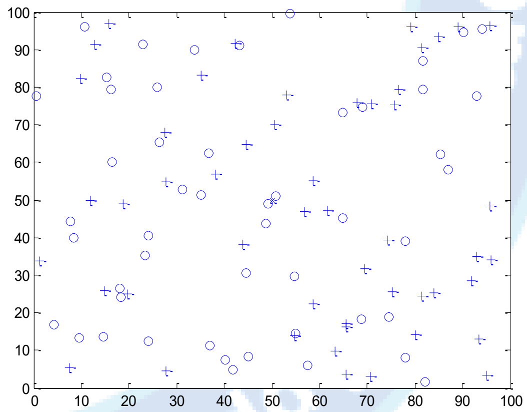

Fig 1: Setup for the Advanced and normal node for SEA phase 2

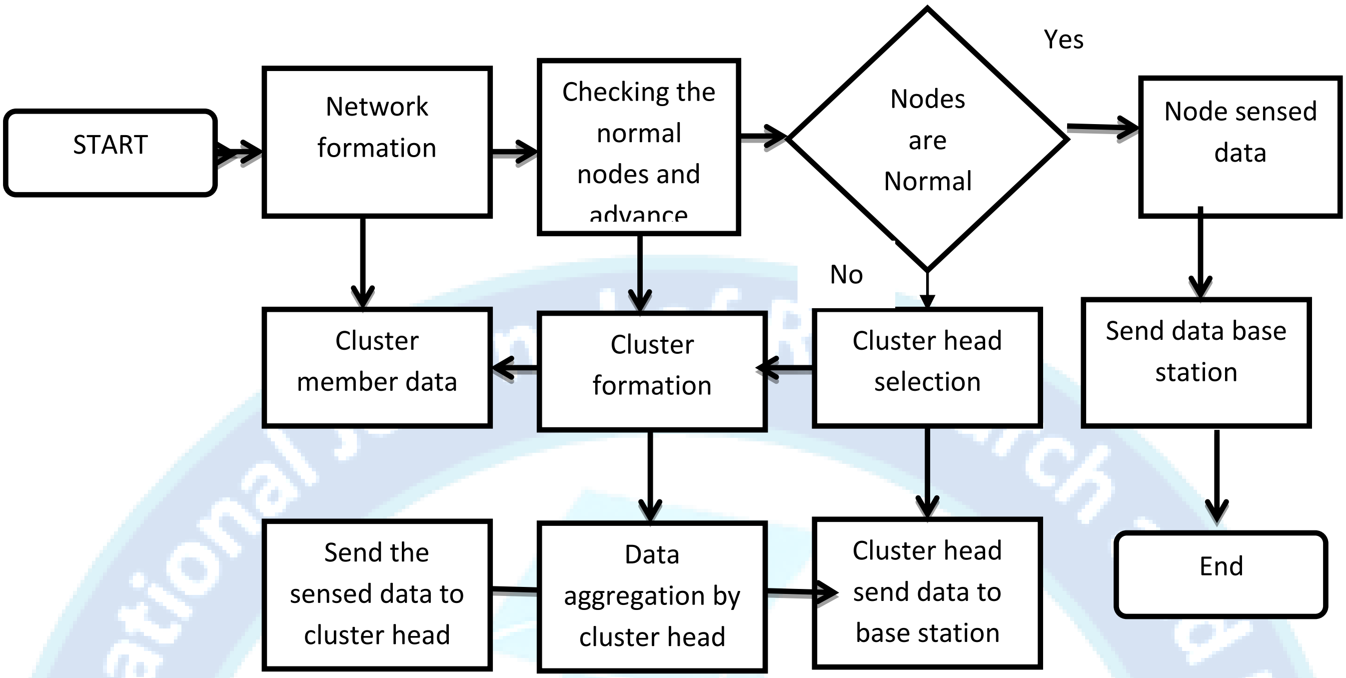

Fig. 2. Flow chart.

Fig 2 briefly explain the operations of Hand phase 2 for normal and advanced nodes. Because of the energies of normal nodes are less than those of advance nodes, normal nodes are not able to form a cluster. Also in receiving the data from all other nodes, the cluster head will consume more energy. If normal nodes are allowed to become cluster head then they will die soon making the stability period short.

4. Result and Discussion:

In this project work we are developed an energy efficient wireless sensor network model having modified version of LEACH protocol having special energy activated sensor nodes called as HAND LEACH. In this we have considered an area having randomly distributed wireless sensor network having equivalent initial energy some of the node having additional energy known as special node.We have taken m as the special node e.i m=0.1 then it mean that 10% node are special mode out of all the nodes the energy of these node is Es=E(1+a).There Es is energy special node. If a=0.5 then Es=(1.5*E) that is energy of special node is 1.5 times of the normal node. For various combination of m and a we have run our algorithm to generate the different number of dead nodes at different rounds. All the result are divided in to 9 difference case, We show only one case here for m= 0.1, a=1.0

For Case m=0.1 and a=1.0 we have generated plots for number of alive nodes of difference round shown in fig. 3(a). Where y axis represented the number of alive nodes and x axis represented the number of rounds. There are two lines green and blue colour where green colour normal LEACH and blue colour HAND LEACH. We can observed that in the LEACH alive nodes start decreasing from round 965 and while in HAND LEACH it start decreasing from 1577 round.

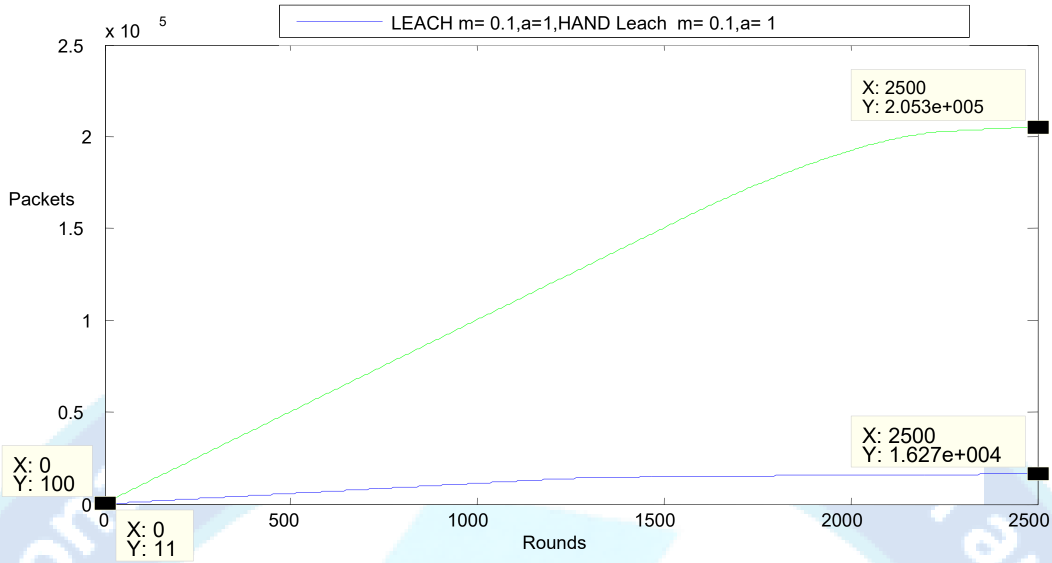

Fig 3(a). Number of Packets Sent at different rounds.

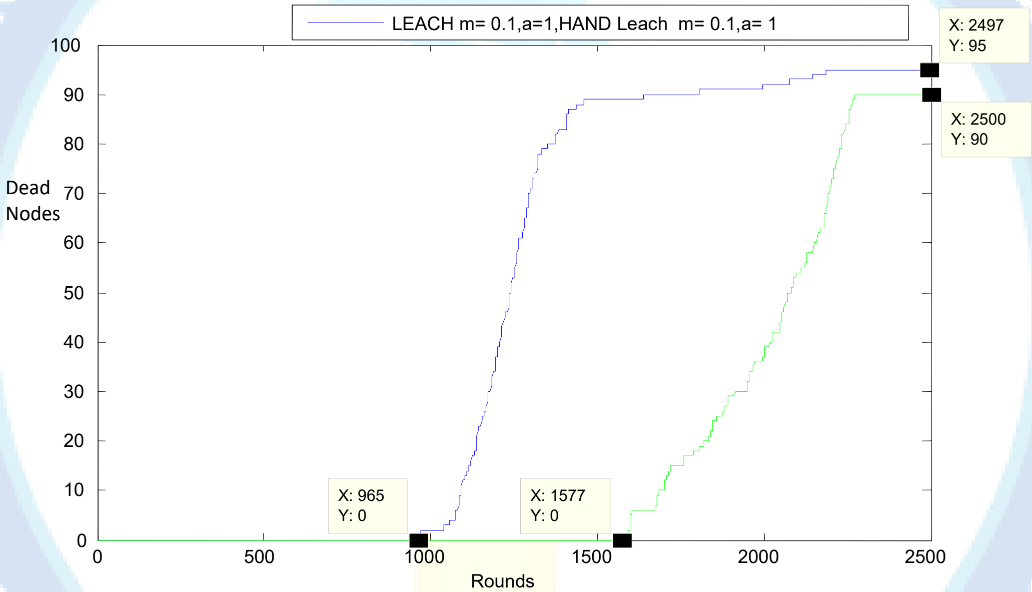

Fig 3(b). No. of dead nodes at different rounds.

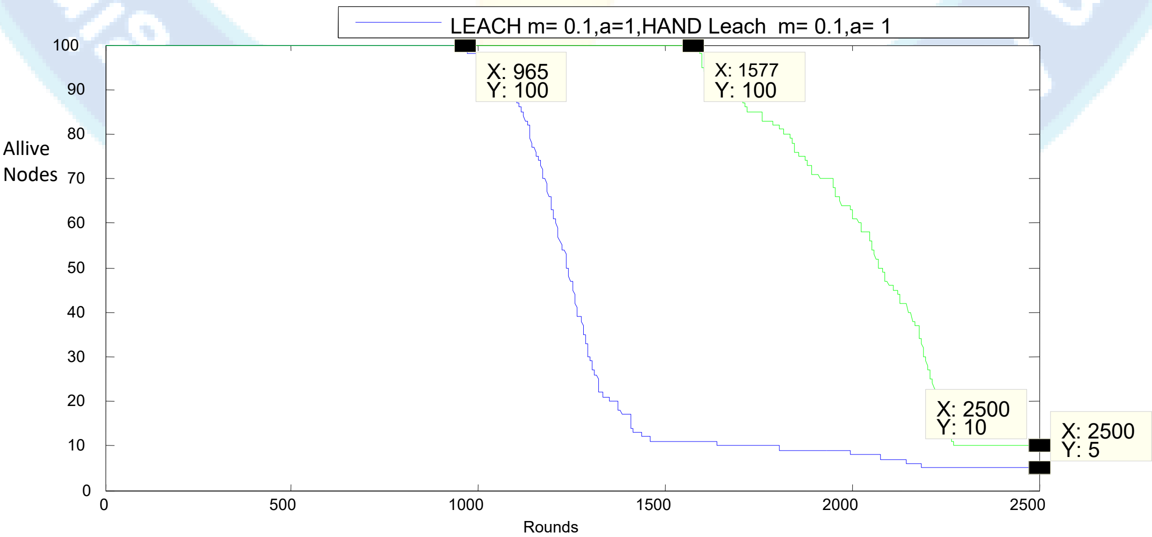

Fig 3(c). No. of alive nodes at different rounds.

Table 1:HAND LEACH parameter evaluation for opimizef WSN lifetime.

m	a	p	First dead	Last Dead	Send Pkt
.3	1	.05	1199	4141	$1.315*10^4$
.3	1.25	.1	1265	3810	$2.422*10^4$
.3	1.5	.15	1272	3485	$3.594*10^4$
.4	1	.05	1227	3597	$1.374*10^4$
.4	1.25	.1	1308	4099	$2.668*10^4$
.4	1.5	.15	1382	3825	$4.061*10^4$
.5	1	.05	1342	4397	$1.429*10^4$
.5	1.25	.1	1361	3429	$2.886*10^4$
.5	1.5	.15	1374	1 alive till 5000	$4.424*10^4$
.4	1	.1	1199	1 alive till 5000	$2.311*10^4$
.5	1	.15	1242	4386	$3.465*10^4$
.3	1.25	.05	1219	4085	$1.443*10^4$
.5	1.25	.15	1419	3092	$4.111*10^4$
.3	1.5	.05	1295	3677	$1.539*10^4$
.4	1.5	.1	1283	3776	$2.83*10^4$
.4	1.25	.05	1293	1 alive till 5000	$1.584*10^4$
.5	1.5	.05	1429	4346	$1.724*10^4$
.3	1	.1	1442	2880	$2.278*10^4$
.5	1.5	.1	1429	3988	$3.125*10^4$
.3	1	.15	1002	2640	$3.149*10^4$
.4	1.25	.15	1252	1 alive till 5000	$3.713*10^4$

5. Conclusion:

In our work we have briefly describe how cluster based routing protocol LEACH can be utilized in better way for homogeneous and heterogeneous environment. Our simulation shows HAND LEACH gives better throughput of the system compare to LEACH. We can get better efficiency by including new CH replacement scheme and different transmission energy. Results are generated for different number of special energy activated nodes out of total nodes for different probabilities of election of SEA nodes as the cluster heads. It has been observed that in any combinations of m and a the HAND LEACH sends higher number of packets as compared to normal LEACH. For minimum value of m=0.1 and a=0.5 the HAND LEACH shows higher life time than the LEACH. Hence it can be concluded that even if we consider only 10 %cent nodes as SEA nodes with energy 50% higher than other nodes we can significantly enhance the network life time and data transmission rate. Moreover, stability of HAND LEACH can be improvised by using two different transmission techniques direct transmission and CH to sink transmission in heterogeneous. In future, HAND LEACH can be improvised by adding more techniques for hierarchal transmissions between CH to Sink. Again it will be interesting to apply advanced node concept with Energy heterogeneity.

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