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ORIGINAL ARTICLE

A NEW ENERGY-EFFICIENT CLUSTER-HEAD SELECTION (NEETCH) TECHNIQUE TO INCREASE WIRELESS SENSOR NETWORK's LIFETIME

Abdul Qayyum[1], Haseeb ur Rahman[2], Mohammad Zahid Khan[3], Mohammad Faisal[4]

[1]M.phil Scholar, Department of Computer Science & Information Technology, University of Malakand, Malakand
[2]Assistant Professor, Department of Computer Science & Information Technology, University of Malakand, Malakand
[3]Assistant Professor, Department of Computer Science & Information Technology, University of Malakand, Malakand
[4]Lecturer NS2 Expert, Department of Computer Science & Information Technology, University of Malakand, Malakand

ABSTRACT

Wireless Sensor Network (WSN) is the compounding of sensor devices (i.e. sensing unit, processing unit, communication unit and energy unit) connected through wireless medium. The applications and diversity of WSNs have greatly increased due to its deployment in environments difficult or nearly impossible for human to operate. However, owing to its limited batter power of sensors, these networks have shorter operational life span. To address this issue, various techniques are in vogue to improve network lifetime, such as clustering technique, in which a network is divided into various clusters where a single node is selected as Cluster Head (CH), where each CH sends aggregated information to a Base Station (BS). These CHs consume more energy comparatively and die earlier due to higher processing and communication load. AS a result, the performance and operational objective of the network is significantly affected. The existing approaches, such as LEACH, uses a static criterion to select a CH throughout the network lifetime, whereas the dynamics of the network changes due to many reasons. In this paper, a new CH selection technique has been proposed, where the CH selection is in accordance with the dynamic behaviour of the network. In the proposed technique, the CH selection is performed in three phases with each phase designed according to current status of the network. Each phase gets activated as soon as a defined criterion is met. The implementation and simulation results showed that our new proposed technique outperform the LEACH protocol in terms of network life span, energy consumption and throughput.

Keywords: WSN, Energy-Efficiency, Cluster-Head Selection.

Author`s Contribution
[1,2,3]*Manuscript writing, Data analysis, interpretation, Conception, synthesis, planning of research, Interpretation and discussion, Data Collection*

Address of Correspondence
Muhammad Faisal
Email: mfaisal_1981@yahoo.com

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INTRODUCTION

A typical Wireless Sensor Network (WSN) consists of a large number of low powered, energy-constrained tiny devices, named sensor nodes also known as motes, deployed within a specific area to monitor a target enviornment. Generally, there is a dedicated resource rich node, commonly known as a "Base Station (BS)" in every WSN, where the whole data of the network is collected[1] [1]. Applications of WSNs include both in Civil and Military domain [2]. For example, WSN for environmental monitoring [3], area surveillance [4], smart farming/agricultural [5], Internet of Things (IoT) [6], medical and industrial monitoring [7], disaster detection [8], commercial applications [9] and many more. Besides their widespread use, WSNs have some design issues and challenges. These challenges are Energy-constraints, Security, Fault Tolerance, Scalability, Self-Management, Heterogeneity, Quality of Service (QoS) etc., [1013].

WSNs are highly recourse and energy constrained, and most of the energy is consumed by in data gathering and communication. Since long, clustering techniques and algorithms are widely used in WSNs for better network management. In Clustering, sensor nodes are grouped into clusters, with every cluster having and Cluster Head (CH), The other nodes in a cluster are known as member nodes [13]. CH locally aggregate/fuse data and further send the data to a BS for their respective cluster. Clustering proves to a good technique in network management and minimizes unnecessary communication in WSNs. A typical scenario of a clustering based sensor network is shown in Figure Error! No text of specified style in document..**1** [14].

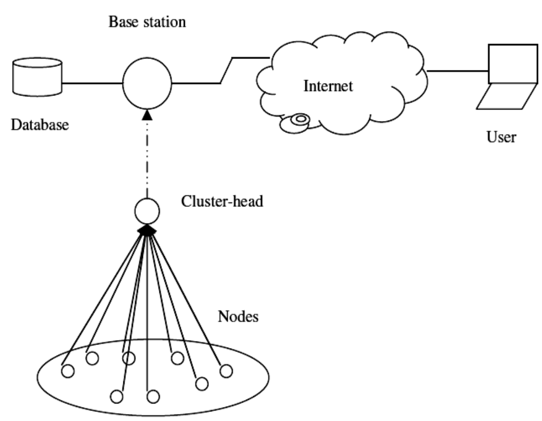

Figure Error! No text of specified style in document..**1: A typical scenario of a clustered sensor network**

Since, CHs play important role in data gathering and communication, therefore, CH in WSNs are selected according to certain parameters e.g. energy, location and so on [15]. Suitable selection of CH can guarantee prolonged network lifetime. While random selection of CH - on the contrary such as in LEACH [16] protocol - can lead to higher energy consumption and overhead, resultantly, re-clustering of the network. This frequent re-clustering consumes more energy of sensor nodes [17]. Therefore, the random selection of CHs and re-clustering of a network results in depletion of energy of a network unnecessarily, and reduction of overall network's lifetime.

Furthermore, the circumstances of a sensor network do not remain constant throughout a network lifetime and change according to various factors such as energy depletion, mobility, location of nodes, and self-organization etc., over the application lifetime [18]. In other words, the status of a network is not the same at the beginning, mid, or end of a network lifetime. Most of the existing solutions fall short in considering the dynamic behaviour of a sensor network. They only consider a single criterion throughout the network life for the selection of a CH, which affect network's overall efficiency [19]. For CH selection, the use of random selection and following some criteria that do not consider the dynamic behaviour of a sensor network throughout a network lifetime may lead to frequent re-clustering of the network and hence may result in communication overhead and increased energy consumption. [20].

LEACH is one of the most widely-used and famous clustering protocol [16], which randomly selects CHs by ignoring present energy resources of sensor nodes, ultimately the overall network lifetime is decreased. Given the motivation, to address this important issue, in this paper, we propose a novel solution called a New Energy Efficient Technique for Cluster Head Selection (NEETCH) to increase network lifetime. In NEETCH, a CH election is based on the following three main parameters:

- Distance from the BS (as compared to received signal strength intensity (RSSI)
- Mobility of the sensor nodes
- Remaining energy of the sensor

Moreover, along with the above, the selection in NEETCH is carried out Phase wise considering the current dynamic circumstances of a network. The results of simulation based evaluation attest that NEETCH significantly improves WSNs lifetime.

BACKGROUND

Over the recent past, Clustering Model/Technique has been proved to be more efficient that flat network model. However, cluster head (CH) selection is the most challenging task in clustered WSN. Pertaining to the design and development of WSNs, various routing protocols have been proposed by researchers to fulfil every possible need of WSNs [21]. Nonetheless, due to the growing application domain to WSNs, enhancement in the existing protocols are also in progress. Related to this, Energy-Efficiency is one of the most important factor in any protocol aiming to prolong the lifespan of WSN with goal to achieve the application target. There are several research articles and survey papers in literature on routing protocols in WSNs. However, to the best of our ability, the most relevant and updated literature for review has been selected and critically analysed as follows:

A. LEACH (Low Energy Adaptive Clustering Hierarchy)

W.B. Heinemann et al. [22] proposed an energy efficient cluster based routing protocol to increase network lifetime known as LEACH. In LEACH, each node in a cluster has a chance to act as a CH. Furthermore, each sensor node in a cluster directly communicates to the CH which performs aggregation on the collected data and sends the fused data to the base station (BS). The network operations of LEACH protocol are completed in rounds like other hierarchical protocols. Moreover, in each round, cluster member nodes collect data from the environment and send it to the CH, and the CH sends the aggregated or fused data to the BS. However, in case the node having little residual energy is selected as the CH, the lifetime of the WSN decreases accordingly.

B. Two-Level LEACH

V. Loscri et al. [23] proposed energy efficient and high throughput routing protocol known as Two Level LEACH (TL-LEACH) as an improvement to LEACH. In this solution, a CH gets data from the cluster members, the CH sends the data to an intermediate CH, rather than sending the data to the BS directly. However, transmission delay issue has not been addressed in TL-LEACH.

C. CH-VCH Approach

A. Mehmood et al. [24] proposed CH-VCH, a vice cluster heads to maximize performance of the network. In this technique when a CH consumes its energy up to some threshold, a high energy node as CH updates all the member nodes of the network with a broadcast. Then, the CH selects a member node, which has the maximum energy in the cluster to be Vice CH (VCH). The VCH transmits aggregated information of the member nodes to BS for further use. VHC minimizes additional round in steady-phase, which also improves performance of the network in terms of lifetime and throughput. However, to evade sudden death of VCH, new advertisement phase takes places, resultantly increase communication overhead.

D. Discrete Particle Swarm optimization scheme

J. Li et al. [25] proposed a novel routing algorithm based on centralized clustering, named as discrete particle swarm optimization (DPSO). Initially DPSO generates different clusters with the help of random particles called a swarm. To get a promising initial swarm, Base Station (BS) selects cluster head from the available swarm having highest energy, while remaining of the nodes become member nodes of WSN. In this way particle/ nodes are coded into two types as cluster head and member nodes. However, no restriction has been implemented on particles/ swarm updates. This improves the performance of WSN by selecting CH having highest energy, however this mechanism also selects sleeping nodes as CH which degrades the performance.

E. Self CH

S. Deng, J. et al. [26] proposed a scheme in which a node select itself as a CH based on residual energy and mobility. It is a time division multiple Address (TDMA) approach in which all the nodes are assigned a time slot to send their sensed data and broadcast a joint request message. After two consecutive frames, a node does not receive message from its cluster head, and the node automatically understood that it has moved out of cluster. Then the node broadcast a cluster joint message. Thus, it joins a new cluster to avoid more packet loss.

The existing research work uses the same criteria for CH selection throughout the lifetime of a WSN. Although the importance and availability of various factors in WSNs changes with respect to its lifetime. The mobility factor has been ignored in most of the proposed solutions for selection of cluster head, which may cause degradation in performance of WSNs. Therefore, a need of different criteria arises for selection of CH with respect to the lifetime of WSNs which also considers other factors such as remaining energy, mobility and distance from the base-station.

PROPOSED SOLUATION

In this section, we present our new energy-efficient technique for cluster head selection. The preliminary details and parameters of the proposed solution are discussed are detail as follows:

A. Preliminary Concepts

According to our proposed technique, the lifetime of a WSN can be divided into three phases i.e. initial startup phase, mature mid phase and near to end phase. The selection of CH in these phases solely depends upon the residual energy, received signal strength intensity (RSSI) i.e. the distance from base-station and mobility of a node. In this section a few preliminary important concepts have been explained before providing a detailed explanation of the proposed solution.

- **RSSI Qualifier**

By RSSI qualifier (RSSIQ) we mean the highest signal strength of the sensor node. Distance from the base station and CH can easily be obtained from RSSI. Highest value of RSSI may be considered near to base station and can be used for CH selection.

- **Mobility of node**

The selection criteria also depend upon nodes mobility. A certain number of nodes in the network move with certain speed from one location to another.

- **Energy level**

Energy or battery life of the sensor device plays an important role in network life time. CH selection also depends on the highest remaining energy of the device. A new CH is selected as soon as its remaining energy drops below certain threshold value. Upon initial deployment, all nodes are supposed to have the same highest energy reserves.

B. A New Energy-Efficient Technique for Cluster-Head Selection (NEETCH)

The proposed NEETCH scheme modifies and improves the conventional LEACH protocol, by having a new CH selection criterion and technique. The lifetime of a sensor network changes with time. So, a dynamic approach is needed to select a cluster head according to the network's present conditions. Therefore, NEETCH uses various criteria for the selection of CH all through the lifetime of a mobile WSNs. The CH selection is carried out according to the present status of the network. The lifetime is categorized into three phases the initial startup phase, the mature mid phase and near to end phase.

- **Initial Startup Phase**

This phase starts the deployment of nodes. At the initial, sensor nodes are deployed all having same energy. In the meantime, all the sensor nodes of cluster advertise their location to base station (BS) polling as carrier sense multiple access (CSMA) protocol. The BS, then set clusters using LEACH protocol and measures signal strength of each sensor thus creating cluster head (CH) in each cluster. This selection is made on RSSI i.e. distance from the BS. The node when selected as CH, announces itself to be a part of the clusters. The only criteria followed at this stage is that the CH should be closer to the BS. This is because all the nodes have same energy and the network behavior is unknown.

During first phase, sensor nodes start communication via the selected CHs. As the energy of a CH may reduce before the remaining nodes, so whenever the energy of a CH reaches certain threshold value, the second phase starts.

- **Mature mid Phase**

In the Mature Mid Phase, when the above mentioned condition meets, a new CH is selected. The selection criteria depend upon the remaining energy and the lowest mobility of the node. In this phase, it is not necessary that a node should be closer to BS although nodes may have more than enough energy to carry out long range communication. However, the lowest mobility keeps a node as a CH for longer period of time. Avoiding frequent selection of CH will reduce energy consumption.

The transition from first phase to the second phase occurs gradually. The second phase begins for only those clusters where the CH energy is lower than the threshold value. So both phases can coexist where some clusters might be in the first phase and others in second phase but eventually all will be moved to second phase.

- **Near to end Phase**

The network remains in the second phase as long as nodes are available with enough energy to continue as CH. As energy of nodes deplete the third phase, called Near to End Phase starts.

In this phase, nodes having higher remaining energy and closer to base station are selected as cluster heads. Since nodes' energy is already at its limit, so a node can die sooner if it is selected far from a BS because longer communication consumes more energy.

C. Algorithm for the proposed scheme

The algorithm developed for the selection of CH is based on three parameters i.e. Remaining Energy, Distance from BS and Mobility of nodes. Table II.1 shows the parameters and their details that are used in the algorithm.

Table Error! No text of specified style in document.**.1: Details of the parameters in the algorithm for the NEETCH**

Parameters	Details
E0	the initial energy of each node
N=(n1, n2, n3…,nn)	No. of Nodes
E=(E1,E2,E3….,En)	Energy of each node
R	Number of rounds
Eavg	The average energy of all nodes in a particular cluster
ECh	The energy of channel head
Tr	The threshold of energy for CH
Eavg	The average energy of all nodes in a particular cluster
Ep	Probability using energy considerations
Er	Reaming energy
RSSI	- (10nlog10 d + A) : Receive Signal Strength Intensity
Mo = a *d +c	d= distance travelled in meters, a = continuous friction losses in joules per minute, c = kinetic energy of node (E= I/2 mv2)
Etr	The energy required for transmitting and receiving data
TDMA	Time division multiple access

The steps performed to select a CH are given as below:

Algorithm: NEETCH {A New Energy-Efficient Technique for Cluster Head selection}
Step-1: Inputs: Er, Emax, N, R, E0, CH=0. // Input to topology
Step-2: Outputs: Number of CHs with balanced clusters, CH= {}, CHi . // Output from Topology
Step-3: Random selection of CH near to BS. // Directly connected node will be selected as CH randomly
Repeat i=1 to N
Rand (n (i))
CH = = n(i)
Step-4: IF (Tr < Tr0) Then // Calculate Residual Energy of nodes probabilistically when CH energy reaches to certain level
Repeat i=1 to N Then
E0 (i) = Ep * (E0 – Er)
(Tr >= Tr0)
E0 (i) = E0 (i-1) Break
Step-5: Repeat i= to N //Calculate Distance by using RSSI of each output of Step-3;
IF (RSSI (E0 (i)) > RSSI (E0 (i-1)) Then
Rs = (RSSI (E0 (i)) Break
Step-6: Repeat i= to N : //Calculate Mobility of each output of Step-4;
IF (Mo (i) <= Mo(i+1)) Then
Mo = Mo (i) Break
Step-7: IF (E0 && Rs > Max of N && Mo = = Min of N) Then // based on three parameters CH will be select
CH ← ni Simulation setup comprising parameters, metrics and result of the simulation will be explained in details. The results will be evaluated in terms of throughput, residual energy and number of alive nodes. This scheme will also be compared with an existing scheme.
Step- 8: Repeat i=1 to Rmax // No. of iterations for network Step-1 to Step-5
Step-9: End if // End of if condition
End Repeat
End if
End Repeat
End if
End Repeat
Step-10: Finish

The above CH selection process is also explained and presented in the flow chart below in the **Error! Reference source not**

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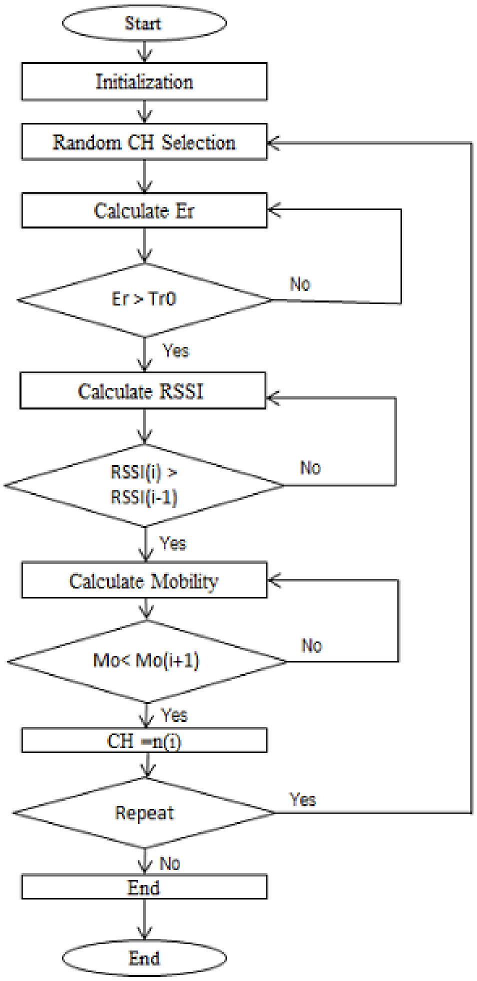

Figure Error! No text of specified style in document.**.2: Flow chart of the NEETCH**

SIMULATION AND EVALUATION

We evaluate NEETCH, and with the simulation results justify that NEETCH outperforms LEACH protocol, and significantly increase the WSN's lifetime. In this section, we further discuss our simulation setup comprising parameters, and metrics. The results are evaluated in terms of throughput, residual energy and number of alive nodes.

A. Simulation Setup

For the evaluation of proposed scheme, we have used NS-2.35 and list of parameters as shown in Table Error! No text of specified style in document..**2**. We have developed different scenarios to analyse the performance. A number of simulation scenarios are designed using NS-2 as mentioned in the table.

Table Error! No text of specified style in document.**.2: Simulation parameters**

S/No.	Parameters	Values
1	Initial Energy of Each Sensor Node	2 Joules
2	Number of Base Station	1 (Base station)
3	Total Number of Clusters	5
4	Number of Nodes	45, 75, 95
5	Mobility Model	Random Way Point (RWP)
6	Mobility Speed	5-10 (m/Sec)
7	Pause Time	2 (Seconds)
8	Simulation Time	500 Seconds
9	Routing Protocol	LEACH / NEETCH
10	Application/Transport Layer Protocol	Constant Bit Rate (CBR) / User Datagram Protocol
11	Simulation Area	700 x 700 (m2)

B. Performance Metrics

Following parameters are considered for evaluation purpose.

- **Throughput**: The amount of data moved effectively from one place to another in specific time period measured in bits per second.
- **Alive Nodes:** The number of nodes that are alive or functional, in terms of energy, in the network.
- **Residual energy:** The remaining energy of a node.

C. Result and discussion

This section presents the simulation results of NEETCH and its comparison with LEACH. In the first section, the network lifetime has been explained with the help of graphs obtained from simulation results. The second section explains energy consumption in the network during varying nodes' densities. The throughput of each network has been shown graphically and then explained in the third section. The details are given below:

- **The effect on alive nodes vs time with varying node densities**

Nodes' densities in LEACH and the proposed NEETCH schemes are evaluated to know its effect on the efficiency of the networks. Networks of size 45, 75 and 95 nodes have been used in simulation.

Alive nodes vs time is depicted in Figure Error! No text of specified style in document..**3** with low density i.e. 45. It can be observed from the figure that with the passage of time, both the schemes show significant fall in number of alive nodes. However, NEETCH shows better performance than LEACH. NEETCH improves the network life time, but the LEACH drops sooner.

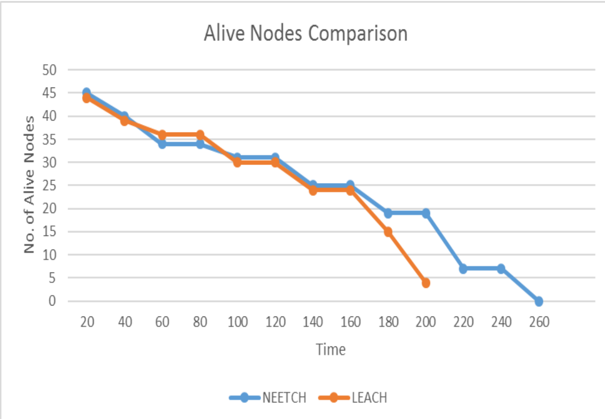

Figure Error! No text of specified style in document.**.3: Alive Nodes vs Time (45 Nodes)**

Alive nodes vs time are shown in Figure Error! No text of specified style in document.**.4** with medium density. NEETCH keeps the nodes alive as time passes, but the LEACH fails to keep the nodes alive for a longer time. It can also be noted from the graph that as the number of nodes increases, NEETCH presents better performance because with a great number of nodes the network lifetime increases.

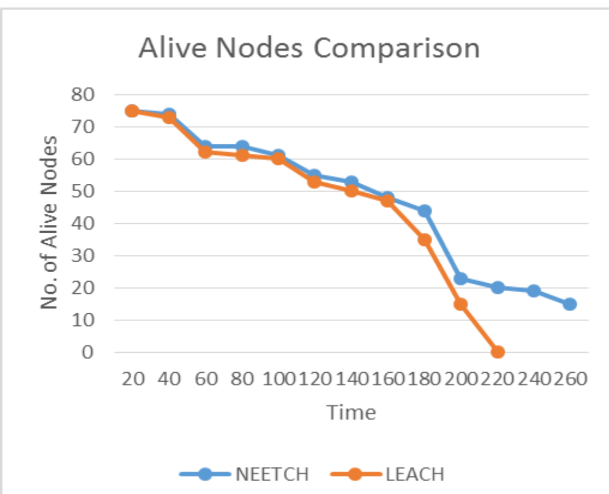

Figure Error! No text of specified style in document.**.4: Alive Nodes vs Time (75 Nodes)**

The efficiency of NEETCH in terms of alive node vs time with high density is shown in Figure Error! No text of specified style in document.**.5**. The graph clearly demonstrates that as the number of nodes increases, NEETCH presents better performance. On the other hand, LEACH performance is very weak.

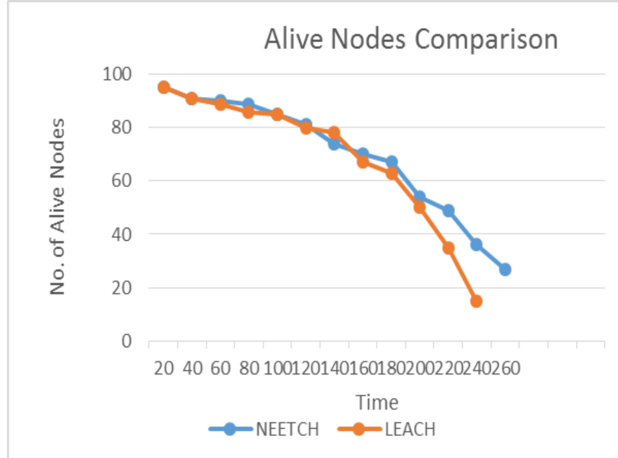

Figure Error! No text of specified style in document.**.5: Alive Nodes vs Time (95 Nodes)**

It can be concluded from the table II.3 that in overall evaluation the NEETCH performs better than LEACH during varying network densities and hence keeps the nodes active for longer.

Table **Error! No text of specified style in document.**.3: Overall Result of Alive Nodes

No. of Alive nodes	LEACH	NEETCH
45	Average	Above average
75	Average	Above average
95	Average	Above average

- **The effect on energy consumption vs time with different number of nodes**

The energy in a network is consumed due to communication, sensing, and management of the network i.e. CH selection in this case. If a CH selection is not proper, then re-clustering occurs frequently and hence consumes most of the energy of a network. This section explains and compares the energy consumption of NEETCH and LEACH protocol for different network sizes i.e. 45, 75 and 95.

The result of Energy consumption vs time for the low-density network is depicted in Figure Error! No text of specified style in document.**.6**. It can be noted from the graph that both the schemes show a decrease in residual energy as time passes. However, due to the high energy consumption of LEACH protocol the overall energy of the network drops sooner whereas the NEETCH performs better.

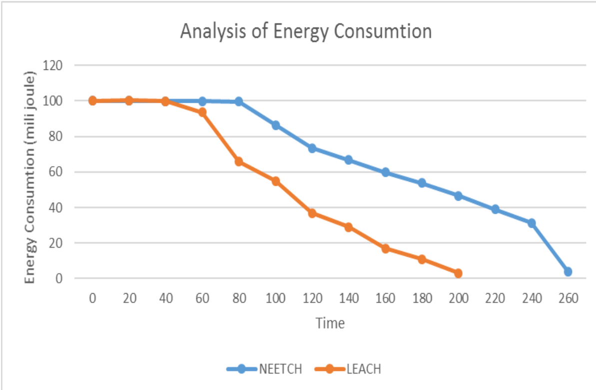

Figure Error! No text of specified style in document.**.6: Energy consumption vs Time (45 Nodes)**

The effect on residual energy with medium density can be observed from Figure Error! No text of specified style in document..**7**. With medium density, residual energy decreases by both schemes linearly. However, the LEACH consumption rate is higher than NEETCH.

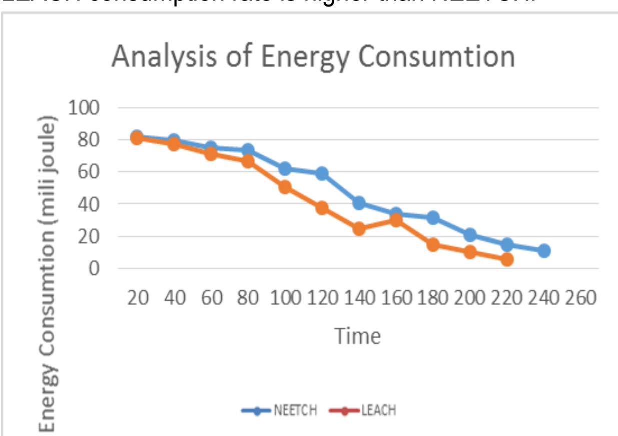

Figure Error! No text of specified style in document.**.7: Energy consumption vs Time (75 Nodes)**

As the number of nodes increases both LEACH and NEETCH present similar behavior in term of energy consumption as shown in Figure Error! No text of specified style in document..**8**.

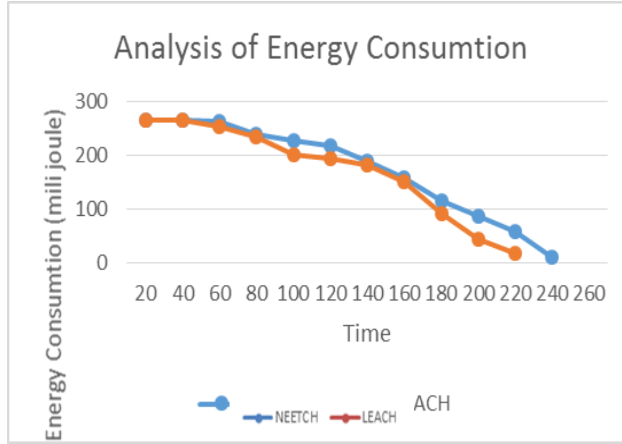

Figure Error! No text of specified style in document.**.8: Energy consumption vs Time (95 Nodes)**

It is obvious that NEETCH performs well with low density. Though, when nodes' densities increase the NEETCH does not perform efficiently as compared to LEACH. However, there can be a number of factors that may affect the performance of NEETCH such as cluster size, etc. Therefore, it needs further investigation.

Table Error! No text of specified style in document.**.4: Overall Result of Alive Nodes**

No. of Alive nodes	Time Elapsed (LEACH)	Time Elapsed (NEETCH)
45	200	260
75	220	240
95	220	240

- **The effect on throughput vs time with different densities**

The effect on throughput with low density is presented in Figure Error! No text of specified style in document..**9**. The throughput of NEETCH protocol increases with time, in contrast to LEACH. As re-clustering consumes a considerable amount of resources hence it affects the throughput of the LEACH. The throughput of NEETCH is increased by almost 22% than LEACH.

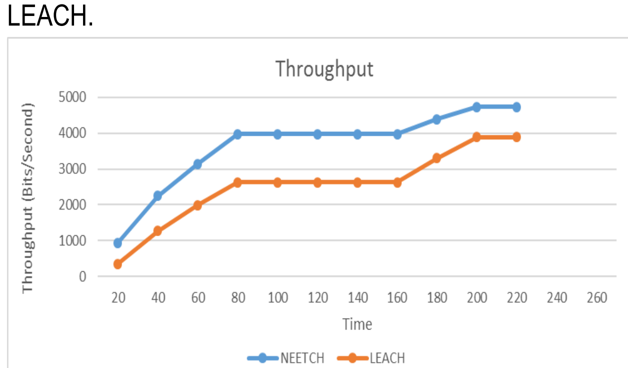

Figure Error! No text of specified style in document.**.9:**

Throughput vs Time (45 Nodes)

The effect of medium density on throughput is shown in Figure Error! No text of specified style in document..**10**. Again, NEETCH's throughput increases with time and the nodes participate rarely in communications thus the throughput of NEETCH is increased by almost 28% than LEACH.

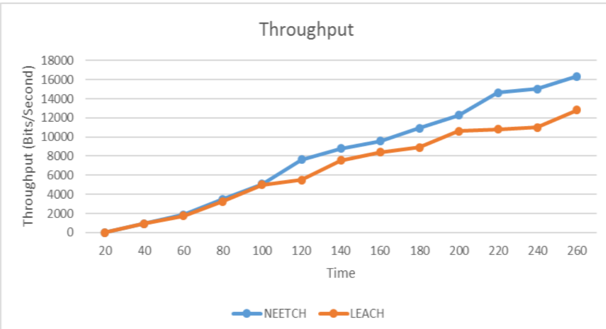

Figure Error! No text of specified style in document..**10: Throughput vs Time (75 Nodes)**

In Figure Error! No text of specified style in document..**11** the effect on throughput with time is depicted in a higher density scenario. In a higher dense network, NEETCH performs well as compared to LEECH. Summing up, NEETCH shows better performance in all scenarios and the throughput is increased by approximately 22% than LEACH.

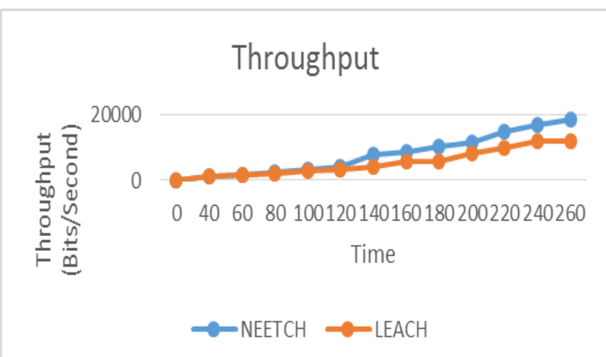

Figure Error! No text of specified style in document..**11: Throughput vs time(95 Nodes)**

The above discussion shows that NEETCH's overall performance is better than LEACH. The reason is that CH selection is done according to the current circumstances of the network. As a result, there is no need of re-clustering and hence resource consumption is avoided. However, there are two situations worth noting. First, in most cases, in the start LEACH and NEETCH show same behavior because NEETCH initial CH selection criteria is same as that of the LEACH. Second, energy consumption of NEETCH does not show much improvement as compared to LEACH because network density increases and as already mentioned, it needs further investigation

Conclusion and Future Work

The aim of this research work is to increase the network WSN's in terms of cluster head (CH) selection. The behaviour of a sensor network changes with time. While using the same criteria, e.g. in LEACH protocol, throughout a network lifetime for the CH selection may result in frequent re-clustering of the network. In this paper, we proposed a new technique called NEETCH that selects a CH using received signal strength intensity (RSSI), mobility of nodes and residual energy of nodes. In the proposed scheme, three phases have been used to carry CH selection process where each phase is activated as soon as change in network behaviour occurs. On the contrary, the simple LEACH protocol selects CH randomly which do not improve performance of the WSN in terms of network lifetime and throughput. The proposed NEETCH technique was implemented and simulated in NS-2.35 simulator, and our simulation results show better performance in terms of throughput and network lifetime as compared to normal LEACH protocol.

In the future, we will investigate as to why the NEETCH efficiency is affected as network becomes denser, Moreover, further investigation is required to find what other parameters can be used for shifting phases for the purpose to improve network efficiency.

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