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# Energy Efficient Scheme for Wireless Sensor Network in Environment Monitoring

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**ABSTRACT**

**As ad-hoc network, wireless sensor networks (WSN) have become increasingly common in several fields of human endeavours requiring information gathering and prediction in both military and civil operation. This work has presented modified energy efficient cluster based routing in wireless sensor networks for environment monitoring. The scheme introduces two level hierarchical routing protocol involving an active cluster head (CH) and associated cluster heads (CHs) that make up a head-set. A WSN work model was developed using MATLAB C code and with the proposed scheme. Simulations were carried out to analyze and investigate the effectiveness of the system in terms of optimum range of clusters required to optimize energy of WSN, which revealed that at number of cluster 20 to 54, the energy consumption by the network was approximately the same. Thus, the maximum number of cluster was 54 because beyond this number the energy of the sensor nodes was zero. The maximum number of headset was 5. The variation of energy per round against the number of clusters showed that energy consumed per round by each sensor node in cluster is reduced as the number of clusters is increased.**

Keywords – **Energy efficient, Environment, Monitoring, Wireless sensor network**

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## I. INTRODUCTION

**W**ireless Sensor Networks using low power capacity nodes are helpful in numerous applications to realize distant or remote wireless connection and flexibility of data communication. Sensor nodes topology has proven to provide unmatched flexibility and cost efficiency when used for closing feedback control loops over wireless networks facilitated industrial automation process. For example, in a smart industry, plants or processes are controlled and monitored through distant controllers with the help of distributed sensors that provide measurement and feedback functions. The heart of WSN operation is to gather and process data at sensor nodes.

Wireless Sensor Networks (WSNs) contain sensor nodes that are usually equipped with a transducer, a radio transceiver, small-controller and a source of power (batteries) deployed in process proposed for monitoring situations and parameters at different locations. It is possible to sense or measure vast types of parameters from the environment including, temperature, light humidity, pressure, wind direction and so on with sensor nodes. The data acquired by sensor nodes are generally transmitted through Radio Frequency (RF) channel to the base station or sink. The base station is a radio transceiver that connects other wireless sensors to central hub, and may serve as a gateway between a wired network and the WSN. The base station node is the main unit of WSN that can be connected to an infrastructure or to the internet through a gateway that lets distant or inaccessible users to access the collected data (Rault, 2015).

Hundreds to thousands of sensing nodes can be contained in WSNs, with a desire to make the nodes inexpensive and energy efficient while taking advantage of the vast numbers to obtain high quality performance (Nuray and Daraghma, 2015). Sensor nodes are used for real time gathering of data that are onward transferred directly or indirectly through relay nodes to sink (Ahmad et al, 2014). As a result of the ability of WSNs to accurately and reliably gather information, there is now the possibility of building systems that can provide real-time detection and early warning function. Therefore, WSNs have been deployed in various monitoring applications such as environmental or habitat monitoring, industrial monitoring and automation process, agriculture, security, and health (Cong and Shujuan, 2016; Rozas and Araujo, 2019) including, enabling quick coordinated responses to address cases of emergency such as bushfires, tsunamis, earthquakes, and other crisis situations in Jing (2015a and 2015b).

In WSN, selection of route between any two nodes begins with the election of neighbours based on some sort of information that is shared among the adjoining neighbours and subsequently all around the network. This whole set-up relies on the ability of the nodes and the lifetime of the battery during the working of the network. Hence, issues

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such as energy, communication range, bandwidth, processing power, and storage capacity pertaining to the design constraints and resource requirements of WSNs in practices are common place.

Recent studies have focused on overcoming these limitations by bringing in new design approaches, either by developing new protocols or improving on existing ones. Techniques are being developed to address specific requirement issues of WSN. An important issue in WSN is energy consumption management. In this paper, a solution is proposed to provide continuous data streaming and monitoring to address energy consumption of sensor nodes in a wireless network deployed for environment sensing.

## II. LITERATURE REVIEW

This section presents the works that have been proposed in by previous research with regard to energy efficient performance capability of Wireless Sensor Networks (WSNs). At the end of this review research gap is established and a new solution is proposed.

Kumar et al. (2016) proposed a modified Low Energy Adaptive Clustering Hierarchy (LEACH) protocol. The algorithm was aimed at reducing the energy utilization, sensor nodes deployment, latency, and fault tolerance in network. The algorithm called MaximuM-LEACH was able to provide load balancing for given number of nodes and at the same time addressing the average number of nodes so that the lifetime of WSN can be increased. However, the study did not address the issue of minimizing the number of nodes stranded as Cluster Heads (CHs) die.

Singh and Singh (2013) presented energy efficient technique for performance evaluation of cluster based WSN. The performance of WSN was evaluated using Heterogeneous Hybrid Energy Efficiency Distributed (H-HEED) protocol. The proposed scheme provided effective communication between sink nodes as well as CH nodes. The overall performance of every node was measured based on the communication between sink and CH node. However, while the study reported consistency in decreasing delay as the number of nodes increases as result of the routing table information stored on each sensor node when communicating over a WSN, it did not mention nor address the effect of distance between adjacent nodes. It also did not provide the energy efficiency of each node.

Zhang (2019) proposed a technique for efficient energy management and route optimization for WSN under the Ubiquitous Power Internet of Things (UPIoT). An energy utilization algorithm of sensor nodes in a network was established after examining the causes of energy loss by node. The algorithm was able to effectively minimize the energy used by every sensor node during clustering. A strategy for computing the quality of node was designed, and CHs selection by node quality was carried out such that energy utilization is uniformly distributed across the WSN. The proposed solution based on node clustering routing algorithm, was shown to vigorously alter the communication radii of CHs and overall nodes, thereby prolonging the lifecycle of the WSN under UPIoT.

Prasad et al (2016) employed Multi-Objective Particle Swarm Optimization (MOPSO)-Differential Evolution (DE) (MOPSO-DE) method for clustering optimization in WSN. Analysis was carried out on various WSN configurations and their routing protocols for energy consumption reduction as well as network life extension. With WSN architecture that relied on clustering technique observed to be more efficient in energy consumption capability, MOPSO-DE was proposed. Since clustering divides networks into inter-related clusters in such a way that each cluster has several sensor nodes with a CH at its head, and the fact that information gathering by sensor is transmitted to data processing centres through CH hierarchy in clustered environments, MOPSO-DE was used to optimize clustering in WSN. The results obtained showed that by packet delivery ratio and the percentage of nodes that remain alive improved while end-to-end delay was reduced. Though there was record reduction of end-to-end delay, the proposed solution did not provide effective delay reduction.

Cong and Shujuan (2016) studied routing algorithm for delay tolerance in WSN. The study proposed a routing algorithm called Multi-Group (MG), which is based on LEACH (MG-LEACH), was used in redundant deployed sensor nodes for network lifetime improvement. The effectiveness of the proposed scheme was evaluated via simulation in MATLAB environment. The result showed that the proposed protocol improved the lifetime of the network by close to 90%.

Chehri and Mouftah (2012) examined the route optimization problem for WSN from the perspective of energy management. The study proposed a routing algorithm using an optimization technique based on adaptive modulation and power control. The objective was to adapt all routes in WSN to deliver data from the node to the sink with the optimum energy performance. The optimization method was evaluated according to certain quality of service (QoS) requirements in terms of total end-to-end delay time and bit error rate. The simulation result indicated that the proposed routing algorithm reduced the route energy consumed by approximately 49% provided the optimal transmission and modulation order was selected by the node.

Nuray et al (2018) proposed a multi-hop energy efficient technique for WSN. While taking distance and residual energy into account, the proposed scheme considers which node has high residual energy and minimum distance to the sink as a cost function in selecting the primary node or forwarder. Energy utilization among sensor nodes is balanced by the residual energy parameters whereas delivery of packet to base station (BS) is guaranteed by distance parameter. Energy consumption comparison was carried out for ZigBee, Bluetooth Low-Energy (BLE), and ANT sensor nodes. Results obtained through simulations indicated that the proposed solution reduces the lifetime of network such that nodes remain active for longer period, for the same transmission power, radio frequency, packet size and data for the three set of sensor nodes, with ZigBee utilizing less energy and provide longer lifetime of network.

Liu et al (2019) proposed a LEACH routing model as application-specific protocol architecture for WSNs. The study reported that without considering cluster heads (CHs) distribution in the rotation basis, energy utilization of WSN will be increased by the LEACH. The proposed scheme is novel modified routing protocol called improved energy-efficient LEACH (IEE-LEACH) algorithm that takes into consideration the residual node energy and the average energy of the networks. For suitable performance to be achieved in terms sensor energy consumption reduction, IEE-LEACH accounted for the optimal CHs numbers and prevented the nodes that are nearer to the base station (BS) to link the cluster formation. The IEE-LEACH protocol employed a novel threshold for electing CHs among sensor nodes; uses single hop, multi-hop, and hybrid communications to further enhanced the energy performance of WSNs. Simulation results showed that IEE-LEACH protocol generally reduced the communication cost and significantly improved the lifetime of network.

The fact that the main challenge with sensor nodes is that life of the network shortens as the operation runs due to fast receding of energy of each battery at the sensor node. This has been the problem with WSNs and several energy efficient routing protocols have been proposed to address it so as to preserve the lifetime of the network. For this reason, routing algorithms in WSN are mainly aimed at accomplishing power conservation. Majority of the recent literature surveyed have shown so many protocols that largely designed to reduce energy consumption in sensor networks. A variety of methods can be found in hierarchical routing protocol. The basic concept of this approach is based on the fact that nodes are clustered so that cluster heads (CHs) can do some aggregation and a compression of data so as to save energy thus extending the longevity of WSN. It is also observed that most of the proposed technique used cluster heads (CHs). In this work, a hierarchical cluster-base routing technique that is appropriate for environment sensing or monitoring is proposed for places such as poultry farm environment where air pollution is a problem. The proposed routing technique is a modified low energy adaptive cluster head (MLEACH) protocol which uses a head-set as an alternative to a CH. That is to say, during every election phase, a head-set comprising many cluster sensor nodes is selected instead of a CH. For a head-set, the members are accountable for sending packets to distance or remote base station (BS). The proposed technique is such that a member of the head-set is active at a time while the other members of the head-set are in sleep mode. This way, energy used at a time is minimized and network lifetime preserved.

## III. METHODOLOGY

This section focuses on the technique developed to realize the objectives of this work. It starts with the system energy model of a sensor node, hierarchical routing technique, network topology of environmental sensing wireless sensor network (WSN), and energy efficiency management model. The block diagram of the proposed system with head-set capability is shown in Fig. 1.

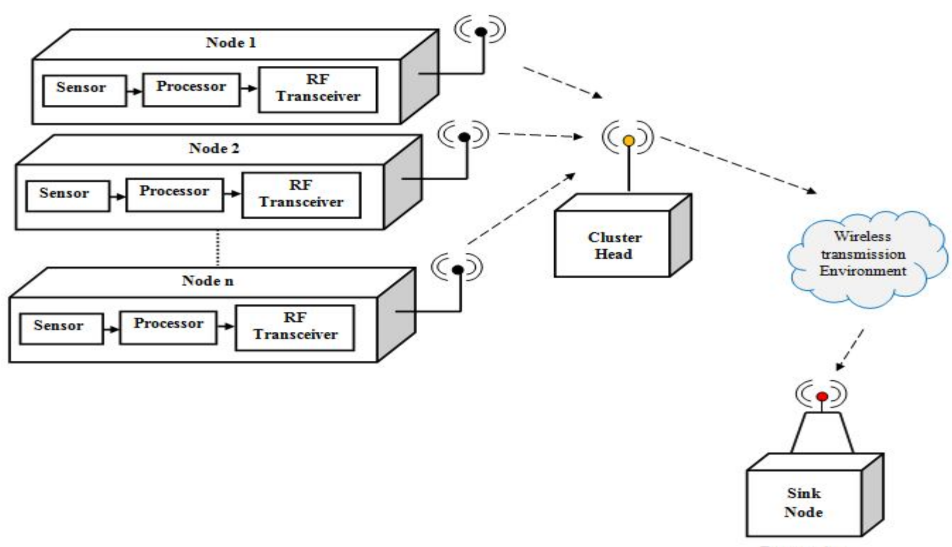


Fig. 1 Block diagram of proposed system

### 3.1 Energy Model of Sensor Node

Sensor node is the component that is responsible for the energy draining during the operation of WSN. The energy model of sensor node in a wireless communication can be represented using a radio model given by (Heinzelman et al., 2000). The radio model be of first order type provides an evaluation of energy used by sensor node when message or packet is being sent or received at every cycle. The minimum energy needed to reach the expected recipient can be guaranteed by the radio since it has a power control to use for this purpose. Fig. 2 is the block diagram of a first order radio communication model (Heinzelman et al., 2000).

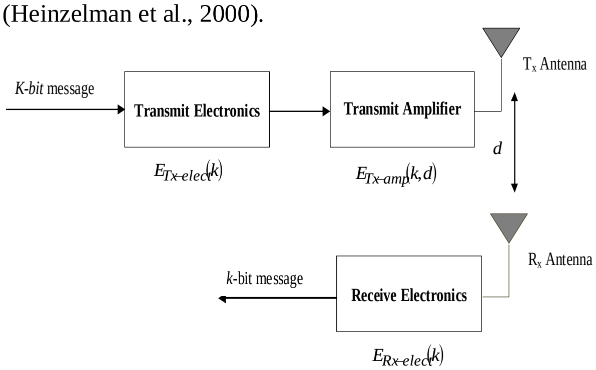


Fig. 2 Block diagram of first order radio communication model

The mathematical expressions regarding the energy consumed when *k*-bit of message (or packet) is transmitted through a distance *d* is given by:

$$E_{Tx} = E_{elect} \times k + E_{amp} \times \left(k \times d^2\right) \quad (1)$$

While Eq. (1) serves well for energy dissipated for over a shorter transmission distance such as within clusters. However, for transmission over a longer distance, such as from a cluster head to the base station, Eq. (1) can be expressed by:

$$E_{Tx} = E_{elect} \times k + E_{amp} \times \left(k \times d^4\right) \quad (2)$$

Similarly, the energy utilized with respect to receive of message is given by:

$$E_{Rx} = E_{elect} \times k \quad (3)$$

However, including the cost of beam forming into Eq. (3) gives:

$$E_{Rx} = E_{elect} \times k + E_{bf} \times k \quad (4)$$

where: $E_{Tx}$ is the energy consumed per *k*-bit message at transmitter, $E_{Rx}$ is the energy consumed per *k*-bit message at receiver, $E_{amp}$ transmit amplifier coefficient (or amplification factor), $E_{elect} = E_{Tx-elect} = E_{Rx-elect}$ is the energy consumed by the transmit electronic or the receive electronic, $k$ is the number of bits transmitted, and $d$ is the distance between a sensor node and its cluster head (CH) or distance between a CH and another CH nearer to the base station (BS) or simply the distance between CH and BS.

The inclusion of the cost of beam forming strategy reduces energy consumption (Hussain and Matin, 2005). The concept of the square of transmission distance ($d^2$) is based on the fact that the energy utilized by a transmit amplifier is proportional to the square of distance between the nodes ($r^2$).

3.2 Propoposed Routing Protocol

This section presents the proposed solution for energy consumption optimization in wireless sensor network deployed for automation process sensing for improved quality of service (QoS) management. The solution is a hierarchical cluster-based routing technique which is based on the fact that the energy used for long range transmission of message (or packet) is very much greater than the energy required for sending message over short range. That is more energy will be consumed to send a message to a distant node than to a closer node. However, the Low Energy Adaptive Cluster Head (LEACH) technique is modified in this work by extension such that a head-set is used as a substitute for cluster head (CH). This way, a head-set that comprises many nodes is selected during each election instead of a CH. The sending of messages to distant base station (BS) is carried out by members of a head-set. The transmission operation from all the head-set members to BS is equally distributed. The flowchart for the routing process is shown in Fig. 3.

Given $n$ number of nodes, with $q$ optimal number of clusters, a set of $t$ associates is chosen by CH of each cluster. Every cluster has $n/q$ nodes, for clusters that are uniformly distributed. Hence, considering Eq. (1) and (4), the expression for the energy consumed by a CH is given by:

$$E_{CH-elect} = \left[k \times E_{elect} + k \times E_{amp} \times d^2\right] + \left[\left(\frac{n}{q} - 1\right) \times k\left(E_{elect} + E_{bf}\right)\right] \quad (5)$$

In Eq. (5), the energy utilized by the CH in transmitting advertisement message to sensor nodes is represented by the first part, while the second part stands for the energy consumed in receiving messages from nodes of the same cluster. The expression $(n/q - 1)$ is the number of received messages from the sensor nodes of the same cluster.

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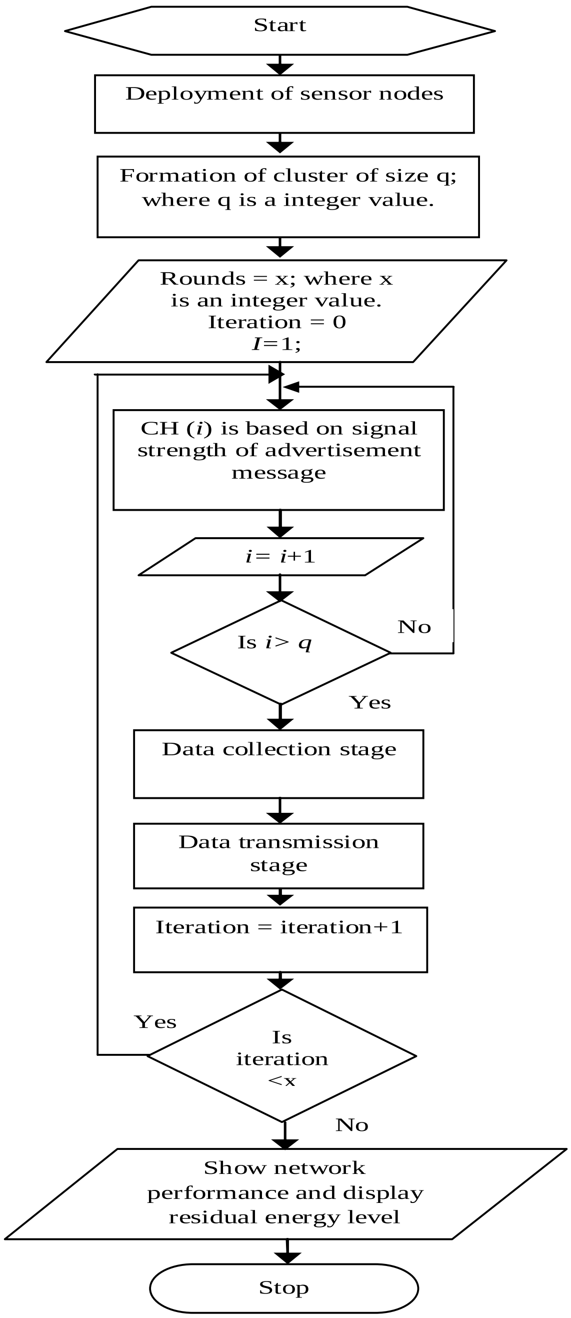


Fig. 3 Flowchart of the energy level routing process

Also, energy used by sensor nodes that are non-cluster head (n-CH) can be determined considering Eq. (1) and (4) and it is given by:

$$E_{non-CH_{-elect}} = q\left[kE_{elect} + E_{amp}\right] + k\left[E_{elect} + E_{amp} \times d^2\right] \quad (6)$$

As advertisement broadcast messages are sent from $q$ CHs, the sensor nodes expend a certain amount of energy to receive these messages. This energy consumed to receive messages is represented by the first part of Eq. (6), while the second part resents the energy expended by the sensor node to transmit the decision to the corresponding CH.

At the data transfer stage, messages are transmitted by the nodes to their individual CH. Then aggregated messages are transmitted to a distant BS by the CHs. The energy expended by a CH can be determined using Eq. (2) and (4) and it is given by:

$$E_{CH/frame} = \left[k \times E_{elect} + k \times E_{amp} \times d^4\right] + \left[\left(\frac{n}{q} - b\right) \times \left(k \times E_{elect} + k \times E_{bf}\right)\right] \quad (7)$$

where $b$ is the number of nodes in a head-set.
The energy utilized in transmitting message to distant base station by a CH is represented by the first part of Eq. (7), while the second part represents the energy consumed in receiving message from the remaining $(n/q - b)$ sensor nodes, which are regarded as non CH nodes.
For non CH node transmitting data to a CH, the energy consumed is given by:

$$E_{nonCH/frame} = k \times E_{elect} + k \times E_{amp} \times d^2 \quad (8)$$

For ring clusters with uniformly distributed sensor nodes and a network of diameter D, the average value of $d^2$ is expressed as (Hussain and Matin, 2005):

$$avg\left[d^2\right] = \left(\frac{D^2}{2\pi q}\right) \quad (9)$$

With $n$ number of nodes and $q$ clusters, there are $b$ number of nodes elected per cluster. Therefore, in every iteration, there are $bq$ nodes elected as head-sets members. There are $(n/bq)$ number of iterations required for all $n$ nodes to be elected. This represents the number of iterations per round. The initial energy, $E_o$ of a sensor node is assumed to be adequate for no less than a round and is given by:

$$E_o = \frac{1}{b}\left[\begin{array}{l}\left(E_{CH-elect} + E_{nonCH-elect}\right) + \\ \left(z_1 N_f \times E_{CH/frame} + z_2 N_f \times E_{nonCH/frame}\right)\end{array}\right] \quad (10)$$

Where $N_f$ is the frame transmitted in each iteration and The fractions are $z_1$ and $z_2$ for CH and non CH and are given by:

$$z_1 = \left(\frac{1}{\frac{n}{q} - b + 1}\right)\frac{1}{q} = \left(\frac{1}{n - bq + q}\right) \quad (11)$$

$$z_2 = \left(\frac{\frac{n}{q} - b}{\frac{n}{q} - b + 1}\right)\frac{1}{q} = \left(\frac{n - bq}{n - bq + q}\right)\frac{1}{q} \quad (12)$$

The minimum number of cluster to optimize energy of the WSN is given by:

$$X = D\sqrt{\frac{n}{2\pi}}\left(\frac{E_{amp}}{E_{amp}d^4 + (1-2b)E_{elect} - bE_{bf}}\right)^{\frac{1}{2}} \quad (13)$$

Since there are $n$ nodes and $bq$ head-set such that for $n/bq$ iterations per round, the time for a round is given by:

$$t_{rnd} = t_{iter} \times \left(\frac{n}{bq}\right) = \frac{n}{bq} \times \left(\frac{n}{q} - b + 1\right) \times N_f \times R_{data}^{-1}$$

3.3 Simulation Parameters

The parameters as shown in Table 3.1 is used for the purpose of simulation in this work were obtained from the study involving environmental monitoring of gas distribution pipelines network using WSN in Abbas et al. (2021) and were modified by including number of data frame.

Table 1 Simulation parameters

| Parameters | Symbol | Value/units |
|---|---|---|
| Total nodes | n | 1480 |
| Total area of the field | A | 1,798,262 $m^2$ |
| Average distance between nodes | d | 512 m |
| Transmitted energy per bit | $E_e$ | $9.229\times10^{-6}$ J/bit |
| Receiver energy per bit | $E_e$ | $9.229\times10^{-6}$ J/bit |
| Data aggregation energy per bit | $E_{bf}$ | $5\times10^{-9}$ J/bit |
| Energy consumed by transmit amplifier to transmit at a shorter distance | $E_s$ | $10\times10^{-12}$ J/bit |
| Energy consumed by transmit amplifier to transmit at a longer distance | $E_l$ | $0.0013\times10^{-12}$ J/bit |
| Size of packet | $l$ | 4000 bit |
| Number of transmitter frame/iteration | $N_f$ | 10,000 |

## IV. RESULTS AND DISCUSSION

The results from the simulations conducted with the routing algorithm proposed in this work for optimizing energy consumption in wireless sensor network (WSN) deployed to carry out continuous environment monitoring are presented. Simulations were conducted for different scenarios as presented in the following sections.

### 4.1 Results

In this subsection, simulations were carried out to determine the optimum number of clusters that is required to efficiently optimize the level of energy used by WSN. The results are presented in terms of number of clusters against size of head-set as shown in Fig. 4 and distance of cluster from base station in Fig. 5.

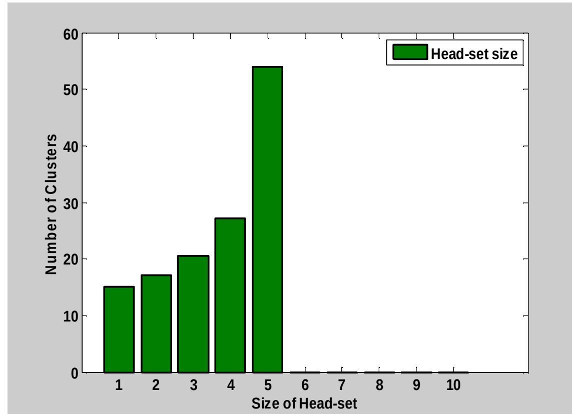


Fig. 4 Plot of maximum number of clusters against size of head-set

Fig. 4 shows the simulation plot for varying number of clusters against size of head-set such that the average distance between nodes is 512 m and the number of nodes is 1480. As shown in the graph, a variation between 1 and 5 is possible for the size of the head-set. The plot shows that the maximum head-set for the WSN is 5, and the corresponding optimum number of clusters is 54.

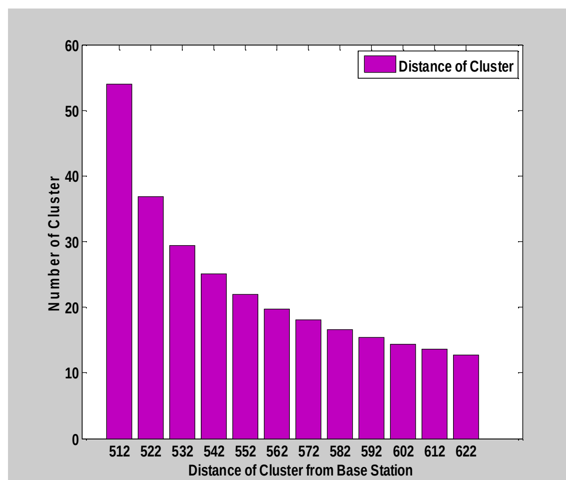


Fig. 5 Plot of number of clusters against distance from base station

The variation in maximum number of clusters against distance from base station is shown in Fig. 5. The graph shows that increase in the distance from base station results in decreased number of clusters. This is because when the base station distance is increased, more energy is consumed to perform distance transmission. Hence, at any given time the maximum number of clusters certainly drops as distance of transmission to base station increases, which can be attributed to some nodes in the network die due to energy sap. Also, an obvious indication of accuracy of the algorithm is that the distance between nodes (512 m) matches the optimum number of clusters, such that as nodes move further apart measured from the base station the ability to form cluster drops since this will require more energy to communicate within the network.

### 4.2 Analysis of Energy

In this subsection, the energy consumed for a given number of packet size and different sizes of head-set (m) with regard to varying number of clusters and size of network diameter are examined. Fig.6 to Fig. 10 show residual energy per number of clusters and energy consumed per round against number of clusters. Table 2 presents the numerical performance of all graphs shown in Fig. 6 to Fig. 10. Figure 11 shows energy consumed per round against number of clusters

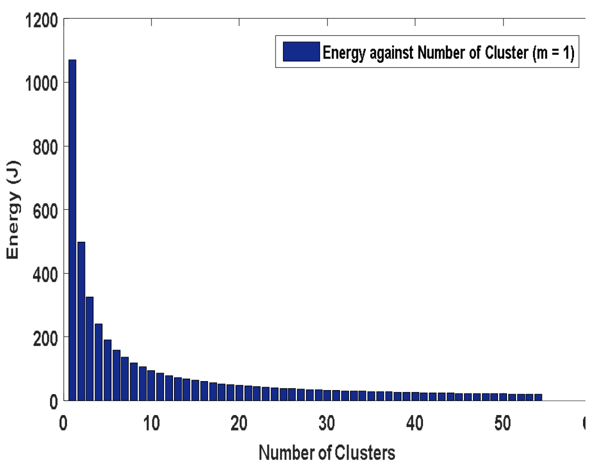


Fig. 6 Energy per number of clusters (head-set size = 1)

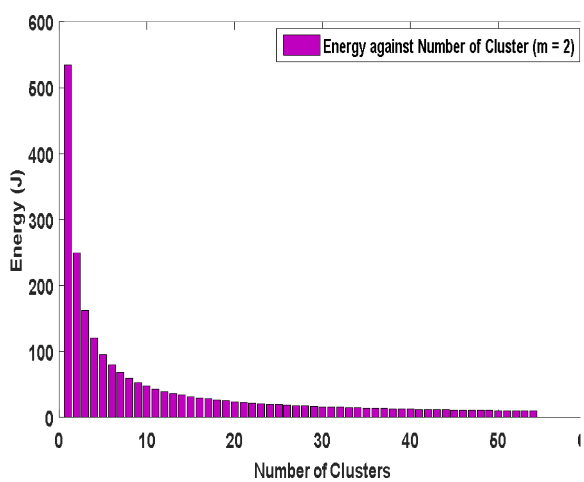


Fig. 7 Energy per number of clusters (head-set size = 2)

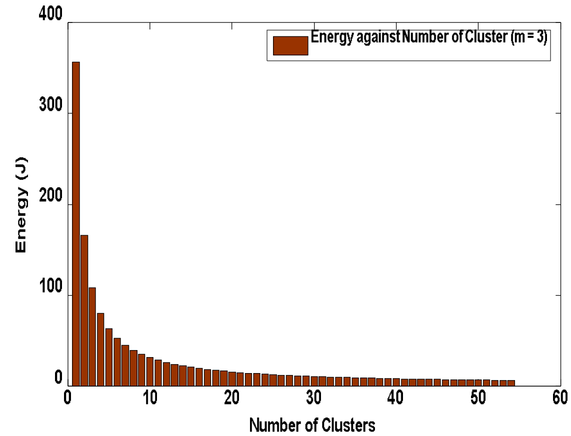


Fig. 8 Energy per number of clusters (head-set size = 3)

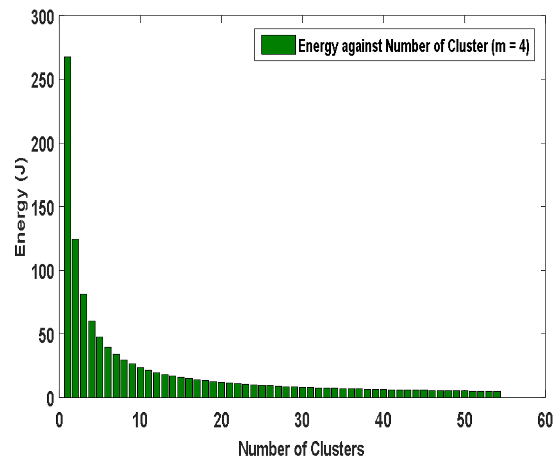


Fig. 9 Energy per number of clusters (head-set size = 4)

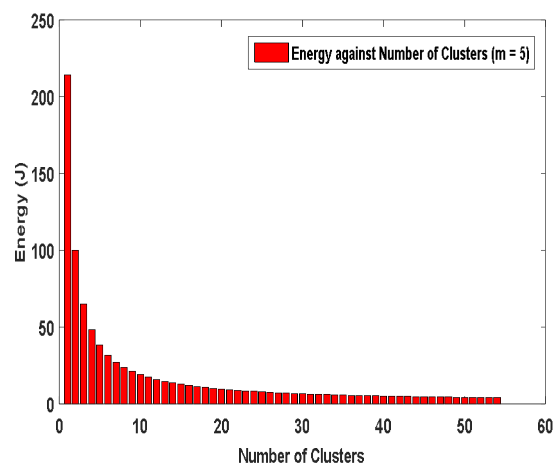


Fig. 10 Energy per number of clusters (head-set size = 5)

Fig. 6 to Fig. 10 are the simulation plots of residual energy with respect to cluster number. The graphs show that the residual energy reduces as the number of clusters increases. It also indicates that the optimum range of cluster to optimize the energy of the WSN is between 20 and 54. This is because from cluster number of 20 to 54, the energy consumption by the network is approximately the same in all cases with respect to size of the head-set. However, the exact optimum number of clusters is 54. Furthermore, the energy consumption reduces as the size of the head-set becomes higher.

Table 4.1 Performance of energy consumption against number of clusters for varying head-set size
It can be seen from Table 2 that energy consumption reduces as the head-set size increases. Thus, to save energy in the network and prolong the life of sensor nodes a maximum of 5 head-set are to be formed from 54 clusters.

Table 2 Performance of energy consumption

| Size of Head-set (m) | Number of Clusters | Energy Consumption (J) |
|---|---|---|
| 1 | 54 | 19.8 |
| 2 | 54 | 9.9 |
| 3 | 54 | 6.59 |
| 4 | 54 | 4.94 |
| 5 | 54 | 3.94 |

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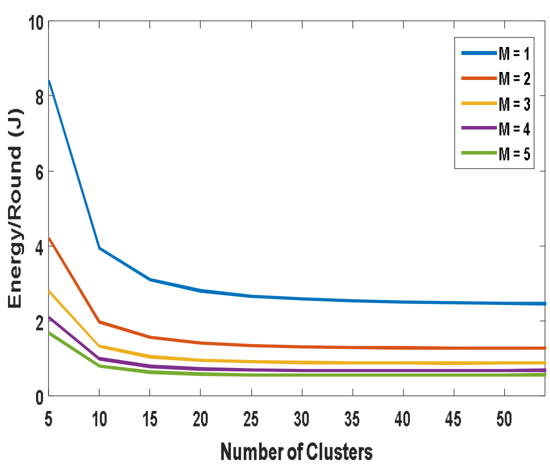

Fig. 11 Energy per round against number of clusters

The simulation curves in Fig. 11 illustrate the variation of consumed energy per round by each node with respect to number of clusters. The plots show that energy consumed per round by each sensor node in cluster is reduced as the number of clusters are increased. For the simulated WSN of 1480 nodes, the results show that optimum number of clusters is 54. Looking at the figure, when the number of clusters is 10 below optimum range, the energy consumed per round by each sensor data making up a cluster is high. But as the number of cluster increases, the energy consumed per round reduces.

## V. CONCLUSION

This paper has presented application of energy efficient cluster based routing in wireless sensor network for environment monitoring. The results of the simulation analysis performed for the modified energy efficient cluster based routing techniques indicated that by increasing the number of sensors in a head-set can result in systematic reduction in energy consumption in WSN. The modified routing scheme resulted in satisfactorily energy conservation of WSN. The MATLAB based simulations have shown that the number of clusters in the network was optimized, which invariably resulted in the minimization of energy consumed.

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