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EDITORIAL PREFACE

This special issue is focused on defining new problems and developing novel techniques for data management and network control issues in wireless and mobile networks. With the emergence of data-intensive wireless networks such as wireless sensor networks and data-centric mobile applications such as location-based services, the traditional boundaries between the disciplines of wireless networking and data management are blurring.

This special issue provides a venue for researchers to present new ideas with impact on two communities –wireless networks and databases. Researchers and practitioners working in these areas are expected to take this opportunity to discuss and express their views on the current trends, challenges, and state of the art solutions addressing various issues in wireless networks. This special issue solicits papers from two main categories: (1) papers that consider the data collection, transmission, storage, publishing, and sharing in wireless networks broadly defined, e.g., MANET, satellite, cellular, vehicular, ad hoc, cognitive, as well as sensor networks, and (2) papers that use data and network analytics techniques to address network control problems in wireless networks.

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Data Management and Network Control in Wireless Networks (SICN)

TABLE OF CONTENTS

April 2011

Pages

Fuzzy Optimization for Mobile Ad Hoc Networks: a Bottom-up Cross-layer Approach

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Abstract

In this paper, we introduce a new method for cross-layer design in mobile ad hoc networks. We use fuzzy logic system (FLS) to coordinate physical layer, data-link layer and application layer for cross-layer design. Ground speed, average delay and packets successful transmission ratio are selected as antecedents for the FLS. The output of FLS provides adjusting factors for the AMC (Adaptive Modulation and Coding), transmission power, retransmission times and rate control decision. Simulation results show that our cross-layer design can reduce the average delay, increase the throughput and extend the network lifetime. The network performance parameters could also keep stable after the cross-layer optimization.

Keywords: Cross-layer Design, Fuzzy Logic System, Ad Hoc, Network Performance, Mobile.

1. INTRODUCTION

The demand for energy efficiency and Quality of Service (QoS) in mobile ad hoc networks is growing in a rapid speed. To enhance the energy efficiency and QoS, we consider the combination of physical layer, data-link layer and application layer together, a cross-layer approach. A strict layered design is not flexible enough to cope with the dynamics of the mobile ad hoc networks [1]. Cross-layer design could introduce the layer interdependencies to optimized overall network performance. The general methodology of cross-layer design is to maintain the layered architecture, capture the important information that influence other layers, exchange the information between layers and implement adaptive protocols and algorithms at each layer to optimize the performance.

Lots of previous works have focused on cross-layer design for QoS provision. Liu [2] combine the AMC at physical layer and ARQ at the data link layer. Ahn [3] use the info from MAC layer to do rate control at network layer for supporting real-time and best effort traffic. Akan [4] propose a new adaptive transport layer suite including adaptive transport protocol and adaptive rate control protocol based on the lower layer information.

Some works related to energy efficiency have been reported. Banbos proposes a power-controlled multiple access schemes in [5]. This protocol reveals the trade-off of the transmitter power cost and backlog/delay cost in power control schemes. Zhu [6] proposes a minimum energy routing scheme, which consider the energy consumption for data packets as well as control packets of routing and multiple access. In [7], Sichitiu proposes a cross-layer scheduling method. Through combining network layer and MAC layer, a deterministic, schedule-based energy conservation scheme is proposed. This scheme drives its power efficiency from eliminating idle listening and collisions.

However, cross-layer design can produce unintended interactions among protocols, such as an adaptation loops. It is hard to characterize the interaction at different layers and joint optimization across layers may lead to complex algorithm.

Our algorithm is quite different from all the previous works. We propose to use the Fuzzy Logic System (FLS) in the cross-layer design. We define a coherent time, a certain period of time. During this coherent time, the AMC (Adaptive Modulation and Coding), transmission power, retransmission times and rate control decision are used for packet transmission. After this time, we adaptively adjust these parameters by FLS again basing on current ground speed, average delay and the packets successful transmission ratio.

By applying the FLS mechanism to the cross-layer, a better QOS provision and energy efficiency are achieved.

The remainder of this paper is structured as following. In section 2, we introduce the preliminaries. In section 3, we make a overview of fuzzy logic systems. In section 4, we apply the FLS into the cross-layer design. Simulation results and discussions are presented in section 5. In section 6, we conclude the paper.

2. PRELIMINARIES

1. IEEE 802.11a OFDM PHY

The physical layer is the interface between the wireless medium and the MAC [8]. The principle of OFDM is to divide a high-speed binary signal to be transmitted over a number of low data-rate subcarriers. A key feature of the IEEE 802.11a PHY is to provide 8 PHY modes with different modulation schemes and coding rates, making the idea of link adaptation feasible and important, as listed in Table 1. BPSK, QPSK, 16-QAM and 64-QAM are the supported modulation schemes. The OFDM provides a data transmission rates from 6 to 54MBPS. The higher code rates of 2/3 and 3/4 are obtained by puncturing the original rate 1/2 code.

Mode	Modulation	Code Rate	Data Rate	Bps
1	BPSK	1/2	6Mbps	3
2	BPSK	3/4	9Mbps	4.5
3	QPSK	1/2	12Mbps	6
4	QPSK	3/4	18Mbps	9
5	16-QAM	1/2	24Mbps	12
6	16-QAM	3/4	36Mbps	18
7	64-QAM	2/3	48Mbps	24
8	64-QAM	3/4	54Mbps	27

TABLE 1: Eight PHY Modes of the IEEE802.11A PHY

2. IEEE 802.11 MAC

The 802.11 MAC uses Carrier-Sense Multiple Access with Collision Avoidance (CSMA/CA) to achieve automatic medium sharing between compatible stations. In CSMA/CA, a station senses the wireless medium to determine if it is idle before it starts transmission. If the medium appears to be idle, the transmission may proceed, else the station will wait until the end of the in-progress transmission. A station will ensure that the medium has been idle for the specified inter-frame interval before attempting to transmit.

Besides carrier sense and RTS/CTS mechanism, an acknowledgment (ACK) frame will be sent by the receiver upon successful reception of a data frame. Only after receiving an ACK frame correctly, the transmitter assumes successful delivery of the corresponding data frame. The sequence for a data transmission is: RTS-CTS-DATA-ACK.

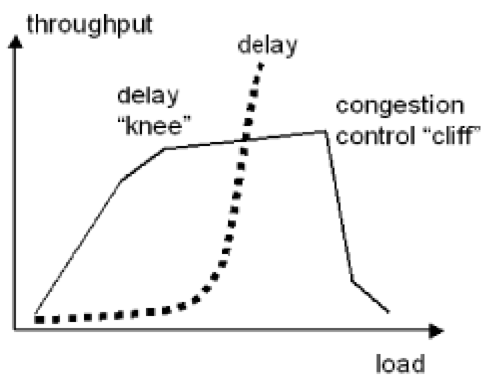
A mobile node will retransmit the data packet when finding failing transmission. Retransmission of a signal packet can achieve a certain probability of delivery. There is a relationship between the probability of delivery p and retransmission times n:

$$n = 1.45 \ln \frac{1}{1-p}$$

The IEEE 802.11 standard requires that the transmitter's MAC discard a data frame after certain number of unsuccessful transmission attempts. According to the requirement of probability of delivery, we choose the minimum number of retransmission. The advantage is we can save energy through avoiding unnecessary retransmission, and ensure probability of delivery.

3. Application Layer

Traffic in application layer is divides into two classes: real-time and best-effort. Each node in the mobile ad hoc networks independently regulates best effort traffic. It is proposed to control the rate of the best-effort traffic to avoid excessive delays of the real-time traffic by using local per-hop delays as a feedback to local rate controller [3]. The general behavior of a congestion-controlled system is illustrated in Fig.1. The control algorithm ensures that the system operates around, or preferably close to the "cliff", which ensure maximum system throughput, but at the cost of large average packets delay. The control algorithm discussed, one the other hand, keep the system at the delay "knee" where the system throughput is almost the same as the at the cliff, but the buffers are significantly less loaded, so the delay is close the minimum. Due to loss typically happens at the cliff, while delays start to increase at the knee, we use the per-hop MAC delay as a feedback for local control instead of the packet loss.



Error! Not a valid link.

FIGURE 1: General Behavior of a Congestion-controlled System

When MAC layer acquires access to the channel, the nodes will exchange the RTS-CTS-DATA-ACK packets. After the transmitters receive an ACK packet, a packet is transmitted successfully. The packet delay represents the time it took to send the packet between the transmitter and the next-hop receiver, including the deferred time and the time to fully acknowledge the packet. In this paper, we assume that there will be always best-effort traffic present that can be locally and rapidly rate controlled in an independent manner at each node to yield necessary low delays and stable throughputs.

4. Energy

A mobile node consumes significant energy when it transmits or receives a packet. But we will not consider the energy consumed when the mobile node is idle.

The distances between two nodes are variable in the mobile ad hoc networks and the power loss model is used. To send the packet, the sender consumes [9],

$$P_{tx} = P_{elec} + \varepsilon_{fs} \cdot d^2$$

and to receive the packet, the receiver consumes,

$$P_{rx} = P_{elec}$$

where P_{elec} represents the power that is necessary for digital processing, modulation, and ε_{fs} represents the power dissipated in the amplifier for the free space distance d transmission.

A joint characteristic of most application scenarios of mobile ad hoc networks is that mobile nodes only have a limited energy supply which might not even be rechargeable, hence they have to be energy-efficient as possible. Transmitter power control allows interfering communication links sharing the same channel to achieve their required QoS levels, minimizing the needed power, mitigating the channel interference, and maximizing the network user/link capacity.

5. Delay

The packet transmission delay between the mobile nodes includes three parts: the wireless channel transmission delay, the Physical/MAC layer transmission delay, and the queuing delay[10]

Defining D as the distance between two nodes and C as the light speed, the wireless channel transmission delay as:

$$Delay_{-ch} = \frac{D}{C}$$

The Physical/MAC layer transmission delay will be decided by interaction of the transmitter and the receive channel, the node density and the node traffic intensity etc.

The queuing delay is decided by the mobile node I/O system-processing rate, the subqueue length in the node.

In order to make the system ``stable'', the rate at which node transfers packets intended for its destination must satisfy all nodes that the queuing lengths will not be infinite and the average delays will be bounded

6. Node Mobility and Channel Fading

Mobility of a mobile node generates a doppler shift, which is a key parameter of fading channel. The doppler shift is

$$f_d = \frac{v}{c} f_c$$

Where v is the ground speed of a mobile node, c is the speed of light ($3\times10^8 m/s$), and f_c is the carrier. In our simulation, we used the carrier is 6GHz. For reference, if a node moves with speed 10 m/s, the doppler shift is 200Hz.

We model channel fading in ad hoc networks as Rician fading. Rician fading occurs when there is a strong specular (direct path or line of sight component) signal in addition to the scatter (multipath) components. For example, in communication between two infraed sensors, there exists a direct path. The channel gain,

$$g(t) = g_I(t) + jg_Q(t)$$

can be treated as a wide-sense stationary complex Gaussian random process, and $g_I(t)$ and $g_Q(t)$ are Gaussian random processes with non-zero means $m_I(t)$ and $m_Q(t)$ respectively; and they have same variance σ_g^2, then the magnitude of the received complex envelop has a Rician distribution,

$$p_\alpha(x) = \frac{x}{\sigma^2}\exp\{-\frac{x^2+s^2}{2\sigma^2}\}I_0(\frac{xs}{\sigma^2}) \quad x \ge 0$$

Where $s^2 = m_I^2(t) + m_Q^2(t)$ and $I_0(\cdot)$ is the zero order modified Bessel function. This kind of channel is known as Rician fading channel. A Rician channel is characterized by two parameters, Rician factor K, which is the ratio of the direct path power to that of the multipath, i.e., $K = s^2/2\sigma^2$, and the Doppler spread (or single-sided fading bandwidth) f_d . We simulate the Rician fading using a direct path added by a Rayleigh fading generator. The Rayleigh fade generator is based on Jakes' model[11] in which an ensemble of sinusoidal waveforms are added together to simulate the coherent sum of scattered rays with Doppler spread f_d arriving from different directions to the receiver. The amplitude of the Rayleigh fade generator is controlled by the Rician factor K. BPSK, QPSK, 16-QAM and 64-QAM are the supported modulation schemes for IEEE 802.11a OFDM physical layer. We can show their performance curves with Rician fading in Fig. 2.

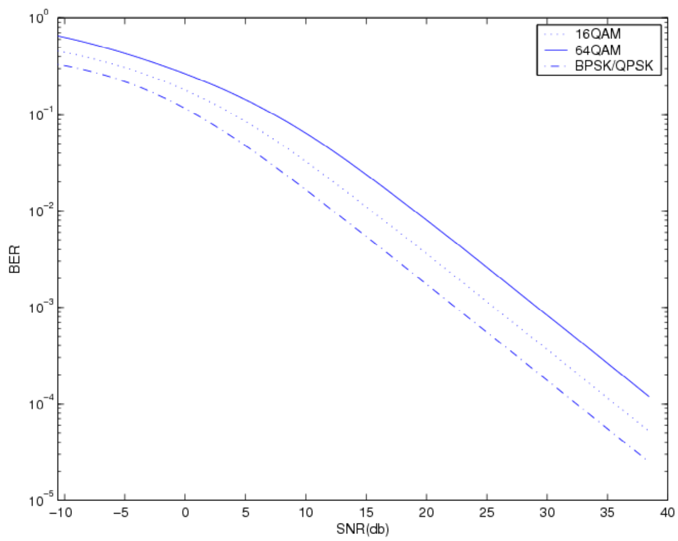


FIGURE 2: Modulation Curves with Rician Fading

After we introduce the channel coding and node mobility into the modulation schemes, the modulation curves will change a lot. For the same SNR, channel coding will improve the BER performance and the mobility will degrade the BER performance.

7. One-step Markov Path Model

The mobile nodes are roaming independently with variable ground speed. The mobility model is called one-step Markov path model [12]. The probability of moving in the same direction as the previous move is higher than other directions in this model, which means this model has memory. Fig.3 shows the probability of the six directions.

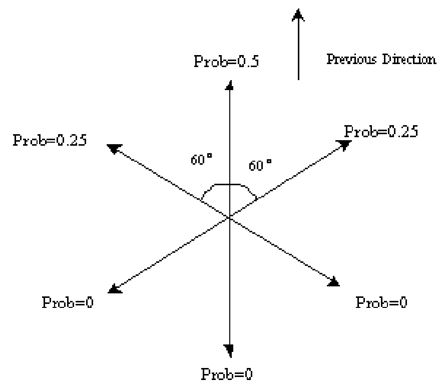


FIGURE 3: One-step Markov Path Model

3. OVERVIEW OF FUZZY LOGIC SYSTEMS

Fig. 4 shows the structure of a fuzzy logic system (FLS).

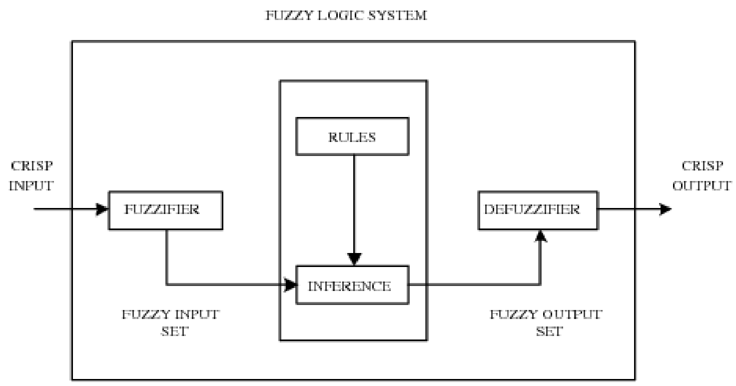


FIGURE 4: The structure of a fuzzy logic system

When an input is applied to a FLS, the inference engine computes the output set corresponding to each rule. The defuzzifer then computes a crisp output from these rule output sets [13].

Consider a p-input 1-output FLS, using singleton fuzzification center-of-sets, defuzzification[14] and ``IF-THEN" rules of the form[15].

R^l: IF x_1 is F_1^l and x_2 is F_2^l and … and x_p is F_p^l, THEN y is G^l.

Assuming singleton fuzzification, when an input $X^{'} = \{x_1^{'}, \cdots, x_p^{'}\}$ is applied, the degree of firing corresponding to the lth rule is computed as

$$\mu_{F_1^l}(x_1^{'}) * \mu_{F_2^l}(x_2^{'}) * \cdots * \mu_{F_p^{l'}}(x_p^{'}) = \Gamma_{i=1}^{p} \mu_{F_i^l}(x_i^{'})$$

where $*$ and both indicate the chosen t-norm. There are many kinds of defuzzifiers. In this paper, we focus, for illustrative purposes, on the center-of-sets defuzzifier. It computes a crisp output for the FLS by first computing the centroid, c_G^l, of every consequent set G^l, and, then computing a weighted average of these centroids. The weight corresponding to the lth rule consequent centroid is the degree of firing associated with the lth rule, $\Gamma_{i=1}^{p} \mu F_i^l(x_i^{'})$, so that

$$y_{\cos}(x') = \frac{\Sigma_{l=1}^{M} c_{G^l} \Gamma_{i=1}^{p} \mu_{F_i^l}(x_i^l)}{\Sigma_{i=1}^{M} \Gamma_{i=1}^{p} \mu_{F_i^l}(x_i')}$$

where M is the number of rules in the FLS.

4. FUZZY APPLICATION FOR CROSS-LAYER DESIGN

AMC, transmission power, retransmission times and rate control decision will manage the energy consumption and QoS provision. How to choose a proper adjusting factor for these parameters will determine the wireless ad hoc networks performance.

We collect the knowledge for adjusting factor selection based on the following three antecedents:

1) Antecedent 1. Ground speed.
2) Antecedent 2. Average delay.
3) Antecedent 3. Packets successful transmission ratio.

The linguistic variables used to represent the Ground speed, average delay and packets successful transmission ratio were divided into three levels: *low, moderate, and high.* The consequents -- the adjusting factor for the AMC, transmission power, retransmission times and rate control decision were divided into 9 levels, *decrease one, decrease two, decrease three, decrease four, unchanged, increase one, increase two, increase three and increase four*. Fig.5 shows the FLS application for the cross-layer design.

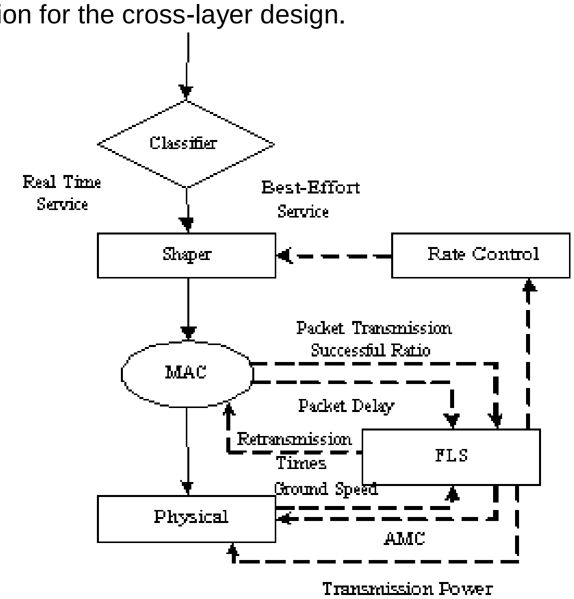


FIGURE 5: Cross-layer Design Algorithm

We designed questions such as: IF *ground speed* is *low*, *average delay* is *low* and *packets successful transmission ratio* is *high*, THEN *the adjusting factor* is ________

So we need to set up $3^3 = 27$ (because every antecedent has 3 fuzzy sub-sets, and there are 3 antecedents) rules for this FLS. We summarized these rules in Table 2. Antecedent1 is its ground speed, Antecedent 2 is its average delay, and Antecedent 3 is its packet transmission ratio. Consequent 1 is adjusting factor for retransmission times, Consequents is the adjusting factor for AMC, Consequent 3 is adjusting factor for transmission power, and Consequent 4 is adjusting factor for rate control decision.

R #	A 1	A 2	A 3	C1	C2	C3	C4
1	low	low	low	Increase two	Decrease two	unchanged	unchanged
2	low	low	moderate	unchanged	unchanged	Decrease two	Decrease two
3	low	low	high	Decrease two	Increase two	Decrease four	Decrease four
4	low	moderate	low	Increase one	Decrease one	Increase one	Increase one
5	low	moderate	moderate	Decrease one	increase one	Decrease one	Decrease one
6	low	moderate	high	Decrease three	Increase three	Decrease three	Decrease three
7	low	high	low	unchanged	unchanged	Increase two	Increase two
8	low	high	moderate	Decrease two	Increase two	unchanged	unchanged
9	low	high	high	Decrease four	Increase four	Decrease two	Decrease two
10	moderate	low	low	Increase three	Decrease three	Increase one	Increase one
11	moderate	low	moderate	Increase one	Decrease one	Decrease one	Decrease one
12	moderate	low	high	Decrease one	Increase one	decrease three	Decrease three
13	moderate	moderate	low	Increase two	Decrease two	Increase two	Increase two
14	moderate	moderate	moderate	unchanged	unchanged	unchanged	unchanged
15	moderate	moderate	high	Decrease two	Increase one	Decrease two	Decrease two
16	moderate	high	low	Increase one	Decrease one	Increase three	Increase three
17	moderate	high	moderate	Decrease one	Increase one	Increase one	Increase one
18	moderate	high	high	Decrease three	Increase three	Decrease one	Decrease one
19	high	low	low	Increase two	Decrease four	Increase one	Decrease one
20	high	low	moderate	Increase two	Decrease two	unchanged	unchanged
21	high	low	high	unchanged	unchanged	Decrease two	Decrease two
22	high	moderate	low	Increase three	Decrease three	Increase three	Increase three
23	high	moderate	moderate	Increase one	Decrease one	Increase one	Increase one
24	high	moderate	high	Decrease one	Increase one	Decrease one	Decrease one
25	high	high	low	Increase two	Decrease two	Increase four	Increase four
26	high	high	moderate	unchanged	unchanged	Increase two	Increase two
27	high	high	high	Decrease two	Increase two	unchanged	unchanged

TABLE 2: The fuzzy rules for cross-layer design

We used trapezoidal membership functions (MFs) to represent *low, high, increase four* and *decrease four*, and triangle MFs to represent *moderate, unchanged, increase one, increase two, increase three, decrease one, decrease two* and decrease *three*.

We show these MFs in Fig.6 and Fig.7.

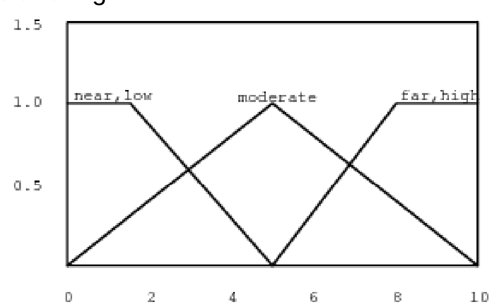


FIGURE 6: MFs for Antecedents

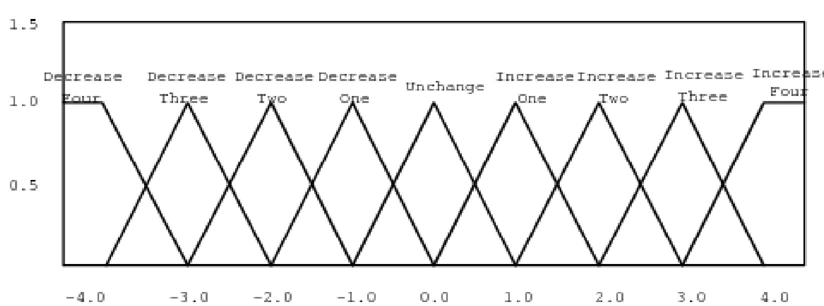


FIGURE 7: MFs for Consequents

In our approach to form a rule base, we chose a single consequent for each rule. We design a fuzzy logic system using rules such as:

R^l: IF ground speed (x_1) is F_l^1, average delay (x_2) is F_l^2, and packet successful transmission ratio (x_3) is F_l^3, For every input (x_1, x_2, x_3), the output is computed using

For every input ($(x_{1,} x_{2,} x_3)$, the output is computed using

$$y(x_1, x_2, x_3) = \frac{\Sigma_{l=1}^{27} \mu_{F_l^1}(x_1) \mu_{F_l^2}(x_2) \mu_{F_l^3}(x_3) c_G^l}{\Sigma_{l=1}^{27} \mu_{F_l^1}(x_1) \mu_{F_2^2}(x_2) \mu_{F_l^3}(x_3)}$$

We compute the adjusting factors and adjust the network parameters dynamically. Comparing to the constant parameters, the fuzzy optimization for cross-layer design can meet QoS and energy requirement.

5. SIMULATIONS

We implemented the simulation model using the OPNET modeler. The simulation region is 300×300 meters. There were 12 mobile nodes in the simulation model, and the nodes were roaming independently with variable ground speed between 0 to 10 meters per second. The mobility model was called one-step Markov path model. The movement would change the distance between mobile nodes.

1. Average Delay

Because data communications in the mobile networks had trimming constraints, it was important to design the network algorithm to meet a kind of end-end deadline [16]. We used the average delay to evaluate the network performance.

$$d_{avergage} = \frac{\sum_{i=1}^{k} d_i}{k}$$

Each packet was labeled a timestamp when the source mobile node generated it. When its destination mobile node received it, the time interval was the transmission delay.

Fig.8 showed the delay performance of the constant parameters and the one after cross-layer optimization for the real time traffic, the best effort traffic and all the traffic. Cross-layer optimization made a tradeoff for the average delay between the real time traffic and the best effort traffic. For the real time traffic, the cross-layer optimization would enlarge about 0.6 seconds. However for the best effort case, the cross-layer optimization could reduce the delay by up to 90.53%. For the all traffic, the cross-layer optimization could reduce the delay by up to 71.85%, which meant the cross-layer optimization could improve the average delay performance for the whole system. As showed in the best effort case, the cross-layer optimization could make the average delay "stable", which was important for the communication system design.

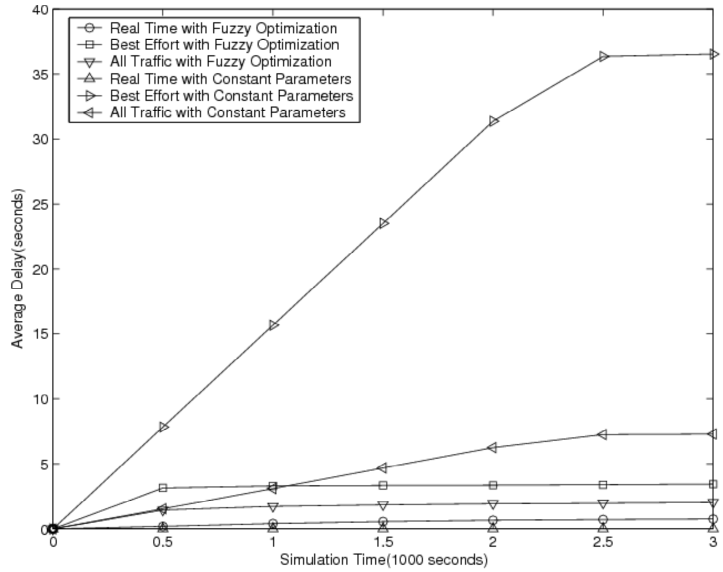


FIGURE 8: Average Delay

2. Energy Efficiency

It was not convenient to recharge the battery, so the energy efficiency was extremely important for mobile ad hoc networks. The network should keep an enough number of ``live'' mobile nodes to collect data, that meant the network need to keep the energy among the mobile nodes in balance. We used the number of remaining alive nodes as the parameter of the energy efficiency.

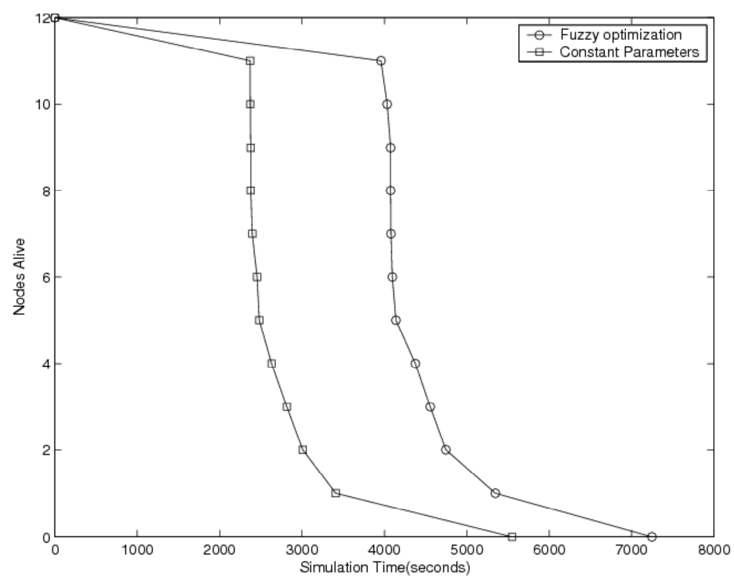


FIGURE 9: Energy Efficiency

We assumed P_{elec} was equal to 6.0×10^{-4} and ε_{fs} was equal to 6.0×10^{-4}. We assumed that the energy of each mobile node was 0.07 J.

When the remaining energy of a mobile node was lower than a certain threshold, the node was considered as ``dead''. In this simulation, we chose $1.2\times10^{-3}$ as the threshold. A sensor was ``dead'' meant it could not transmit/receive packets any longer, so it would be ignored by network. The number of nodes of mobile ad hoc networks which was below a certain threshold meant this network does not work.

As Fig.9 showed, after fuzzy optimization, the duration of the first node ``dead'' is 1.67 times longer than that of the constant parameters, which is 1589 seconds.

3. Networks Efficiency

The mobile ad hoc networks were used to collect data and transfer packets. The throughput of packets transmitted was one of the parameters to evaluate the networks efficiency. In our simulation, we assumed the collecting data distribution of the mobile node was Poisson distribution and the arriving interval was 0.2 second. Observing from Fig.10, the cross-layer optimization made a tradeoff between the real time traffic and the best effort traffic. For the real time traffic, after the cross-layer optimization, the throughput of the network was about 0.02% smaller than that of the constant parameters. However, for the best effort traffic, the throughput of the network was up to 71.99% larger. For the all the traffic case, after the cross-layer optimization, the throughput of the network was up to 32.52% larger, which meant the cross-layer optimization could improve the throughput performance for the whole system. As the performance of the average delay, the cross-layer optimization could achieve a "stable" throughput performance.

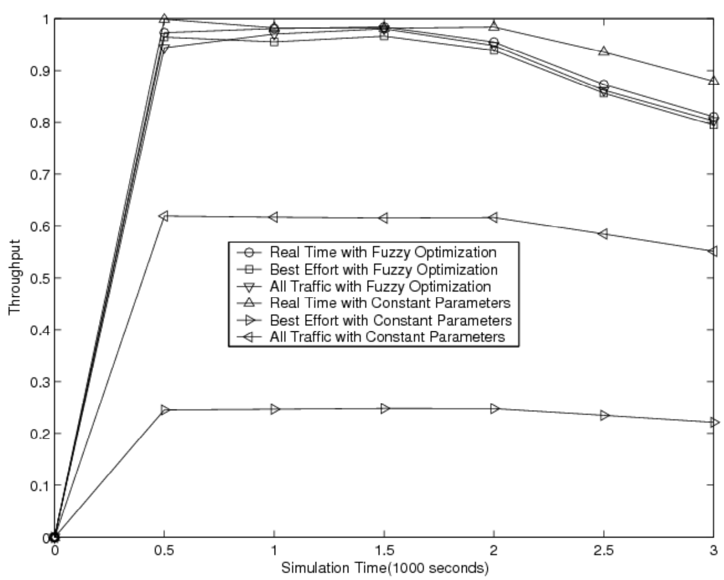


FIGURE 10: Network Efficiency

We introduced the fuzzy logic system in the cross-layer design. Comparing with other algorithms for cross-layer design, the fuzzy method could be flexible and simpler to implement and the performance outputs were also impressive.

6. CONCLUSION

Cross-layer design is an effective method to improve the performance of the mobile ad hoc network. We apply the fuzzy logic system to combine physical layer, data-link layer and application layer together. We selected ground speed, average delay and packets transmission successful ratio as antecedents. The output of FLS provides adjusting factors for the AMC, transmission power, retransmission times and rate control decision. Simulation shows the FLS application in cross-lay design could reduce the average delay, increase the throughput and extend the network lifetime. After the cross-layer optimization, the network performance parameters could also keep stable. In the future, we can consider other layers, such as network layer for the cross-layer design.

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EERR: Performance Evaluation of Energy Efficient and Reliable Routing Protocol for Wireless Sensor Networks

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Abstract

A wireless sensor network is composed of hundreds or thousands of nodes that are densely deployed in a large geographical area. And these sensor nodes are small, wireless and battery powered. Routing is often a challenge and difficult problem because various factors like limited energy of sensor nodes, unreliable communication channels i.e. harsh environment, battery depletion etc are to be considered. There are various routing protocols that can be broken down based on some techniques. According to network structure it can be classified as flat, hierarchical or location based. In this paper, we propose an energy efficient and reliable routing protocol (EERR), which uses hierarchical clustering and to develop it we introduce a set of cluster heads and headset in which two phases namely election phase and data transfer phase are considered. During the election phase a head-set consisting of several nodes is selected and in the data transfer phase the headset member receives data from the neighboring nodes and transmits the aggregated results to the distant base station, which is done on a rotation basis. The results show that the energy consumption can be decreased and the lifetime of the network is also increased.

Keywords: Energy Efficiency, Reliable Routing, Network Lifetime, NS-2, Wireless Sensor Networks

1. INTRODUCTION

Wireless Sensor Networks typically consists of a large number of sensor nodes distributed over a certain region [1]. These sensor nodes are characterized by their low power, small size and cheap price. They actually transform the data into electric signals, which are then processed to reveal some of the characteristics about the phenomena located in the area around the sensors. The unique nature of the sensor networks is the cooperative effort of sensor nodes. The applications of WSNs are quite numerous. Some of the application areas are health, military, and home.

2. RELATED WORKS

Heinemann W.B et al., [2] proposed that a hierarchical clustering algorithm for sensor networks, called Low Energy Adaptive Clustering Hierarchy (LEACH). LEACH uses localized coordination to enable scalability and robustness for dynamic networks, and incorporates data fusion into the routing protocol to reduce the amount of information that must be transmitted to the base station. The simulation results of the paper shows that LEACH can achieve as much as a factor of 8 reductions in energy dissipation compared with conventional routing protocols. Quanhong Wang et,al [3,[4],]In this paper various clustering schemes based on a comprehensive classification has been compared and analyzed. A bi-dimensional Markov chain model for analyzing a class of distributed, dynamic, and randomized (DDR) clustering schemes has been proposed. With this model extensive evaluation of stochastic properties of a representative DDR clustering scheme – Low Energy Adaptive Clustering Hierarchy (LEACH), in terms of the distribution of cluster number, the mean, the standard deviation and coefficient of variation of number of clusters has been presented. The results indicate that the number of clusters generated in LEACH-like DDR schemes is a random variable, which cannot concentrate with in a narrow range of the optimal value. This variability in the number of clusters adversely affects the system lifetime.

Intanagonwiwat C et. al [5] proposed, the directed diffusion protocol The main idea of the directed diffusion protocol is to combine the data coming from different sources enroute by eliminating redundancy, minimizing the number of transmissions; thus saving network energy and prolonging its lifetime. However, directed diffusion may not be applied to applications such as environmental monitoring that require continuous data delivery to the BS. This is because the query-driven on demand data model may not help in this regard. Moreover, matching data to queries might require some extra overhead at the sensor nodes.

Lindsey S. et al., [6],[7] an enhancement over LEACH protocol was proposed. The protocol, called Power-Efficient Gathering in Sensor Information Systems (PEGASIS), is a near optimal chain-based protocol. The main idea in PEGASIS is for each node to receive from and transmit to close neighbors and take turns being the leader for transmission to the BS. This approach will distribute the energy load evenly among the sensor nodes in the network PEGASIS assumes that all sensor nodes have the same level of energy and they are likely to die at the same time. Note also that PEGASIS introduces excessive delay for distant node on the chain.

Authors [8],[9] proposed the threshold sensitive energy efficient protocol. These protocols were proposed for time-critical applications. The main drawbacks of the two approaches are the overhead and complexity associated with forming clusters at multiple levels, the method of implementing threshold-based functions, and how to deal with attribute-based naming of queries.
The “Zone Based routing” [10],[11] is a hierarchical approach to routing in sensor networks which groups nodes into geographic zones to control routing. It uses energy estimation based on data transmission direction. This implementation was not chosen because geographic networks were not being simulated

Peter Kok Keong Lohet al [17] proposed a viable routing protocol, EAR, for data aggregation in fixed-power WSNs. They proposed network setup; nodes relay all data packets to the hub. In networks with a single, centrally-located hub, neighbouring nodes to the hub route more packets than other nodes. These nodes will drain their energy-reserve at a much faster rate. One possible solution to this problem could be to adopt a clustering approach wherein cluster node members route only to the cluster heads and cluster heads may be implemented with variable-powered motes.

S. D. Muruganathan et.al [13] proposed the Base-Station Controlled Dynamic Clustering protocol for WSN. In this protocol they divide the network into equally sized clusters. BS makes all the high energy consumption decisions like cluster head selection and route calculation etc, which is assumed to have enough computational power and resources. During the set up phase each node sends the value of its current remaining energy to the base station. The base station will determine the nodes that have more than average remaining energy. Out of these nodes a specified number of nodes become CHs. The high burden of being CH is distributed by repeating this process.

A. Abbasi et al[14] proposed an energy efficient hierarchical or cluster based routing in sensor networks for different scenarios and various applications. However, most protocols in the previous literatures have not been considering event driven WSNs and, their focus is on continuous networks. Therefore in this work they focus on energy efficient clustering algorithm for event-driven wireless sensor network. In order to extend the lifetime of the whole sensor network, energy load must be evenly distributed among all sensor nodes so that the energy at a single sensor node or a small set of sensor nodes will be drained out very soon.

Some authors proposed [15][16] a good solution to reduce energy dissipation using cluster head selection algorithm based on sensors' residual energy. But, in many algorithm, each node sends information about its current location and energy level to the BS. The BS needs to ensure that the energy load is evenly distributed among the all the nodes Another approach is the BS selects cluster head nodes depending on the number of clusters alive in the network . But the, LEACH protocol does not guarantee the number of cluster head nodes and their distribution because the cluster head nodes are selected stochastically by the value of probability. The different cluster numbers in WSNs will make the node numbers in every cluster different and uneven cluster numbers dissipate uneven energy in each round.

Mhatre, et al. proposed a clustering algorithm CODA [12],[18] in order to ease the imbalance of energy depletion caused by different distances from the sink. CODA divides the entire network into a few groups based on node's distance to the base station and the routing strategy, each group has its own number of clusters and member nodes. CODA differentiates the number of clusters in terms of the distance to the base station. The farther the distance to the base station, the more clusters are formed in case of single hop with clustering. It shows better performance in terms of the network lifetime and the dissipated more energy than those protocols that apply the same probability to the whole network. However, the work of CODA relies on global information of node position, and thus it is not scalable.

3 PROPOSED ROUTING PROTOCOL (EERR)

The proposed routing protocol that has been designed uses a headset instead of a cluster head, which reduces the energy consumption and increase the lifetime of the network.

3.1Proposed Routing Model

The Energy Efficient Reliable Routing (EERR) protocol is an extension of LEACH where the cluster head is being replaced by a headset. The headset consists of several nodes and each node will be acting as a cluster head for a particular interval of time. The operation of the proposed routing protocol can be explained using the Figure1. There are mainly two phases namely Election Phase and Date Transfer Phase.

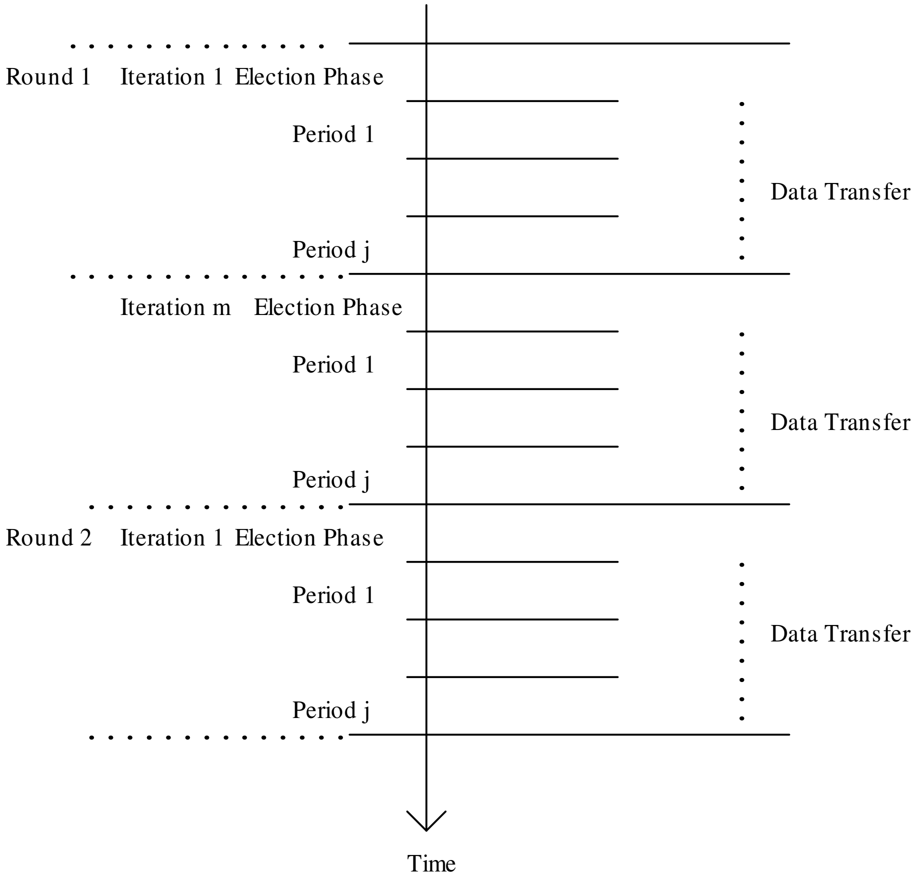

FIGURE 1: Stages in a cluster for a Wireless Sensor Network

3.1.1 Election Phase

In the election Phase, at the beginning the cluster heads is selected on a random basis for a predetermined number of clusters. Once the nodes have been selected as cluster heads the cluster head nodes must let all the other nodes in the network know that they have chosen this role for the current round. To do this each cluster head node broadcasts an advertisement message using a non-persistent carrier sense multiple access CSMA MAC protocol. This message is a small message containing the node's ID and a header that distinguishes this message as an announcement message. However this message must be broadcast to reach all the nodes in the network. Each non-cluster head node determines to which cluster it belongs by choosing the cluster head that requires the minimum communication energy based on the received signal strength of the advertisement from each cluster head.

Assuming symmetric propagation channels for pure signal strength the cluster head advertisement heard with the largest signal strength is the cluster head to which the minimum amount of transmitted energy is needed for communication. However if there is some obstacle impeding the communication between two physically close nodes for example a building, a tree etc such that communication with another cluster head located further away is easier, the sensor will choose the cluster head that is spatially farther away but closer in a communication sense. In the case of ties a random cluster head is chosen. After each node has decided to which cluster it belongs it must inform the cluster head node that it will be a member of the cluster. Each node transmits a join request message Join_REQ back to the chosen cluster head using a non-persistent CSMA MAC protocol as an acknowledgement. This message is again a short message consisting of the node's ID, the cluster head's ID, and a header.

Based on the acknowledgements received the cluster head will choose its associates to form a headset. So the headset constitutes the cluster head and its associates. The headset will act as local control centers to coordinate the data transmissions in their cluster. For each iteration a particular headset is chosen for transmitting the information to the base station. During each period of iteration one of the headset members will be acting as a cluster head for a particular interval of time. So the headset members will be transmitting the information to the base station on a uniform rotation basis.

The headset sets up a TDMA schedule and transmits this schedule to the nodes in the cluster. This ensures that there are no collisions among data messages and also allows the radio components of each non-cluster head node to be turned off at all times except during their transmit time thus minimizing the energy dissipated by the individual sensors. After the TDMA schedule is known by all nodes in the cluster, the election phase is complete and the steady state operation data transmission can begin.

3.1.2 Data Transfer Phase

In the data transfer phase all the non-cluster head nodes will collect the information and transmits it to the headset, which in turn sends the information to the base station. Each member of the headset will be acting as a cluster head during a particular period. The steady state operation is broken into frames where nodes send their data to the cluster head at most once per frame during their allocated transmission slot. The cluster head must keep its receiver on to receive all the data from the nodes in the cluster. Once the cluster head receives all the data, it can operate on the data, performing data aggregation and then the resultant data are sent from the cluster head to the base station. Since the base station may be far away and the data messages are large this is a high-energy transmission.

So the member that becomes the cluster head will keep its radio on so as to receive the information frames from the non-cluster head nodes and the associates will go to the sleep state. After a particular interval of time the next associate of the headset becomes the cluster head. This continues on a uniform rotation basis until all the headset members have become cluster heads. For each period one of the headset member acts as a cluster head. So at the end iteration all the headset members should have become cluster heads for once. For the next iteration the next headset is chosen and at the end of a round all the nodes would have become a cluster head once. So for the next new round all the nodes are considered as normal nodes and the process continues as discussed earlier.

3.2 Quantitative Analysis

The Radio energy model that is being used in our analysis is shown in Figure 2. A simple model is assumed where the transmitter dissipates energy to run the radio electronics and the power amplifier and the receiver dissipates energy to run the radio electronics.

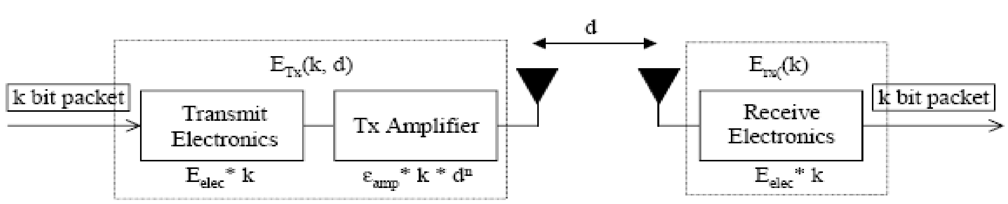

FIGURE 2: Radio Energy Dissipation Model

3.2.1 Simulation Setup

In this paper the simulation setup has 100-nodes network where nodes were randomly distributed between (x=0, y=0) and (x=100, y=100) with the Base Station at location (x=50, y=50). Each data message is 500 bytes long. The power attenuation is dependent on the distance between the transmitter and receiver. For relatively short distances, the propagation loss can be modeled as inversely proportional to d^2, whereas for longer distances, the propagation loss can be modeled as inversely proportional to d^4. Power control can be used to invert this loss by setting the power amplifier to ensure a certain power at the receiver. For the experiment described here, both the free space and the multipath fading channel models were used, depending on the distance between the transmitter and receiver.

Thus, to transmit an 1-bit message for a shorter distance d, the radio expends

$$E_{TS} = lE_{elec} + l\varepsilon_{fs} d^2 \tag{1}$$

For transmitting an l- bit message over a longer distance d, the energy consumed is

$$E_{TL} = lE_{elec} + l\varepsilon_{mp} d^4 \tag{2}$$

The energy expended by the radio to receive the l-bit message is given by,

$$E_R = lE_{elec} + lE_{DA} \tag{3}$$

The Electronics energy, E_{elec} is the energy consumed in the electronics circuit to transmit or receive the signal which depends on factors such as the digital coding, modulation and filtering of the signal before it is sent to the transmit amplifier. While using DS-SS, the electronics energy accounts for the spreading of the data when transmitting and the correlation of the data with the spreading code when receiving. The amplifier energy, $\varepsilon_{fs} d^2$ or $\varepsilon_{mp} d^4$, depends on the distance to the receiver and the acceptable bit-error rate. For the experiment described in this paper, the communication energy parameters are set as: E_{elec} =50 nJ/ bit, ε_{fs} =10 pJ/ bit /m^2, and ε_{mp} =0.0013 pJ/ bit /m^4. Using the previous experimental results [16], the energy for data aggregation is set as E_{DA} = 5nJ /bit signal.

3.2.2 Energy Consumption During the Election Phase

In the election phase both the cluster head and non-cluster head nodes consumes energy. Initially it is assumed that all the sensor nodes have same amount of energy and the energy consumed is the same for all the clusters. In the election Phase, the cluster head first sends advertisement messages to all the non-cluster head nodes. Next the non-cluster head nodes receive the broadcasted messages from the different cluster heads and based on the received signal strength it chooses its own cluster head. The cluster head will then receive the acknowledgment signals and based on it the associates are also chosen to form the headset. It is considered that there are totally n number of sensor nodes, m associates and k clusters. Since we have assumed that the clusters are uniformly distributed there are totally $\frac{n}{k}$ nodes in each cluster. The energy consumed by the cluster head is given by equation (4).

$$E_{CHE} = \left\{ lE_{elec} + l\varepsilon_{fs} d^2 \right\} + \left\{ \left(\frac{n}{k} - 1 \right) l \left(E_{elec} + E_{DA} \right) \right\} \tag{4}$$

In the equation (4) the first part is the energy expended by the cluster head node to transmit the advertisement message. The transmission of messages is within the cluster so free space model is being used. The second part of the equation is the energy expended by the cluster head to receive the acknowledgement messages from $\left(\frac{n}{k} - 1 \right)$ sensor nodes.

On simplification of the equation (4) the following equation (5) has obtained.

$$E_{CHE} = lE_{elec}\frac{n}{k} + lE_{DA}\left(\frac{n}{k} - 1\right) + l\varepsilon_{fs}d^2 \quad (5)$$

The energy consumed by the non-cluster head nodes is given by equation (6).

$$E_{nonCHE} = \{klE_{elec} + klE_{DA}\} + \{lE_{elec} + l\varepsilon_{fs}d^2\} \quad (6)$$

The first part of the equation (6) gives the energy expended to receive the messages from k clusters and the second part of the equation gives the energy expended to transmit the acknowledgement messages to the corresponding cluster head. On simplification of the equation (6) the following equation is obtained.

$$E_{nonCHE} = lE_{elec}(1+k) + klE_{DA} + l\varepsilon_{fs}d^2 \quad (7)$$

3.2.3 Energy Consumption During the Data Transfer Phase

During the data transfer phase the non-cluster head nodes transmits the data to the headset and then the aggregated data is sent to the base station. The energy expended by the cluster head is given by equation (8).

$$E_{CH\_frame} = \{lE_{elec} + l\varepsilon_{mp}d^4\} + \left\{\left(\frac{n}{k} - m\right) l(E_{elec} + E_{DA})\right\} \quad (8)$$

In the equation (8) the first part gives the energy consumed to transmit the aggregated message to the base station so here multipath-fading model is being used. The second part of the equation gives the energy consumed due to the reception of the acknowledgement messages from $\left(\frac{n}{k} - m\right)$ nodes. On simplification of equation (8) we obtain the following equation

$$E_{CH\_frame} = l\varepsilon_{mp}d^4 + \left(\frac{n}{k} - m + 1\right) lE_{elec} + \left(\frac{n}{k} - m\right) lE_{DA} \quad (9)$$

The energy consumed by the non-cluster head node to transmit the data to the base station is given as follows

$$E_{nonCH\_frame} = lE_{elec} + l\varepsilon_{fs}d^2 \quad (10)$$

The area occupied by each cluster is approximately $\frac{M^2}{k}$. In general, this is an arbitrary-shaped region with a node distribution $\rho(x, y)$. The expected squared distance from the nodes to the cluster head (assumed to be at the center of mass of the cluster) is given by (11)

$$E[d^2] = \iint (x^2 + y^2)\rho(x, y)dxdy \quad (11)$$

$$E[d^2] = \iint r^2 \rho(r,\theta) rdrd\theta \quad (12)$$

If we assume this area is a circle with radius $R = \frac{M}{\sqrt{\pi k}}$ and $\rho(r,\theta)$ is constant for r and θ, (12) simplifies to (13)

$$E[d^2] = \rho \int_{\theta=0}^{2\pi} 1 \int_{r=0}^{\frac{M}{\sqrt{\pi k}}} r^3 drd\theta = \frac{\rho}{2\pi}\frac{M^4}{k^2} \quad (13)$$

If the density of nodes is uniform throughout the cluster area, then

$\rho = \left(1/\left(M^2/k\right)\right)$ and (14)

$$E[d^2] = \frac{1}{2\pi}\frac{M^2}{k} \tag{15}$$

Using (15) in (10)

$$E_{nonCH\_frame} = lE_{elec} + l\varepsilon_{fs}\frac{M^2}{2\pi k} \tag{16}$$

The frames that are transmitted in each iteration is N_f . So the number of frames transmitted by each cluster is N_f/k . These frames are uniformly distributed among the n/k nodes of the cluster. The fractions of the frames that are to be transmitted are given as follows

$$f_1 = \left(\frac{1}{\frac{n}{k} - m + 1}\right)\frac{1}{k} \tag{17}$$

$$f_2 = \left(\frac{\frac{n}{k} - m}{\frac{n}{k} - m + 1}\right)\frac{1}{k} \tag{18}$$

The energy expended during the data transfer phase is given as follows

$$E_{CHD} = f_1 N_f E_{CH\_frame} \tag{19}$$

$$E_{nonCHD} = f_2 N_f E_{nonCH\_frame} \tag{20}$$

3.2.4 Energy Consumption for Iteration

For every iteration m associates are being elected for each cluster. So for k clusters totally mk nodes are being elected as members of the headset. Hence the total number of iterations that are required for all the nodes to be elected is (n/km). So in one round there are (n/km) iterations. The energy consumed by a cluster during iteration is given by the following equations

$$E_{CH\_iter\_cluster} = E_{CHE} + E_{CHD} \tag{21}$$

$$E_{nonCH\_iter\_cluster} = E_{non\_CHE} + E_{non\_CHD} \tag{22}$$

There are m associates in the headset so energy given by equation (21) in uniformly distributed among the headset members and is given by equation (23)

$$E_{CH\_node} = \frac{E_{CH\_iter\_cluster}}{m} \tag{23}$$

There are $\left(\frac{n}{k} - m\right)$ non-cluster head nodes in each cluster, so the energy given by equation (22) is uniformly divided among them as follows

$$E_{nonCH\_node} = \frac{E_{nonCH\_iter\_cluster}}{\frac{n}{k} - m} \tag{24}$$

3.2.5 Initial Energy

The energy of a sensor node initially at the beginning should be such that it should sustain for at least one round. In a round a particular sensor node becomes a cluster head for one time and becomes a non-cluster head node for $\left(\frac{n}{km} - 1\right)$ times.

$$E_{ST} = E_{CH\_node} + \left(\frac{n}{km} - 1\right) E_{nonCH\_node} \tag{25}$$

Using (23) and (24) in equation (25) we obtain

$$E_{ST} = \frac{1}{m}\left(E_{CH\_iter\_cluster} + E_{nonCH\_iter\_cluster}\right) \tag{26}$$

Using (21) and (22) in (26) becomes

$$E_{ST} = \frac{E_{CHE} + E_{nonCHE}}{m} + \frac{N_f}{m}\left(f_1 E_{CH\_frame} + f_2 E_{nonCH\_frame}\right) \tag{27}$$

From equation (27) the number of frames is given using equation (28).

$$N_f = \frac{mE_{ST} - E_{CHE} - E_{nonCHE}}{f_1 E_{CH\_frame} + f_2 E_{nonCH\_frame}} \tag{28}$$

3.2.6 Optimum Number of Clusters

The optimum number of clusters can be found by setting the derivative of the total energy with respect to k to zero. The energy dissipated in a cluster during frame transmission is given below

$$E_{cluster} = E_{CH\_frame} + \left(\frac{n}{k} - m\right) E_{nonCH\_frame} \tag{29}$$

So the total energy consumed by all the k clusters is given by equation

$$(E_{total} = kE_{cluster}) \tag{30}$$

Substituting equations (9), (16), (29) in equation (30) we obtain the following equation

$$E_{total} = \left\{kl\varepsilon_{mp}d^4 + (n-km+k)lE_{elec} + (n-km)lE_{DA}\right\} + \left\{(n-km)lE_{elec} + (n-km)l\varepsilon_{fs}\frac{M^2}{2\pi k}\right\} \tag{31}$$

The optimum number of clusters can be obtained as follows

$$\frac{dE_{total}}{dk} = 0$$

$$k = \sqrt{\frac{n}{2\pi}}\sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}d^4 - (2m-1)E_{elec} - mE_{DA}}}M \tag{32}$$

3.2.7 Iteration Time and Time Taken for a Round

It is considered that the data transfer rate is R_b bits/second and message length is l bits. Then the time taken to transfer a message is given by equation (33).

$$t_{message} = \frac{l}{R_b} \tag{33}$$

The time consumed to transmit a frame is the summation of the transmission times of all the nodes that belongs to the cluster. So the time consumed for transmitting one frame is

$$t_{frame} = \left\{ \sum_{i=1}^{\frac{n}{k}-m} t_{message_i} \right\} + t_{message_{CH}} \tag{34}$$

The first part of the equation gives the fact that all the $\left(\frac{n}{k}-m\right)$ non-cluster head nodes are transmitting and the second part informs that only one of the headset members will transmit at a particular time. Assuming that the message transfer time is the same for all the nodes we obtain

$$t_{frame} = \left(\frac{n}{k}-m+1\right) t_{message} \tag{35}$$

The time taken for iteration is given as follows

$$t_{iteration} = t_{frame} \times N_f \tag{36}$$

On simplifying equation (36) using equations (32), (34) and (35) we obtain

$$t_{iteration} = \frac{l}{R_b}\left(\frac{n}{k}-m+1\right) N_f \tag{37}$$

Time taken to complete a round is calculated as follows

$$t_{round} = t_{iteration} \times \frac{n}{km} \tag{38}$$

$$t_{round} = \frac{l}{R_b}\frac{n}{k}\left(\frac{n}{k}-m+1\right)\frac{N_f}{m} \tag{39}$$

4 SIMULATION RESULTS

The simulation results have been obtained using the quantitative analysis. NS-2 has been used to simulate the results. The energy consumption of LEACH and the EERR routing protocol designed is being compared and the results are shown.

EERR is organized into rounds, where each of them begins with a set-up phase, and is followed by data transfer phase. Usually, the latter phase is longer than the former phase. Their sub-phases include advertisement, cluster set-up, schedule creation, and data transmission phases. In advertisement phase, the self-selected cluster-heads broadcast advertisement messages in their clusters, and the non-cluster-head nodes decide which clusters they belong to based on the received signal strength. In cluster set-up phase, each non-cluster-head node tells its cluster-head its decision by using CSMA MAC protocol. Then the cluster-heads create TDMA schedules and broadcast them back to their members in schedule creation phase. In data transmission phase, each node waits for its turn to send data if needed. EERR protocol *provides* sensor networks with many good features, such as clustering architecture, localized coordination and randomized rotation of cluster-heads. The Figure 3 (a, b, c) shows example of the random sensor network for different round. In the figure 100 nodes are being deployed in the sensor network.

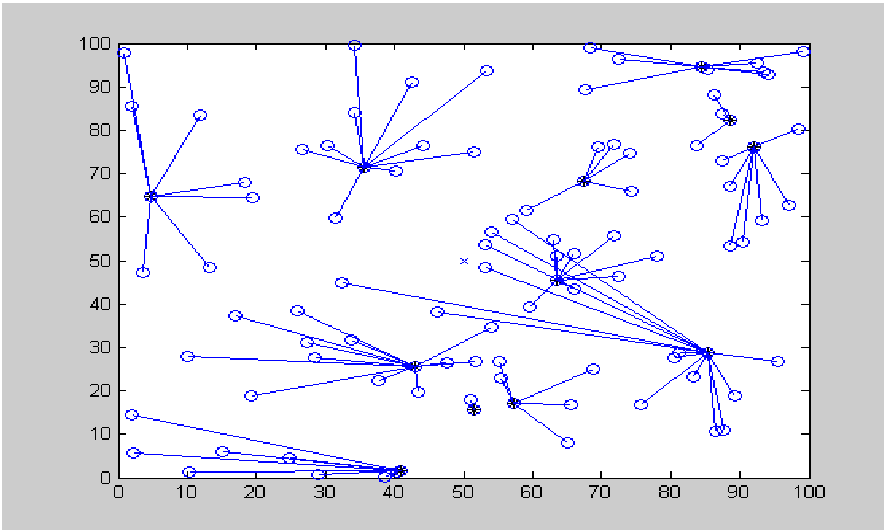

FIGURE 3 (a): 100-node random sensor network for round1

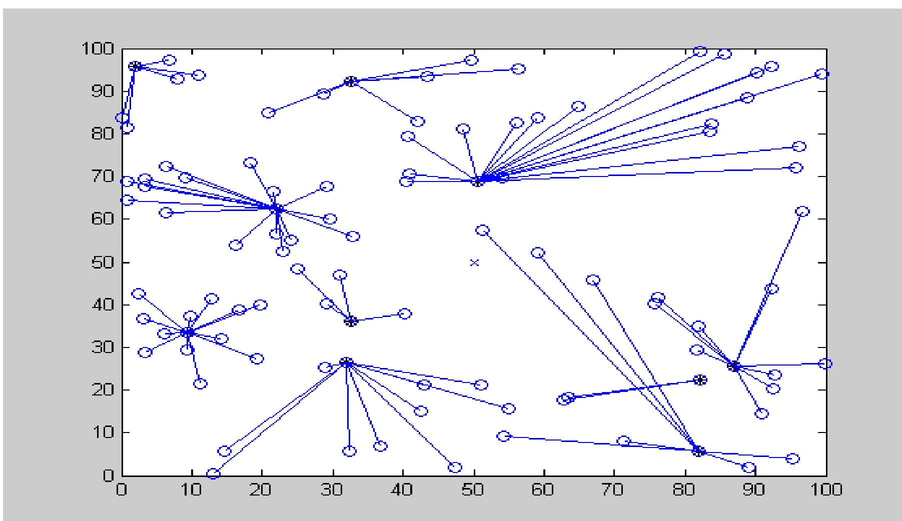

FIGURE 3: (b) 100-node random Sensor Network for round 2

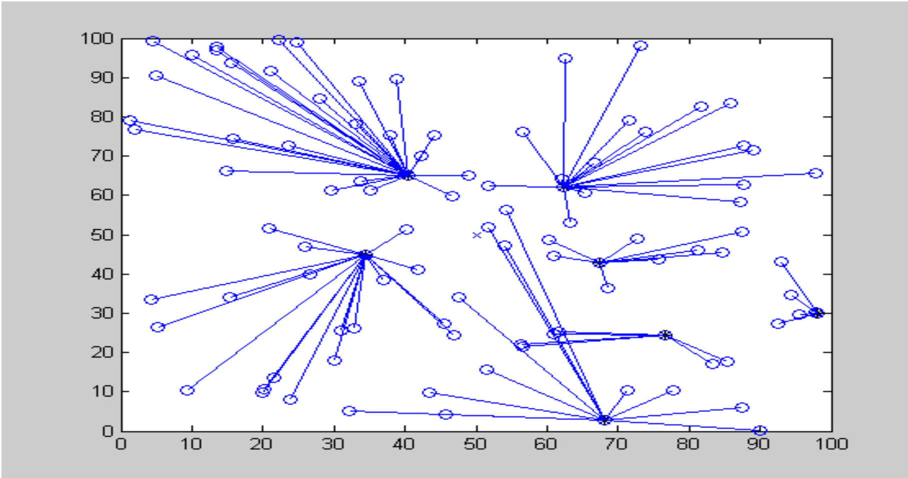

FIGURE 3: (c) 100- node random sensor network for round 3

4.1 Optimum Number of Clusters

The optimum number of clusters is obtained using the equation (32).

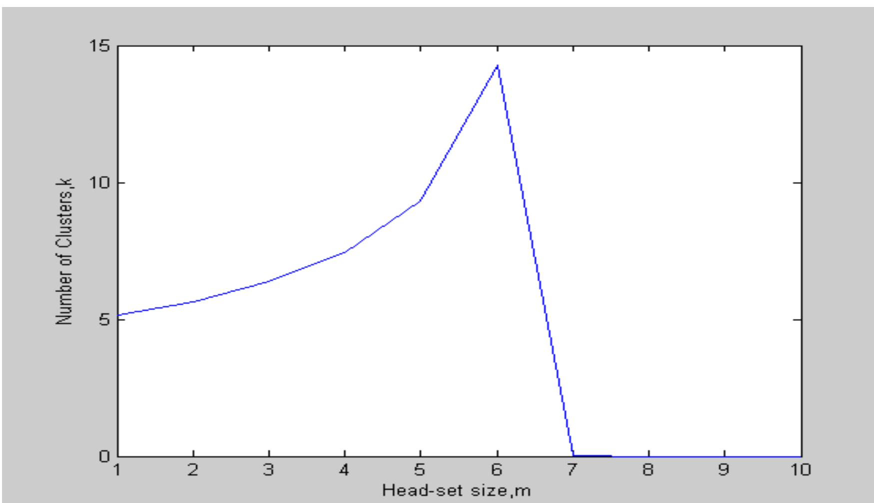

FIGURE 4: Optimum numbers of clusters

From the figure 4 it can be said that the headset size can be within 1 and 6. If the headset size is greater than 6 then the number of clusters drops down rapidly and so the energy consumption also reduces. For a small headset size there is small number of clusters, so there are few sleeping nodes. But if we increase the headset size to a reasonable value then optimum number of clusters is obtained thereby increasing the sleeping nodes, which in turn reduces the energy consumption.

4.2 Energy Expended

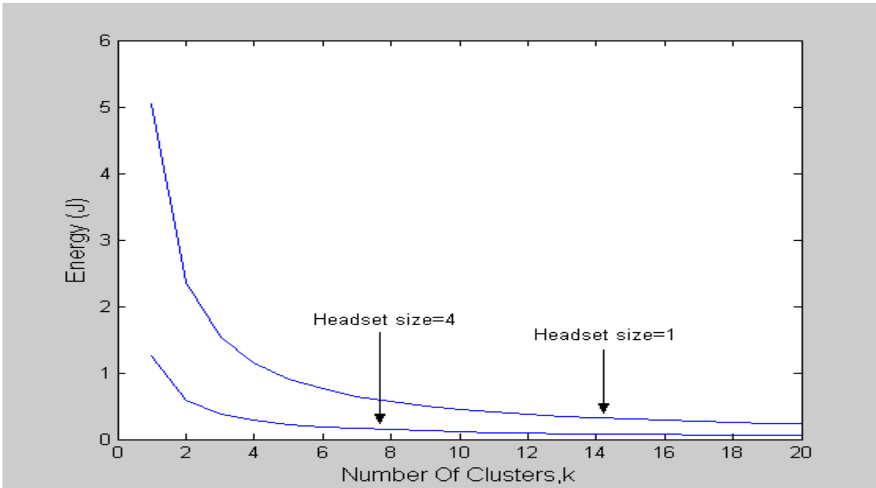

FIGURE 5: Energy consumption vs number of clusters

The figure 5 describes the energy consumption with respect to the number of clusters for various headset sizes. From the graph it can be said that as the number of clusters increases the energy consumed reduces. It is so because when the number of clusters is increased the number of long distance transmissions is reduced that is the number of transmissions to the base station is reduced thereby conserving energy. As the headset size is increased the energy consumption is reduced because of the increase in sleeping nodes.

4.3 Number of Clusters With Respect to Distance and Headset Size

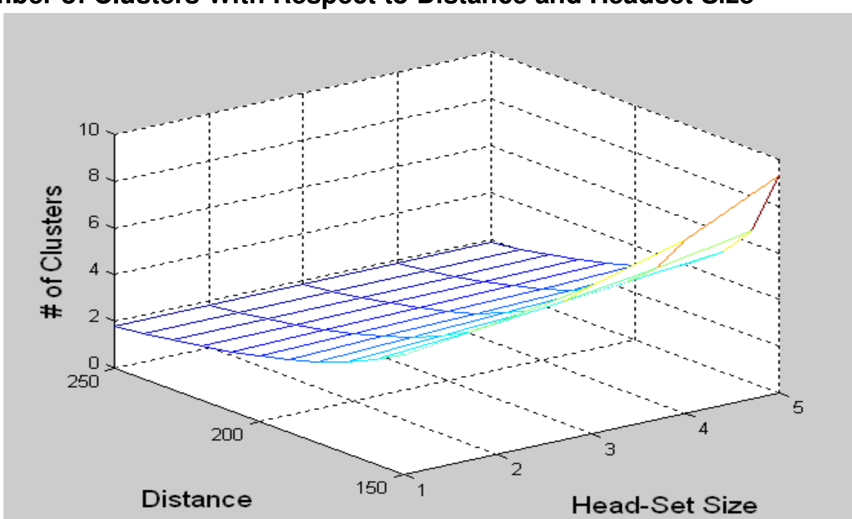

FIGURE 6: Number of clusters with respect to distance and headset size

Figure 6 infers that the number of clusters increases as the headset increases. It is seen that for constant headset size the number of clusters decreases when the distance to the base station increases. It is so because when the distance is small then the energy consumed to transmit messages to the base station over a shorter distance is comaratively less and it is advisable to have large number of clusters. But if the distance is very long then ,having large number of clusters is not advisable because here the energy consumed for long distance transmission is very high

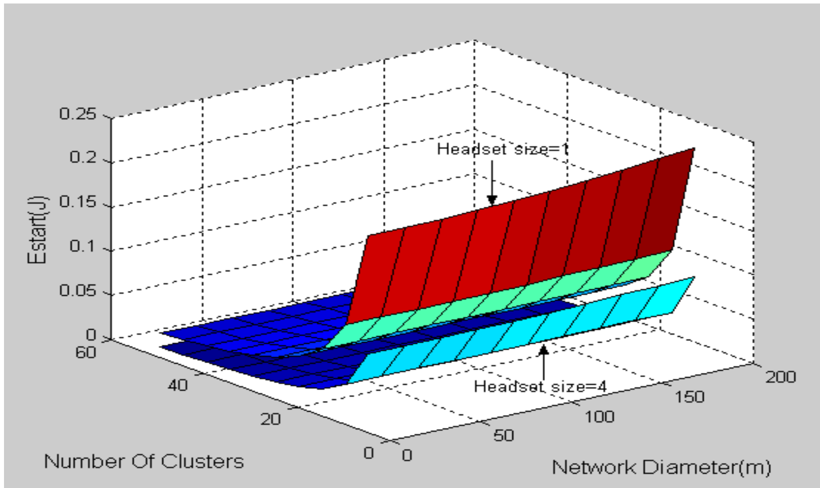

FIGURE 7: Energy consumption for a round with respect to number of clusters and network diameter

The energy required to complete a round , E_{ST} should be such that the sensor node has to become cluster head once and become a non-cluster head node $\left(\frac{n}{km}-1\right)$ time.

The figure 7 illustrates the same for headset size 1 and 3. Equation (27) is being used to calculate the energy. The energy consumption is reduced when the number of clusters is increased .But when the number of clusters increases above the optimum range or when the number of clusters decreases below the range the energy consumption increases. When the number of clusters increases above the optimum range then there are more number of long distance transmissions thereby wasting energy.

4.4 Time Consumption

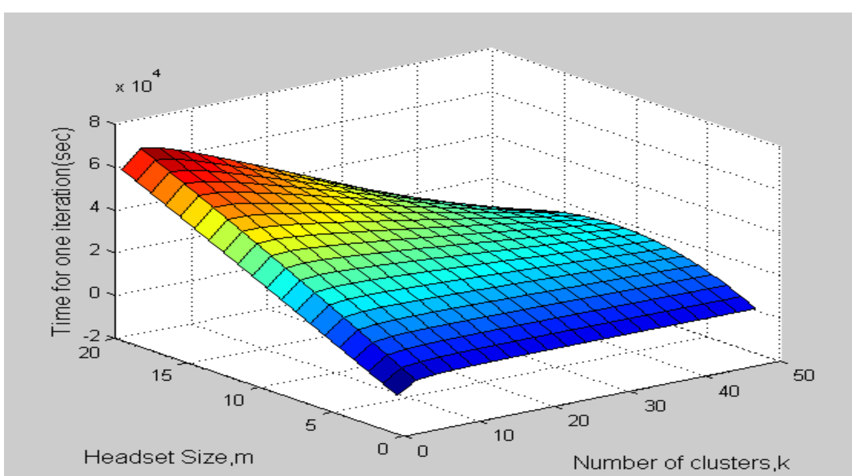

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FIGURE 8: Iteration time with respect to number of clusters and headset size

Figure 8 which gives the time taken to complete one iteration with respect to headset size and number of clusters is obtained using the equation (36). From the graph it is found that for constant values of k, iteration time increases when the headset size increases thereby increasing the lifetime.But for larger values of k iteration time reduces because the number of headset size decreases. So we have to see to that that the optimum number of clusters is being maintained.

4.5 Number of Frames Transmitted With Respect to Headset Size

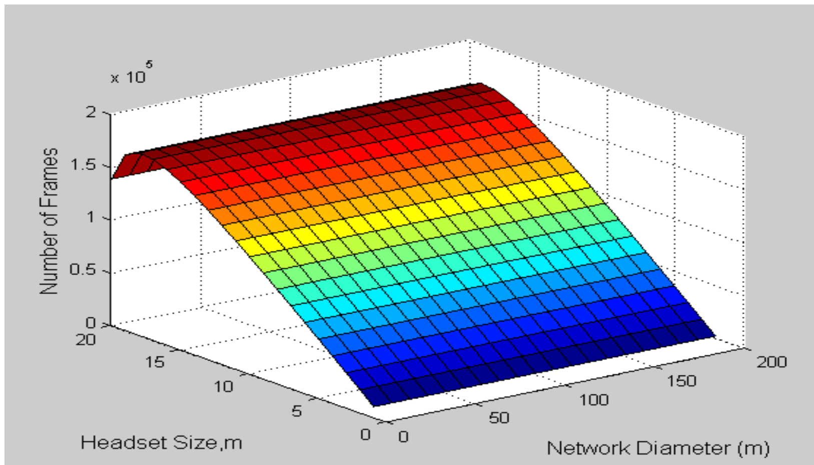

FIGURE 9: Number of frames transmitted with respect to headset size and network diameter

The figure 9 gives the number of frames transmitted with the help of equation (28). N_f is the number of frames sent per iteration, m is the number of associates present in the headset and M is the network diameter. From the graph it is obvious that when the headset size increases the number of frames transmitted also increases thereby increasing the iteration time.

4.6 Network Lifetime

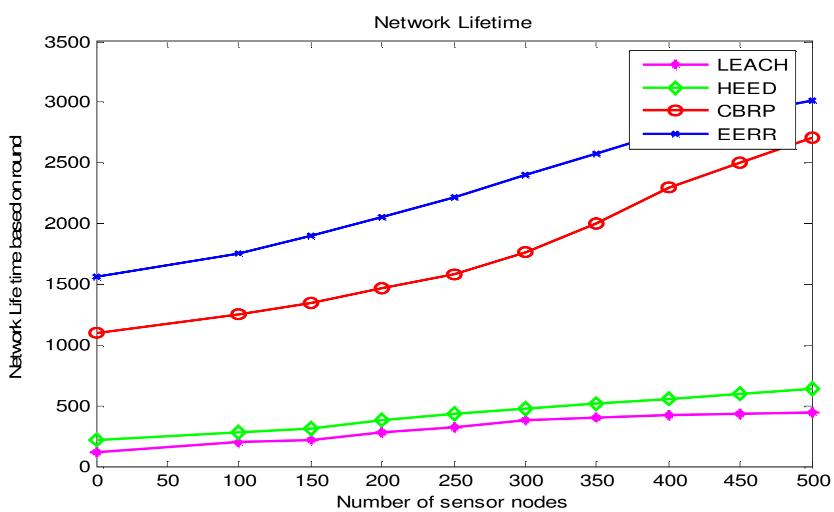

FIGURE 10: Number of Sensor Nodes Versus Network lifetime based on round

Figure 10 infers that the proposed protocol gives the better lifetime compared to LEACH and other clustering algorithms. This may due the following reasons. First, an alternating the role of cluster heads can balance energy consumption among cluster members. Second, by using variable head set size, as the headset size is increased the energy consumption is reduced because of the increase in sleeping nodes.Third, EERR protocol considered distance and residual energies of nodes and elect optimum cluster heads that can save more energy in nodes.

4.7 Comparison of Leach and Modified Routing Protocol in terms of Energy

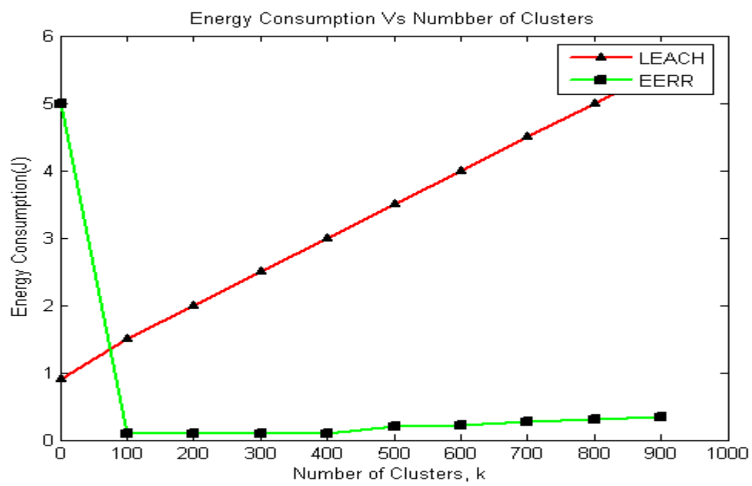

FIGURE 11: Comparison of LEACH and the modified routing protocol

Figure 11 illustrates the comparison of the LEACH routing protocol and the modified routing protocol proposed in terms of energy. This is done using the equations (31) and (32). From the graph, it is seen that as the number of clusters increases the energy consumed in the modified routing protocol is comparatively less than the LEACH routing protocol. In LEACH the energy is drastically increasing when the number of clusters is increased and so our EERR routing protocol is conserving energy when compared to that of LEACH.

5 CONCLUSION AND FUTURE WORK

The proposed EERR routing protocol that has been designed shows that the energy consumption is reduced when compared to that of LEACH. The simulation result shows that the modified routing protocol has a good performance in terms of energy and the lifetime of the network is increased. This is obtained by increasing the number of headset members because when the number of associates increases the number of nodes that are in the sleep state also increases thereby it saves the energy. Here the number of elections is also reduced when compared to LEACH from $\frac{n}{k}$ to $\frac{n}{km}$.

The future vision is to include node heterogeneity in the modified routing protocol that has been designed and to consider the node failures also. So considering the node failures fault tolerance feature should be included in the protocol.

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