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An Energy Efficient Design in LEACH Protocol Using Reactive Approach in Wireless Sensor Network

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Abstract: Wireless sensor networks are defined as building the network over the internet by connecting the data in a wireless kinship through sensors observing the environmental condition and reverting back in response. These wireless networks are made up of Routing Protocols, tracking the appropriate path to transmit data from sources to the reachable position. The routing protocols work between the nodes, there is the probability of unequal distribution of the energy amid them where LEACH Protocol comes to existence. The objective of the LEACH Protocol is to maintain the energy consumption which is used between the clusters so that it distributes energy equally in all the sensors of the network. Wireless network requires Throughput Optimization to observe the time taken by the system to convey the message, which helps to use the protocol in a well-mannered way and also to improve the lifespan of WSNs. The proposed research of the leach network analysed the efficiency using throughput in three scenarios. The throughput achieved by the leach network is higher as compared to the study done in other research.

Keywords: *LEACH protocol, Energy Efficiency, Throughput*

1. Introduction

A wireless network is a network of computers or other devices that operates wirelessly. It is frequently connected to a telecommunication network where nodes are connected to one another without the need of cables. The implementation of wireless telecommunication networks typically occurs at the physical level, or "layer," of the network and involves some kind of remote data transmission system, automation, or control that uses electromagnetic waves, such as radio waves, as the carrier. [11]

Some of the challenges while designing wireless sensor networks are: efficiency in energy, complexity, scalability, delay and robustness. The wireless networks are operated by battery. There can be thousands of nodes in wireless networks. Every node in the network has limited energy capacity due to partial amount of power. If the wireless network is complex then it will require more energy and more sophisticated hardware but there is a shortage of energy in wireless networks and unavailability of competent hardware. Scalability: The routing protocol should be scalable such that if number of nodes increases in the network, then the routing protocol should not interrupt it.[12] [13]

The classification of routing protocols is shown below:

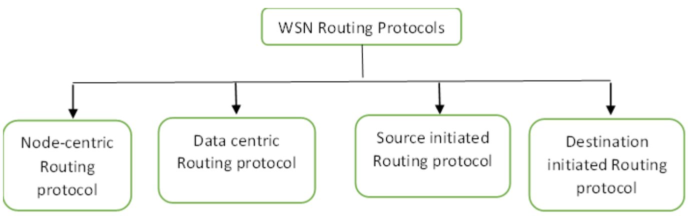

Fig 1: Basic classification of routing protocols

Low energy adaptive clustering hierarchy (Leach protocol): Leach protocol is a node centric routing protocol which is built on TDMA based MAC protocol. The aim of leach protocol is to reduce the energy consumption needed in generating and maintaining the clusters. This is because a node is no more useful once its battery dies away so minimizing the energy consumption enables that wireless sensor network to work for longer time.[15] Leach is a hierarchical routing protocol mostly used in heterogeneous networks. In hierarchical protocol, all nodes are grouped together to form clusters in the network. Each cluster is assigned a cluster head which collects data from other nodes in cluster and transmits that data to base station. The clusters of nodes are formed in such a way that equal amount of energy is divided among all sensor nodes of the network. The node with maximum energy is selected as a cluster head. In this type of network, all nodes send data to the nearest cluster heads in time division (TDMA) format according to the schedule created by cluster head. This scheduling is done in such a way that minimum energy is spent in reaching the cluster head. The work of cluster head is to collect data from all nodes, compress data and forward it to base station (also called sink).[14]

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NS2 refers to Network Simulator Version 2. It is an open-source event simulator. It provides code support to simulate the process of following protocols like TCP, FTP, UDP, https and DSR. The simulations of both wired and wireless networks can be made in NS2. The simulation is written in the scripting language of TCL. All the events of network simulations are saved in a trace file. The data from the log (trace files) is processed using the AWK script. The performance metric of networks can be determined by writing the script in awk.[16].

2. Literature Review

A.This defines the scholarly written articles by renowned authors who have given the brief description on WSNs and its protocols as well as some other connections. Through researches we understand the development in the particular field from the past few years and also find the new discoveries made in present era. Previous notes study plays a vital role while reviewing and research is settled for the topic and problem. As stated in the study of wireless sensor networks, sensors are the important part as they detect every type of thing, whether it is the target or any physical conditions (such as temperature, pressure, etc.). WSNs have a grasp over many of the sections in the technology nowadays and had impacted the IOT field a lot. The problems in regard to the WSN nowadays faced within their applications and then the contributions made by the authors in order to resolve the problems faced by the web of links and how it will be going to help in future are stated one by one below and as much as the area of problem to be known is important than the area of its utilization to be known is also necessary with the help of which it understanding the problem had become easy.

B. Utilization: WSNs network are utilized in observing, detecting and tracking appliances and one of the most important applications where this network had become the topmost priority is IOT and this is all because of the links developed over the web of internet. These are used for detecting the physical and environmental condition through sensors in built inside the system and track the target which makes things easier even over the remote areas. These wireless sensor networks play a wonderful role while communicating over the network’s setups at the remote areas.

For Example: Smart home, WSN based hospitals, buildings with IOT appliances, etc.

C. Modern Era have taken a lift in the growth of the technology. Technologies today have vast strength that they can easily provide solution to few of the problems. As we know that both if a statement has its good side than it basically also has bad side. In the same order if wireless sensor network has advantages in order to benefit us then it also has some challenges which are faced in comparison to another network such as redundancy, system life time, scalability, adaptability [1], production cost, node deployment and also lack of global identification, a database for the storage [1].

The authors stated possible solutions with the aspect of today’s world. They contributed a lot in order to resolve the problem to meet the modern era’s requirements and still the process is going on in the present. In order to cope up with the challenges of the wireless sensors network, different routing techniques are used as the routing protocol is none other than a sort of router organised in a cluster to conversate between the nodes in the network so as to share the data and choose the appropriate routes to reach the destination. Routing protocols use only one path at a time, but there are a few multiple paths routing protocol which uses many different paths at a time [1]. According to the research, protocols are based on the nodes to find each other and they are classified in few of the ways that are: Proactive protocols, Reactive protocols. There are few architecture-based routing protocols too which are: Flat based routing, Cluster based routing and Location Based Routing and many more also [1]. Wireless sensor networks have few reductions such as bounded bandwidth, limited energy supply and etc.

When the new nodes don’t replace the dead nodes which are caused by the energy consumption [2] and is only possible with the increased lifetime of the network. Other problems discussed by the authors are production cost and node deployment and as said by authors, LEACH protocol when the sticks to the cluster head and the high-end nodes will be leading the network and the low end might be working as the head node leading to a sudden collapse which assists the death of the cluster node and pauses the reach to the cluster. The probability of replacement of the new nodes becomes easy after using the LEACH protocol. This protocol stands for Low Energy Adaptive Clustering Hierarchy. As it is known that every protocol carries its own aim such as this protocol also has the aim of upgrading the longevity of the infrastructure less networks. These are helpful in reducing the consumption of energy in order to distribute equal amount to maintain the cluster in all sensor nodes. As per stated in the study, the LEACH Protocol have lots of modifications consisting of different types of rounds having two phases i.e., the Set-up phase and the Steady phase [2]. This protocol uses the central control algorithm also known as the global routing algorithm, which diminishes the exhaustion of energy as well as this algorithm is best known for developing better cluster heads which will be adaptable and the performance can be saved. The authors used simulation graphs to compare different types of LEACH protocols and compared their results in order to get the better solution in order to help getting a better network. Thus, the modifications are as such LEACH-C, MODLEACH, LEACH-B (Balanced LEACH), etc. Under the observation with the help of modifications of the LEACH Protocol shows the dead as well as alive nodes

This implementation of LEACH protocol improves the solution by improving the lifespan of the wireless sensor network. Also, the LEACH protocol and its classification helps in increasing the ability of tracking leading the applications to be efficient. The result after implying these techniques improved form of wireless sensor network works and enhances the quality of the network. Also, after the proposed solution the quality of services are provided and the network is improved with no duplicity and reduces the limitation of the sources.

Whenever the usage of WSNs utilization comes, the consequences of the issues that will be faced are problems related to the energy and network maintenance [3]. According the authors, the execution of the cluster head is implemented with different parameters design and also, the biggest problem faced is to keep up the settled proportion for the energy and not let the decreases in the speed. The solution proposed to resolve the problem of energy and network maintenance the algorithm is proposed in C language by the authors and they compared the range of dead and alive nodes with the protocols already existing in the world. The use of the programming languages take place persisting high technology naming MATLAB perfectly suitable for the algorithm. With the help of this the output terminated in the end is increase in the alive nodes and transmitted packets at the base station and network and also decrease in the number of the dead nodes. This solution in turns improve the development of sensors among the nodes of the network. Therefore, after the upgrade in the algorithm helps to save the energy as well reduce the cost.

Due to the neglection of the nodes after setting up in the remote areas there are few of the protocols which are prone to threats and attacks leading to the decrease of throughput with the increase of the attacks [4]. When the attacks start to enter the network, they eventually take place of the data and due to what the measure of the total amount of the information transmission doesn’t process in the particular time period. The threats create a trouble in the wireless networks as if they entered any one of the nodes it can destroy the whole network and sometimes this doesn’t get observed and reduces the performance of the routing protocols as well.

When the attacks take place, they degrade the performance which can be saved according to the authors by the energy efficient intrusion detection system to prevent from all sort of the security threats [4]. The authors stated that to stop the threats a secure protocol should be developed and intrusion detection system, a system that can detect the threats about to happen or the one approaching the network in order to take precautions beforehand in this wireless sensor network.

After the progress of the new developed solution, we can observe a better detecting machine or a target tracking machine which made it easier to track the target approaching the system. And, the increase in the throughput optimization is observed as the system in future will be less prone to the attacks which will not affect the time of message transmission in a particular time period.

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All these results helped and will help in the development of future generation as they have improved the result to tackle the problem with the new solution. The result after the enhancement of the techniques lead to very few chances of facing the above-mentioned risk and that is possible at higher risks.[5]

These reviews describe the importance of studying various types of forms and protocol from the previous studies and tell the drawbacks that can be sorted by the upcoming generation in order to keep up the pace with the growth of the technology. Things changes when solutions are proposed out for the problem.

3. Research Design

A. Experimental Setup

Experimental setup: Tcl language is used to design wireless network (Set parameters node, node configurations, topology, Connection between nodes, transfer packages and simulation time). To design Wireless network to be known all variable and define options to nodes. Some parameters used in wireless network to design are shown below:

a. Routing Protocol: LEACH

b. MAC layer Protocol: TDMA (Time division multiple access based medium access control)

c. Physical layers: different channels, directional antenna, Omni directional antenna.

d. Radio propagation, mobility models, Energy Models.

e. Topology Generation tools.

f. Visualization tools (NAM), Tracing.

S.No.	Parameters	Values
1	Area of simulation	500mX500m
2	Node Number	6
3	Types of Routing Protocol	Leach
4	Internet Protocol Type	MAC
5	Antenna Model	Omnidirectional
6	Packet transmission Rate	1.0 MB
7	Packet size	1500bytes(max.) and 1000 bytes(CBR)
8	Connection Agent	UDP

Fig 2: Parameters used in building leach network

B. Procedure:

Step 1: Initialize variables: In the proposed wireless network, 6 nodes are used. The routing protocol used is AODV: Ad hoc on demand distance vector. The network, on demand, forms the route and then transmits the packet. The two-way ground propagation model is used in this case. The wireless physical layer used which depends upon radio model. The radio model, by default, in NS2 is WAVELAN DSSS of frequency 2.4 GHz. The queue type used is DropTail and Priority queue. The priority queue is used so that if some packets need a priority then priority can be given to them. The omnidirectional antenna is used which can be used in any direction, spherical in shape which has a gain of unity. The interface queue length is chosen to be 50 bytes. The values of x and y represents the amount of area used for simulation which is kept fixed to 500metre X 500metres. This equates to 2.5 square kilometre of total area is being covered.

The initialized variables are being called in nodes after the node creation.

Step 2: Creation of a simulator object.

Step 3: Create, write and save a tracing and animation file: All the activities during the simulation of network are written in trace file which is named wireless1_leach.tr in new trace format. The animation file is created which displays the complete simulation of network. The area chosen for simulation display is provided by values of x and y - 500 by 500.

Energy Model: By default, nodes have infinite energy so to make it finite, energy model is implemented. The energy model decides the level of energy in a node. The energy of the mobile node is fixed in ns2 by building an energy model. The following components are important for designing of the energy model. These components are initialEnergy, txPower, rxPower, idlePower and sleepPower. Initial energy is the energy of node at starting of the simulation which is set to 100 Joules for all 6 nodes. A node loses some amount of energy whenever it transmits or receives a packet. The current remaining energy in node after transmitting and receiving the packets is called residual energy. The power consumed in transmitting each packet is set to 0.9 Watt, in receiving each packet is set to 0.5 Watt, power consumed by the node in idle state is set to 0.45 Watt and power consumption in sleep state is set to 0.05 Watt. The Initially, node 0 is chosen as Maximum energy. Traffic agents UDP and traffic source CBR is set up. It enables to creation of CBR traffic source using UDP as transport protocol.

Step 4: Create topography: The wireless nodes are moving on the floor i.e. in two dimensions. When nodes are moving they are moving in two dimensions – x and y axis whereas z-dimension is kept fixed. The flatgrid means simulation happens on flat surface where x and y dimensions are given whereas z axis is fixed 0. However, NS2 support all three dimensions.

Step 5: General Operations Director (GOD): A GOD object is created which handles the routine, packet exchange between the wireless nodes. The wireless nodes are autonomous so there should be something to control them and ask them to transmit the packet. So a GOD object is there for this purpose. It is beneficial to use GOD object because sometimes when node don't have any information what to do then GOD object can handle them. Only one channel is used in the network.[6]

Step 6: Create nodes: All node variables are configured. The mac trace and movement trace are kept on whereas agent trace and router trace are kept off. The initial energy is kept to 100 Joules. The transmission and receiver power is kept at 0.9 and 0.5. The initial position of nodes 1,2,3 and 4 are kept at 20 whereas for node 5 is fixed at 50. The x and y co-ordinates of all nodes are fixed to specific positions which must be less than maximum values of x and y i.e. 500m by 500m. Otherwise our nodes will be placed outside the display screen during simulation.

Step 7: Creation of channel (Communication Path).

Step 8: Position of the nodes: The wireless nodes in motion need a location whereas wired networks does not require location of nodes.

Step 9: Mobility of nodes: As the nodes in our wireless networks are moving so it is required to mention code for their movement. This will provide information about which node to move, the location where to be moved and at what speed. The nodes can move any number of times at any location during the simulation. The nodes which will be moving are nodes 1, 4 and 5. At 1 second nodes 1 and 5 will move at a speed of 25, 5 and 15 metres per second. At 20s, node 5 will move at a speed of 30 m/s.

Step 10: Defining multiple udp agents for sending data: The command is: set udp10 [new Agent/UDP]

Defining udp null agents for receiver: set null01 [new Agent/Null]

Attaching the udp agents to sender nodes: $ns attach-agent $n1 $udp10

Attaching the udp agents to receiver nodes: $ns attach-agent $n0 $null01

UDP traffic: UDP agent is attached and CBR traffic is created and packet size is set at 1500 bytes. The packet transmission rate is set at 1.0 MB.

Defining application instances: set cbr10 [new Application/Traffic/CBR]

Attaching all UDP agent to application agents: $cbr20 attach-agent $udp20

The packet size is set to 1000 bytes at the rate of 1.0Mb

Connecting all sender and receiving UDP agents: $ns connect $udp10 $null10

Step 11: Setting four clusters: A procedure setcluster is created for creating four sets of clusters each with different cluster head. The four scenarios selected cluster head according to the energy of the node. If node 0 has maximum energy then it is declared as cluster head or maximum energy node. Similarly, node1,2 and 3 are declared as cluster head if their energy is maximum among all other nodes respectively. The energy of all nodes is compared and four clusters of these nodes are created. The packets are sent within the cluster, and that node is selected as cluster head which has maximum energy. The simulation is run for a total 50 seconds.

Step 11: According to 4 scenarios of setcluster, four criteria of sending packets are created. Each criteria allows sending and receiving of packets between their respective cluster head and other nodes.

The leach procedure allows the transmission of packets according to selected maximum energy node. Eg. If node 2 has maximum energy, then the sendPackets2 procedure is called for data transmission in the cluster.

Step 11: Run the simulation

After the simulation is run, a trace file named wireless1_leach.tr and wireless1_leach.nam is created. The throughput and packet delivery ratio is determined by writing awk script in another file.

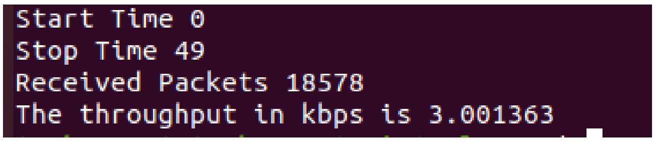

Fig 3: Output of awk script of throughput

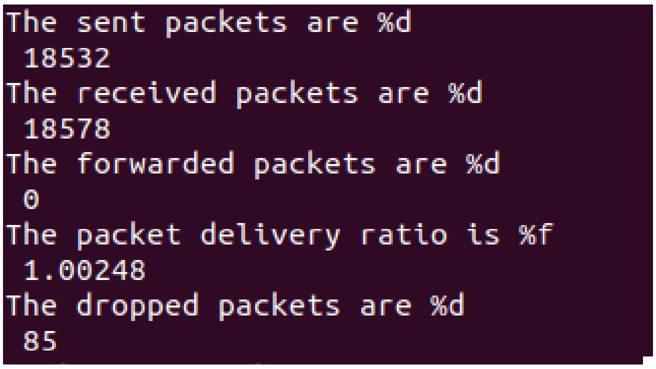

Fig 4: Output of awk script of packet delivery ratio

AWK script: The events of wireless leach network for residual energy are written in leach_exp3.tcl file and are stored in trace file: leach_exp3.tr. When .tcl file is run then trace file and nam files are created. AWK script is used in processing the data from the log (trace file). There are two trace file formats used in NS2: old trace format and new trace format. The new trace format is used in the wireless leach simulation. The trace file is processed columnwise by awk script where $1 represents first column, $2 – second column and so on. The performance metric is measured by packet delivery ratio, average throughput of the network and residual energy of network, written in awk script. The awk script is run with the command: gawk -f filename.awk filename.tr.

To obtain packet delivery ratio, file pdr_leach.awk is run using the following command: gawk -f pdr_leach.awk wireless1_leach.tr. The packet delivery ratio is calculated by taking the ratio of a number of received packets and number of sent packets in the network.

To obtain average throughput, file avg_throu_leach.awk is run using command: gawk -f avg_throu_leach.awk wireless1_leach.tr

To obtain residual energy, file leach_exp4.tcl is run using the command: $ns leach_exp4.tcl. After running the above file, a trace file is created with the name of leach_exp4.tr. The code for residual energy is written in resenergy.awk file which uses the parameter values fron leach_exp4.tr file to obtain residual energy of the network and of each node. The command used to run it is: $ gawk -f resenergy.awk leach_exp4.tr. The trace file is shown in figure 6 below.

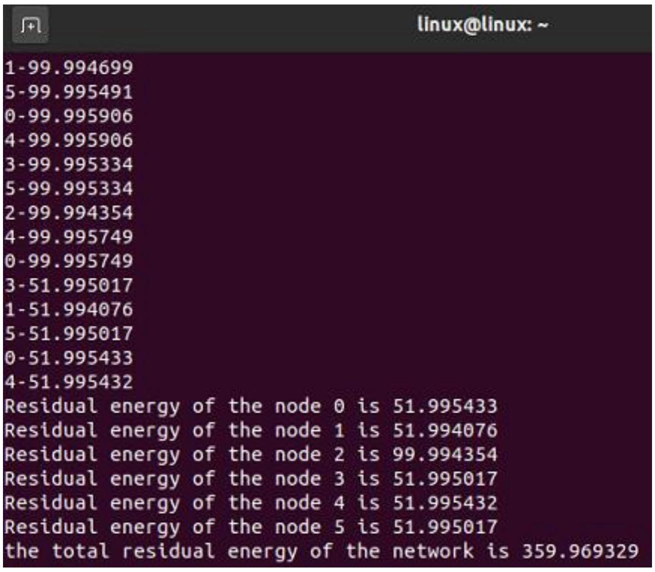

Fig 5: Output from trace file

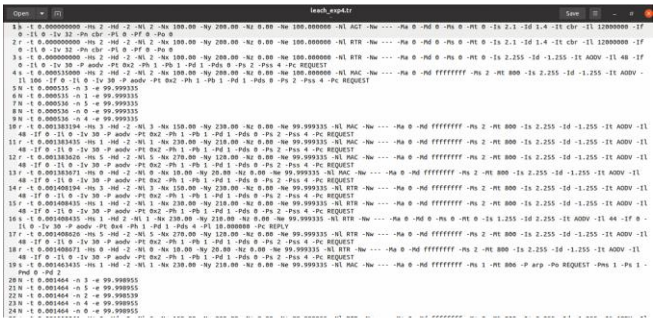

Fig 6: Output from trace file for leach network

Findings:

Throughput is the number of messages successfully transmitted per unit time. The throughput is calculated by dividing the message size with the time taken by the message to reach the destination. A unit of bits per second (bps) is typically used to measure throughput; however, other units of measurement such as bytes per second (Bps), kilobytes per second (KBps), megabytes per second (MBps), and gigabytes per second (GBps) have also been developed.It was concluded from the observations that as packet size increases, the throughput of the network decreases. The queue length is fixed at 100 packets and rate of data transfer to 3Mb. There is no variation in throughput of leach network as queue length increases fixing the packet size to 1000 and rate of data transfer to 3Mb. As the rate of transfer increases, the throughput of network first increases till 3.401 at 3Mb but starts decreasing as rate of data transfer increases further. The queue length is fixed at 100 and packet size at 1000.

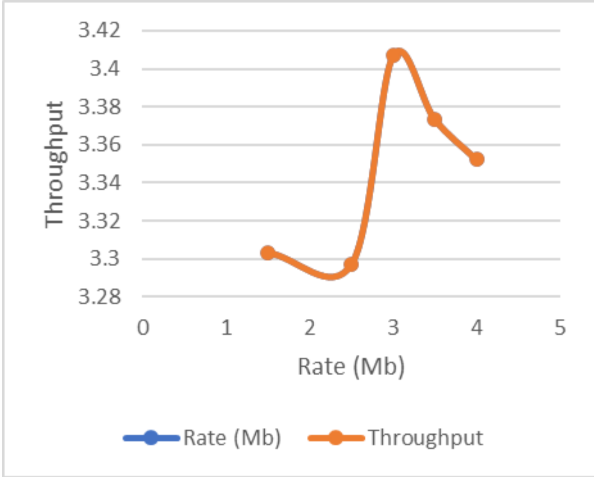

Fig 7: Throughput vaiation vs rate of data transfer

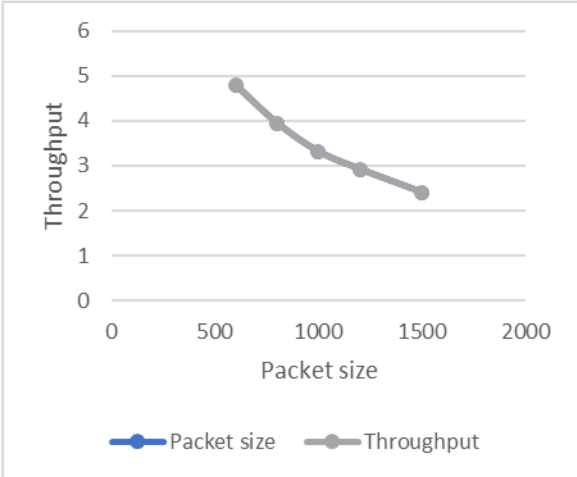

Fig 8: Throughput variation vs packet size

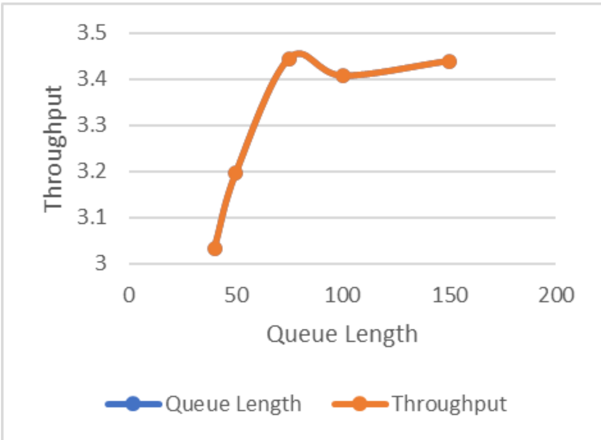

Fig 9: Throughput variation vs Queue length

The work carried out by Umeh et al. consists of throughput and delay analysis in a real time network where three different tools for network analysis were used. These tools are: Netstress, Wireshark and Jperf.

Table 1: Comparison of proposed paper with previous paper

Parameter	Proposed paper			Umeh *et al*. [1]		
	Exp1	Exp2	Exp3	Exp1	Exp2	Exp3
Throughput	3.48	3.3466	3.3041	2.378	2.5348	2.5227

The experimental setup in proposed paper is as follows: the packet size is varied keeping the data transfer rate and queue length fixed in experiment 1, the packet transfer rate is varied fixing the packet size and queue length in experiment 2 and queue length is varied keeping the packet size and data transfer rate fixed.

It is evident from the table 1 that average throughput of leach network is higher in all three scenarios of changing parameters as compared to all three experimental setups performed by Umeh et al.

Residual Energy:

The residual energy refers to the remaining energy level of a network node or device. It represents the amount of energy that is still available for use by that node or device after performing various network operations.

In wireless sensor networks (WSNs), for example, individual sensor nodes are typically powered by batteries, and these batteries have a limited capacity. As the nodes perform sensing, data processing, and communication tasks, they consume energy. The residual energy of a node is the remaining energy in its battery after accounting for the energy consumed during its operations. Monitoring the residual energy of network nodes is crucial in resource-constrained environments like WSNs. It helps in managing the energy resources effectively, identifying nodes that are running low on energy, and implementing energy-aware protocols and strategies. By monitoring the residual energy, network administrators can make informed decisions regarding node deployment, routing, and scheduling to prolong the network's overall lifetime.

Residual energy can be expressed in terms of voltage, battery percentage, or energy units specific to the system or device being used. LEACH network is abbreviated as Low Energy Adaptive Clustering Hierarchy. LEACH is the hierarchical clustering approach in which network is divided into set of clusters and each cluster is governed by clusterhead. The clusterhead is selected randomly initially and threshold in multiple rounds. In each round clusterhead role is rotated for all sensors in the network. The nodes in the network are either static or dynamic. After the first round, cluster head is selected based on the highest residual energy. The network's nodes' energy level is represented by the energy model. The initial value of the energy model defined in a node represents the node's energy level at the start of the simulation. We refer to this energy as beginning energy. In a simulation, the energy level in a node at any given time is represented by the variable "energy." As an input argument, the initial energy value is supplied. Every packet that a node sends or receives costs it a certain quantity of energy. Consequently, a node's initial energy value decreases. The residual energy is the amount of energy left in a node after routing packets have been received or sent. There is established data transmission between nodes using UDP agent and CBR traffic. The problem with energy measurement is that only the node itself can determine the remaining energy of a given node N; no other agent in the network can do so. Although N's neighbor nodes can capture messages sent from N and generate an approximate estimate, they are unable to precisely sort the nodes based on their residual energy since they do not know N's initial energy level at network deployment or the energy N expended on listening.[7]

A node must be asked in order to obtain its leftover energy. The following is a description of the suggested algorithm:

1. Every node assesses its leftover energy during the first phase and transmits the result to the cluster head.

2. The cluster head selects the n nodes with the highest residual energy after receiving the residual energy of every node in the cluster. Then, the cluster head sends them a message designating them as cluster nodes.

The cluster heads are selected based on the remaining energy of the nodes where the node with highest energy is selected as a cluster head.

The graph of residual energy is shown below where variation in packet size with respect to residual energy of the network is plotted. The rate of packet transfer and queue length is kept fixed at 1Mb and 50 packets respectively.

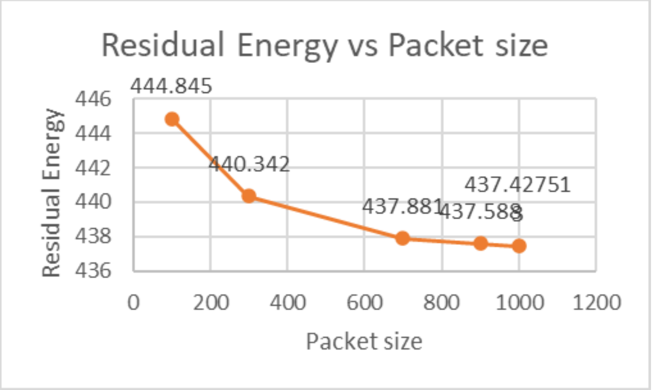

Fig 10: Plot between residual energy vs packet size

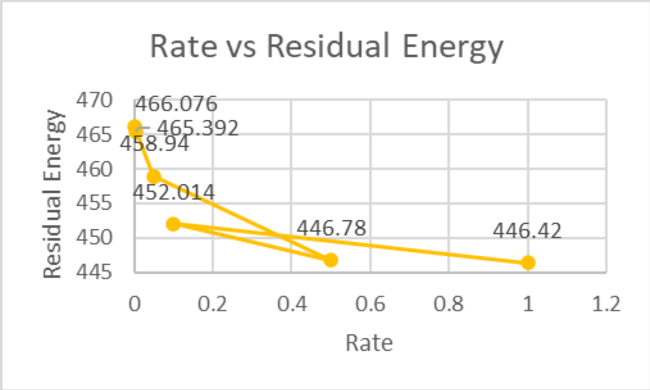

Fig 11: Plot between residual energy vs rate of transfer

The graph between residual energy and packet size of udp from udp10 till udp43 is shown in figure11. The packet size of all udp i.e. 10, 20, 30, 40, 12, 21, 31, 41,13, 23, 32, 42, 14, 24, 34, 43 is kept constant. The rate, queue length and packet size is kept fixed at 10, 50000 and 12000000 respectively.

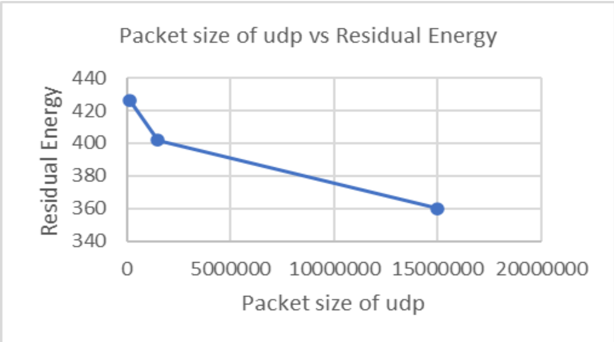

Fig 12: Plot between residual energy vs packet size of UDP

With the variation in UDP packet size, the residual energy of the network varies from 359.97 J till 426.165 J. The default value of residual energy of network and of each node is: 359.97J, 51.99J for node1, 51.99 for node2, 99.99 for node3, 51.99 each for node 4,5 and 6 respectively. The various parameters are optimized such that highest residual energy is achieved as compared to residual energy from default parameters in leach network. Therefore, with the variation in rate of transfer, highest residual energy of the network is achieved which is 466.076J. The residual energy of each node is 77.69J for node1, 77.68J for node2, 77.66J for node3, 77.68J for node4, 77.67J for node5 and 77.685J for node6 respectively. The above enhanced values are achieved at following parameters: rate of 0.0005Mb, queue length and packet size of 50 respectively. The experiment has achieved a percentage increase of 30% in residual energy of the network after variation in parameter values.

Algorithm: Proposed algorithm for enhancing energy efficiency

Step 1: Accessing current variables from trace format:

Event time, Node_id, Packet

Packet_id, Flow_id, Flow_type

Packet_size

Step 2: Reactive Method:

If event is send and packet=MAC and

sending time of particular packet id is 0

If time < start time then: start time = time

Send time of packet id = time

If event is received and packet = MAC

If time > stop time

Stop time = time

received size = received size + packet_size

received time of current packet id = time

Increment the number of received packets by 1

If number of received packets = 0 then display: No packet received

else: DISPLAY throughput value calculated as below

Throughput = Nr / Tr * 8/1000 Kbps

Where Nr = number of packets received

Tr = Time taken by the packet to reach the destination.

4. Conclusion:

The experimental setup of the proposed LEACH network proposed in the paper has achieved a 30% increase in the residual energy of the network. As the residual energy in a LEACH (Low-Energy Adaptive Clustering Hierarchy) network has increased to 30%, it indicates that the network nodes or devices have experienced an improvement in their remaining energy levels. This can be considered a positive development, as higher residual energy implies that the nodes have more energy available for future operations.

An increase in residual energy can have several implications and benefits for a leach network: Extended Network Lifetime: With higher residual energy levels, the network nodes can continue functioning for a longer duration before requiring battery replacements or recharging. This can lead to an extended network lifetime, ensuring sustained monitoring, sensing, and communication capabilities.

Enhanced Reliability: Increased residual energy reduces the risk of nodes running out of energy abruptly, which could result in network disruptions or failure. The higher energy levels provide a buffer, improving the overall reliability of the network and reducing the chances of node failures. Improved Network Performance: Higher residual energy allows nodes to engage in more intensive tasks or transmit data over longer distances. It can enable nodes to participate in more frequent or resource-intensive operations, leading to improved network performance, responsiveness, and data quality.[8]

Increased Scalability: When nodes have more energy reserves, the network can potentially accommodate additional nodes or handle increased traffic demands. This scalability is particularly useful in scenarios where new nodes need to be deployed or when network loads vary over time.[9][10]

Overall, an increase in residual energy to 30% in a LEACH network is a positive outcome. It indicates improved energy management, potentially leading to extended network lifetime, enhanced reliability, improved performance, and increased scalability.

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