ABSTRACT

ENERGY EFFICIENT HIERACHICAL WIRELESS ROUTING PROTOCOL

(EEHW ROUTING PROTOCOL)

By

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The areas of Wireless Sensor Networks and Internet of Things are considered to be the highly embryonic and most emerging arenas in research in the industrial or technical world now. This has brought about the inevitability of introducing or developing highly reliable, highly efficient, low cost, and low power sensor nodes to the market. Primary emphasis of wireless sensor network routing protocol is now on the coup of power preservation. Most of the modern publications have exposed so many protocols primarily intended to mineralize the energy consumption in wireless sensor networks. This thesis work recommends an enhancement to the gradient base hierarchical routing protocol technique introduced by Dr. Mozumdar in 2011. Proposed method introduces active/idle mode for end devices with time division multiplexing to cut down the energy usage and backup route has been introduced to end devices to send data back to the base station when the parent node fails to communicate. It is easy to perceive from simulation results that the enhanced protocol has higher lifetime compared to the original protocol. As a closing section, boosted energy efficient hieratical routing protocol (EEHW protocol) is implemented in Contiki OS.

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(EEHW ROUTING PROTOCOL)

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CHAPTER 1

INTRODUCTION

Wireless Sensor Network (WSN) is a forthcoming technology which has a diversity of applications. It comprises of home automation, building automation, infrastructure protection, medical device sensing, industrial sensing and diagnostics, environment monitoring and so on. Apart from the conventional application, now they are finding their way into many applications in work places, our homes and beyond, transporting new sources of statistics, control and handiness to our individual and professional lives. Wireless sensor networks are typically made up of a huge amount of sensor notes/actuators that could bring themselves together to form a wireless network. The gears of a wireless sensor network are Base Station (BS) (which is managing all the incoming data and controlling the network according to user requirement), Access Point node (AP) (could be a sensor node too), and End Device (ED) which are the sensor nodes. A typical sensor node is mostly a blend of four pieces, communication piece, sensing piece, power piece, and processing piece. This sensing module in a sensor node measures definite physical characteristic like light sensitivity, temperature or senses humidity or soil moisture of a site in which it is positioned. The processing module of a sensor node is accountable for gathering and processing of captured data from nearby it. Then the wireless communication module of the sensor node is accountable for transmission or/and receiving of data from one node to another sensor node or to an end user using any available routing protocol to the base station. These three components of the sensor node (sensor, processing unit, and communication component) need energy to function as anticipated. The power unit in the sensor node, which is of inadequate amount, is exclusively accountable for delivering energy to these three other components. Wireless sensor networks are typically positioned to screen either static or dynamic events in an environment. The capture of static events such as humidity and temperature is very simple to perform. Conversely, dynamic proceedings are naturally non-cooperative occurrence is the movement of whales in the ocean or an unsolicited vehicle in a battle field. They are not easy to screen and they are not steady as static sensing event. Consequently, it is always problematic to study energy profile and come up with a solution with energy saving systems for detecting of dynamic event environments. For instance, a human/animal tracking or vehicle tracking encompasses dynamic monitoring approach whereas disaster monitoring or forest monitoring application encompasses static monitoring approach.

Wireless sensor network requires defined protocol for competent performance. For illustration, WSN protocol can come in respect to precise application with a distinct instruction to amassed data and optimize energy usage. This kind of energy efficient protocol is referred to as hierarchical routing protocol. It is nevertheless vital to improve the energy efficiency for sensor networks as the energy could allocate for sensor nodes is typically tremendously limited and allocated energy required to last for long time for reliable, convenient, and cost effective wireless sensor network. And, due to the statistic that there is an upsurge in general dependence on wireless sensor network technology, we can foretell the intricacy of individual networks as well as massive rise in number of sensor networks.

Owing to the behavior of wireless sensor network, batteries are typically used to power a wireless sensor node. So, that the energy budget is very constrained for battery powered sensor nodes. To efficiently uphold the sensor network to have longer lifetime, and to be energy efficient all the zones of a wireless sensor network should be carefully planned. Among numerous methods, gradient base hieratical routing method is considered to be a good method in terms of energy efficiency; in this method components in the wireless sensor network arranged in a hierarchical way and each has its respective gradient value according to the level it is in the network. The end sensor nodes collect data and sends to their parent node (which is registered during backbone formation stage) and then the parent node (access point) transmits the combined information to the base stations (BS). If we could limit the frequency of data transmission and send some sensor nodes to idle mode, we may be able to minimize energy consumption in WSN. Particularly for WSN that has a great number of energy limitations on sensor nodes, it is essential to send some nodes to idle state when they are not required to collect or send data to their parent or cut down the active state when there is more than one sensor connected to one parent node at a time for non-critical applications. This may save huge amount of energy as the transmission, reception, and also the sensor active period which consumes the most energy is lesser in this enactment. Additionally, some data aggregation could be introduced at the access point node (parent node) to reduce the frequency of transmission also could save huge amount energy in the system. Apart from energy saved, efficiency of the sensor network, packet loss and overhead also should be take into account when designing a routing protocol or network architecture.   It could be good idea to introduce a backup route for end sensor nodes to communicate without discarding collected data when there is a link failure till the new parent has been chosen, which would improve packet loss then efficiency of the network.

Having Chapter 1 presents the thesis and its overview and Chapter 2 elucidates the hypothetical background of different routing protocols that could save energy consumption in wireless sensor network, modern wireless sensor network applications and Internet of things (IoT). Chapter 3 elucidates in depth the hierarchical routing protocol and proposed changes to reduce energy consumption and packet loss. Chapter 4 displays the endorsement of the proposed enhancements and how they are being implemented in NS2 and Contiki by presenting the simulation result of current hierarchical and enhanced hierarchical routing protocol. Chapter 5 settles the report and also the possibility of future enrichments is emphasized.

1.1 Related Work

With the commitment of minimizing energy consumption numerous approaches have been anticipated for wireless sensor network such as by Seema and Coyle [1] who described in what way to use distributed, randomized clustering algorithm with hieratical sensor network. Outcomes in stochastic geometry has been considered to originate resolutions for the standards of constraints of their procedure that minimizes the total energy consumed in the network when sending all the data collected by the sensors to the processing unit (base station) via cluster heads. The placement and the cluster based design was tested and compared with similar existing designs and conformed that this method could save energy in the sensor network.

By Li and Chen [2] who defined the LEACH protocol as cluster based self-organized hierarchical tactic for observing or monitoring applications. In this protocol information collection area of the data is arbitrarily alienated into clusters. In order to transmit data from the sensor to cluster-head time division multiple access (TDMA) has been used by LEACH. Then cluster head process combines the data before it transmits it the BS for dispensation. The contained management and control for the construction and action of clusters are some features of LEACH protocol. In this protocol cluster-head alternates randomly.

The protocol established by Pottie and Kaiser [3] says that it will generate clusters of the same size the between base station and cluster head using multi hop routing. The cluster head which frontwards the last hop is nominated arbitrarily from the groups of cluster heads to diminish the load of the cluster head which are situated bordering to the base station.

1.2 Problem Statement, Research Questions, and Main Contribution

More researches have been done on the topographies of hierarchical method have been found to be a superior method to efficiently lengthen the life time of a wireless sensor network. When considering a wireless sensor network, the energy is primarily expended by few main courses. Data transmission (Tx and Rx component), Data collision, Idle listening, Overhead, Signal processing, and Hardware operation.

It is shown that the 70% of the energy ingesting is triggered at the transceiver during data receive or transmission process [3]. As a result, the process of receiving and transmission of data must be improved to enhance the life time of a wireless sensor network. It is acknowledged that data receiving or transmission in wireless sensor network could be heightened by using well-organized routing protocol and effectual ways of sensor data accumulation. To advance wireless network lifetime, well-organized data collection protocols which assist to eradicate redundant data transmission in a sensor network should be in place. Habitually, a multi hop methodology is essential to ease data gathering by one node which can then forward the acknowledged data to neighboring mote that is closer to the BS. The accessible node aggregates five data collected and also forwards them on. But the procedure of aggregation and forwarding of the data straight from source to the base station roots significant energy surplus as each node in the whole network is vigorously involved in the process.

There is a situation of hieratical gradient base network where the network is former in way that the nodes are in a well-organized structure and sensors sending data to its parent access point and then the access point sends it to the base station using label switching table and next forwarding node. This method also eats an extensive amount of energy which needs to be upgraded upon.

Therefore, the research question could be formulated as. How could I advance the lifespan of the sensor network by sinking energy usage in Wireless Sensor Network for gradient base hierarchical routing technique? Additionally, implementation of this enhanced hieratical routing protocol in Contiki.

The theory which responses the query could then be set as:

To condense energy usage in wireless sensor network, I have anticipated a method with a principle of active and idle mode for end devices (ED), where end devices will go to idle mode for certain pre assigned time period when there is no need of rapid data sensing required by the sensor application when there is more than one end device attached to a access point. Since a hierarchical routing technique introduced by Dr. Mozumdar et al. [4] offers a good scalability, effectual communication tactic, and less energy consumption, its concept is successfully used and some enhancements are included to design energy enhanced routing protocol in wireless sensor network for building automation. In my approach, end devices will be placed in the idle mode when the data from them is not vital, then the access points will aggregate data and reduce the frequency of sending data to base station. Finally I am introducing an alternate parent node for each end device to use as a backup route when its parent node fails to communicate and till re-establishment is accomplished.

The main influence of the thesis could be concise as follow:

The thesis suggests the enhancements to the hierarchical routing protocol introduced by Dr. Mozumdar et al. to be more energy efficient and to improve the network lifetime of wireless sensor network by applying an idle mode using time division multiplexing, data aggregation and by introducing backup route for link failure. I have implemented this in Contiki and validation of the proposed idea has been done with NS2 simulation and the results are analyzed.

CHAPTER 2

HYPOTHETICAL BACKGROUND OF DIFFERENT ROUTING PROTOCOLS

2.1 Overview of Routing Techniques

Challenges come across as an outcome of inhibited energy source and bandwidth in wireless sensor network when handling the network demands and the need for advancement of energy consciousness protocol at all levels of wireless networking protocol stack. To bargain for a better and effectual power management in wireless sensor network, researches have put emphasis on areas such as energy conscious MAC protocols [4], system level power consciousness, and stumpy duty cycle issues. Also, it was easily detected that the network-layer bargains balances energy efficient routes arranged inside the network and reliable imparting of data to expand the lifetime of the network.

It is well known that routing in wireless sensor network has many distinct features related to ad-hoc networks or modern communication [5]. The features of wireless sensor networks are listed below:

1. It is not advisable for wireless sensor network to be built with global addressing (IP addresses) arrangement owing to the huge number of sensor nodes. (But nowadays with IPv6 technology some applications are developing with IP addresses and some devices are available to purchase with both the wireless IP and RF capability for certain applications).

2. There is substantial laying-off in produced data since some sensors may be in the same area and could gather similar kind of data. By saying that, additional or redundancy desires to be detached to upsurge the band-width usage could also to lessen usage of energy in the wireless sensor network.

3. The power of the transceiver (transmitter and receiver), data processing volume, and storing capability are restraint factors need to be well-thought-out when managing a wireless sensor network.

Owing to these alterations, new protocols are being researched, existing protocols being enhanced; researchers and industries are been fashioned to eradicate the problems related to wireless network. These routing protocols have been modified on its architectural requirement, and wireless sensor node characteristics together with its applications. The numerous protocols could be classified as hierarchical, data-centric, or location-centric, even though there are other routing protocols established based on flow quality.

2.2 Data-Centric Protocol

It is known that the difficulty of broadcasting data in a wireless network and numerous energy conscious routing protocols or algorithms were suggested to overcome this issue. Generally those routing protocols could divide to two categories, data centric or location centric. When considering a data centric method[5],[6] use metadata debate or specified data before any real communication to eradicate laid off data sent out, therefore attaining lifetime enhanced energy distribution. Kulik et al. [7] say that the ADV, REQ, and DATA different types of messages were used which is “3-stage” data-centric rule set, to transfer data in-between nodes. Then analytical results were used to determine what kind of packet dissemination method should be use for given set of rules in a wireless network. These methods are named as multi-hop unicast or single-hop broadcast in a WSN.

2.3 Location–Base Protocol

The majority of the routing techniques for wireless sensor network consider the location or position data available of sensor mote for judgment of space within given 2 explicit nodes to infer power usage. Consider an instance: to identify published area, via use of sensor which can detect location, an individual query could be sent to that known section and this will considerably decrease transmitted data matched up to a broadcast call for being sent to the whole network. If we put this in a different way, the area or location considered algorithms make use of location information to pass on the data to preferred section rather than complete set-up. A protocol that is most commonly used by location based technology is minimum energy communication network (MECN). These kind of network sets up and also uphold a low energy in a wireless sensor network by use of low power global power positioning system (GPS).

2.4 Hierarchical Routing

Routers are categorized in groups called regions for hierarchical routing method. In this method, only available data in a each router is only the routers or end devices within its individual sector or region; also there is no data regarding the other regions and their routers. Hence the routing device will put aside single information in its routing chart for different areas. Hierarchical data sending rule capably decreases energy consumption by engaging multi hop communication for an explicit cluster or region and therefore acting accumulation of the data and combination to support declines the amount of data pushing through the wireless network to its sink. Figure 2.1 shows sample hierarchical routing network with separated regions.

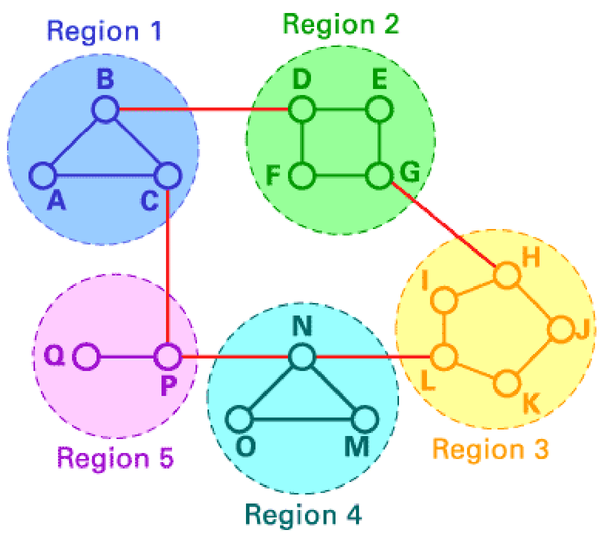

FIGURE 2.1. Hierarchical routing network with separated regions.

In Figure 2.1, if node A is looking for broadcasting data packets to any possible node (router) in region or area 2 (node D, node E, node F or node G), it will send it to mote B, and so on. As we can observe, using this kind of data sending, charts could be potted, hence the set-up effectiveness advances. Picture shows demonstrations of hierarchical routing for two levels. Then always we can look into level three or level four hierarchical method if the network is complex or bigger.

The table below (Table 2.1) demonstrates the contrast [4] of the different routing protocols in terms of lifetime, scalability, power required, and data dispersion in wireless sensor network. By observing we recognize that hierarchical technique gives a tactic to scalability and energy reduction in a WSN.

TABLE 2.1. Contrast of Routing Protocol

	Data Centric	Location Based	Hierarchical
Lifetime	Limited	No	Good
Scalability	Long	Long	Long
Data Diffusion	No	No	Yes
Power usage	Limited	Limited	High

2.5 Internet of Things (IoT) and WSN

The word Internet of Things (IoT) was invented more than a decade ago by engineering industry researchers, but it has arisen into conventional communal view in recent time. Some claim the IoT might wholly alter how the computer networks/sensor networks are used at least for five to six decades, though others have faith in IoT is just propaganda that will not much influence daily lives of the majority of people.

2.6 What Is IoT?

Internet of Things signifies a common idea for capability of network-devices to collect or sense data from anywhere, and then share those collected data through the Internet anywhere it could be used and administered for numerous stimulating resolutions. Now Internet of Things could be found almost everywhere. There are industrial applications, home automation applications, building automation applications, medical applications, and military applications and so on.

CHAPTER 3

HIERACHICAL ROUTING PROTOCOL AND PROPOSED CHANGES

3.1 Hieratical Wireless Network Protocol for Building Automation

This Hieratical Wireless Network Protocol is designed based on the gradient base architecture and it could be separated to few sections for easy observation.

1. Network Formation
2. Handling Node Failures
3. End Device Joining to Backbone Network
4. Upstream Data Flow
5. Downstream Data Flow

3.1.1 Network Formation (Backbone. Beacon Packet)

Network formation is the initial and main element of the hieratical sensor network which makes the backbone of a network. In this phase network will decide which end device is connected to which access point and the route from access point to the base station.

Initiation of the backbone formation starts from the base station by broadcasting a control packet called. "Beacon Packet". The structure of the beacon packet is shown in Figure 3.1.

Beacon packet

Pkt_type	gradientVal	senderID

FIGURE 3.1. Structure of a beacon packet (BP).

Let us consider below network with five nodes and discuss how its backbone and the network work in Figure 3.2 with gradient base hieratical wireless network routing protocol.

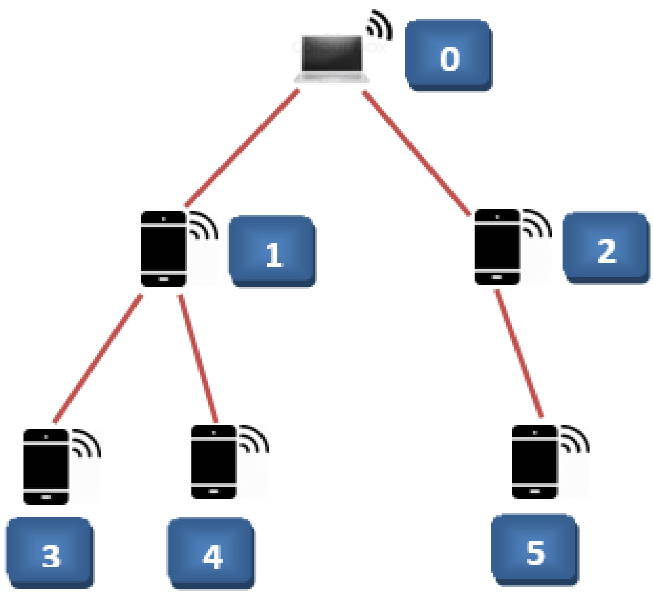

FIGURE 3.2. Sample hierarchical network diagram 1.

To begin with base station (node 0) is broadcasting a beacon packet with below details, GradientVal = 1

SenderID = 0

This beacon packet may receive by the access point 1 and access point 2 as they might be in the range of base station. Then access point node 1 and 2 when they receive beacon packet sent by base station will position their parent to node 0 and then amend their gradient value to 1.

Secondly access point (AP) nodes 1 and 2 will re-broadcast the beacon packet by altering its gradient value and sender ID field as below,

GradientVal = 2

SenderID = nodeID

There could be two scenarios where the re-broadcast from access point 1 and 2 could happen from access point 1 first then access point 2 second or access point 2 first then followed by the access point 1.

Case 1. Access point 1 broadcast the beacon packet (BP) first then access point 2. The beacon packet (BP) coming from access point 1 may receive by node 0, 2, 3, and 4 as they might be in the vicinity (in the range) of access point 1.

1. Node 0, 2 will not alter their parent, as they already have a parent with lesser gradient value.

2. Node 3 and 4 will alter their parent to node 1, then alter their gradient value to 2.

Now node 2 will transmit the beacon packet (BP) and it could be received by node 0, 1, 4, and 5 as they could be in the range of node 2. Since all the nodes already have their parent node and gradient value set except node 5, other nodes will disregard the BP coming from node 2.

3. Now node 5 will acknowledge node 2 as its parent and position its gradient value to 2.

Basic rule for re-broadcasting a beacon packet (BP) is only if node's gradient value changes to lower gradient value it will re-broadcast the beacon packet. In this set-up, node 2 will not re-broadcast the beacon packet received from node one since it already has a parent with lesser gradient value. In this way, each node will have only 1 parent and respective gradient value, even though it might be in the proximity of quite a few potential parents. This process forms a tree and the backbone of the network.

There are few scenarios where node is toggling its parent;

1. Node will do alteration to its parent if its parent is dead.
2. Base station will rebroadcast this beacon packet,
    a. If it is not getting sensor data from certain number of nodes for an explicit period of time to reform the network.

3.1.2 Handling Node Failure

It is important to check the health of the backbone network regularly to have reliable network. In this stage there will be an additional control packet introduced to the network to monitor health of the parent nodes (Parent Status Query packet. PAQ packet)

Structure of the parent status query packet is shown in Figure 3.3, Parent Status Query (PSQ)

Pkt_type	parentID

FIGURE 3.3. Structure of a PSQ packet.

As portrayed earlier, each node will check its parent's wellbeing in an interval by going through subsequent steps (consider the network shown in Figure 3.4),

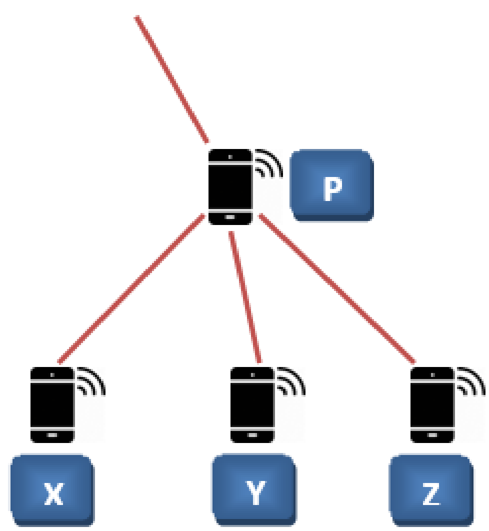

FIGURE 3.4. Sample hierarchical network diagram 2.

Step 1. At nextPSQuaryTime, node X will send a PSQ packet with below values to its parent node.

a. Pkt_type = 40

b. parentID = X

The method to calculate "nextPSQTime" is shown below.

nextPSQTime = Min_feed +Dist * Parent_Status_Check_Interval

Step 2. After receiving PSQpacket node P will change the value of packet type to 41 and re-broadcast it (Pkt_type = 41).

Step 3. After receiving PSQ packet with pkt_type = 41, all child nodes will be updated their parent status to parent is alive. In this scenario X, Y, and Z receive this packet. Since X sent the PSQ and it has received PSQ reply from node P (parent node), X will reschedule an event at the nextPSQuaryTime to check status of P while Y and Z nodes will put off their immediate PSQ and schedule deferred even to check the status of P (parent node).

Step 4. If a child does not receive PSQ response for certain repeated time from its parent, it will set its gradient value to "NIL" and search for a new parent.

It is critical to search for a new parent quickly and efficiently when child node identifies the inactivity of its parent node. In the next section we will discuss how this new parent searching procedure works.

3.1.3 Searching for new parent when parent node Fail

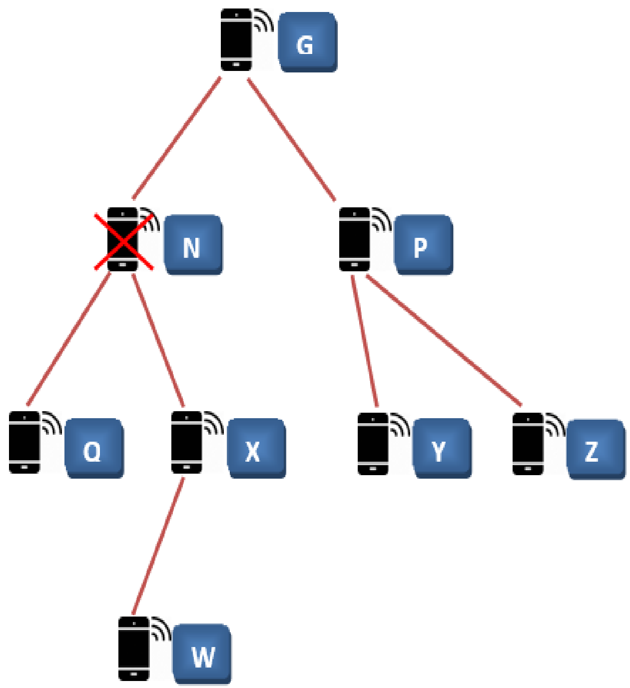

FIGURE 3.5. Sample hierarchical network diagram 3.

The 3.5 shows a simple hierarchical network and there is a failure parent node. Suppose node N is dead and node X fails to get a PSQ response for certain consecutive times from node N (same for node Q, let us consider X at first).

At this time, child nodes will create a new packet called "Parent Discovery" (PD) packet to look for parents.

Parent Discovery (PD)

Pkt_type	senderID

FIGURE 3.6. PD Packet Structure.

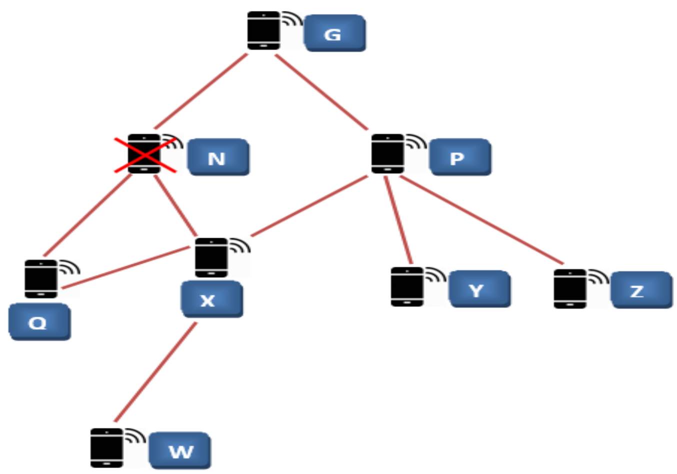

FIGURE 3.7. Sample hierarchical network diagram 4.

For the 3.5 scenario, node X will be broadcasting a PM packet with senderID = X. Presume, this PD packet will receive by P, Q, Y, and Was they in range of X node. Then they will proceed as follow.

1. A node after receiving PD packet, it will check its sender ID

   a. If senderID = Node_parent→Do nothing

This scenario matchers the node W in the three network, so node W will not respond to the PD packet and it will prevent looping circumstances in the network.

b. If senderID != Node_parent→ then check the parent nodes inactivity

If parent not alive → Do nothing [case for Q]

This is the case for node "Q" in the 3 network as its parent is alive

If parent is alive → Generate a Beacon packet and broadcast it

For the 3 network, node P and Y satisfies these condition so they will generate a beacon packet and re-broadcast it again.

Now there could be 2 scenarios where node X receiving beacon packet from node P or node Y first.

Case 1. Node X receives beacon packet from node P at first then from node Y.

1. Beacon from Node P.

Node X will set node P as its parent and also change its gradient value and then will re-broadcast it.

a. Beacon packet from node X might receive by node Q and node W as they might be in the range of node X.

b. Since node Q also looking for a parent, it will set X as its parent and re-broadcast the beacon packet.

c. Node W after getting beacon packet from node X, it will find that the beacon packet is from its parent node, so it will do nothing.

2. Beacon from Node Y.

Node X finds it out that the beacon packet holds higher gradient value than current parents' gradient value, so it will do nothing.

Case 2. Node X receives beacon packet from node Y at first and then from node P.

a. Beacon from Node Y.

Node X will set Y as its parent then change its gradient value and will re-broadcast it. Beacon packet from X might receive by node Q and node W as they might be in the range of node X. Then node Q and node W will pursue the same course of action as mentioned before in the case 1.

3. Beacon from Node P.

Node X comes across it out that the beacon packet (BP) holds lesser gradient value thank its current parent, so it will modify its parent to node P and re-broadcast the beacon packet. Then node Q and node W will update their gradient value but their parent will be the same (node X).

Node Q also finds out that its parent is not alive. This identifies by not receiving PSQ response for 3 consecutive times. Now Q also will broadcast a PD packet, when nodes X also looking for a new parent. Let's look at the steps of finding new parent using 5.

1. The PD packet broadcasting from Q might receive by node X and node W as they might be in the communication range of node Q.

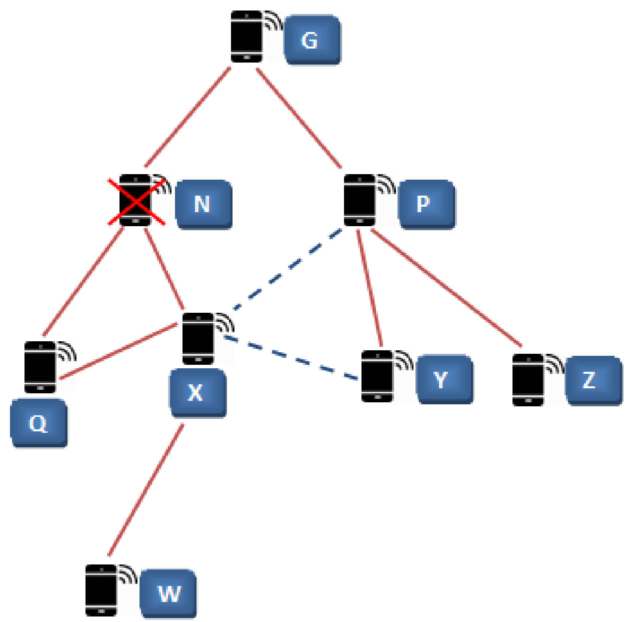

FIGURE 3.8. Sample hierarchical network diagram 5.

2. Presume that node X is still in the course of finding its parent and at present its parent is not alive. Then node X will respond to PSQ coming from node Q.

3. Since node Q is not node W's parent node and parent of node W which is node X is alive, node W will broadcast the beacon packet and it could receive by the node Q and node X as they might be in the range of node W.

4. Now both node X and Q set their parent node as W. This could form a isolated graph and if node X set Q as its parent it could cause to form a loop as well.

5. Then when the node X receives a beacon packet from either node P or node Y in the request of PD packet, it appears that the formerly formed loop will be kaput and network graph will be connected again.

This explains the process of finding a parent node when node fail and end devices are not able to communicate with its parent access point node or the base station.

3.1.4 End Device (ED) Joining into Backbone Network

Joining end devices to the network is also takes a critical part when considering hieratical network architecture. In this section we will discuss how the end device joining to the network and also after formation of the network if there is an additional end device been added to the network as a part of the scalability factor.

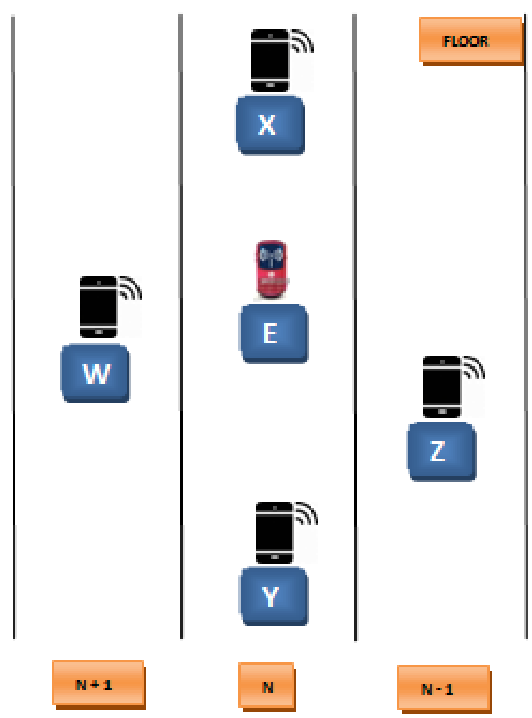

FIGURE 3.9. Sample hierarchical network diagram 6.

In this stage there will be an additional packet been introduced to the network which called "End Device Join Request Response (EJRR)" packet. Below shows the structure of the EJRR packet and a simple network diagram Figure 3.9, to illustrate the steps been perform during this stage.

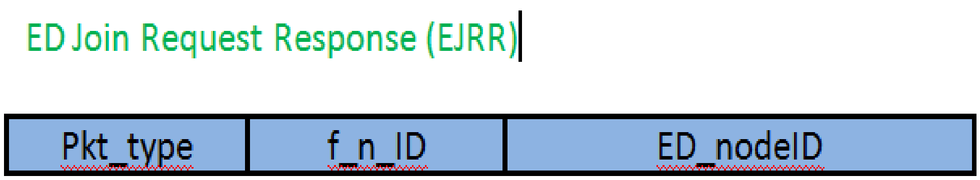

FIGURE 3.10. EJRR Packet Structure.

Assume we are adding a new end device to the network. However, it is essential for user to preset the floor ID, and other useful information on the end device when they adding to the network. Let us consider the steps of end device joining to the network.

1. After powering up the newly added end device node, it will broadcast a EJRR packet with below information.

   a. pkt_type = 20 (This uses to identify the request)

   b. f_n_ID = x (floor ID)

   c. ED_NodeID = nodeID

2. EJRR packet might receive by node X and Y from the same floor and node W and Z from other floor as they might be in the communication range of node E.

3. Now when access point node receives the EJRR packet, firstly it will look at the f_n_ID field to determine whether the request is coming from the same floor. If access point finds out that the request is coming from another floor, it will disregard the EJRR request as it hypothetically designed to add end devices from the same floor. For the given scenario, node W and Z comes to this category and they will not get any response.

4. Then if the EJRR packet from the same floor, access point will modify the request as below and re-broadcast it.

   a. pkt_type = 21 (This identifies the response)

   b. f_n_ID = nodeID (node ID of the access point)

This will be the case for node X and node Y.

5. Finally node will binds to the node from which it receives end device join request response (EJRR) packet at first.

6. Presume node E receives EJRR packet node X first, then it will modify the EJRR packet by setting pkt_type = 22 (This signifies the conformation) and broadcast it.

7. Node X after it receiving EJRR conformation packet set by node E, it will add end device node in to its child list and route all data from it to the base station (BS) which completes the end device joining sequence.

3.1.6 Upstream Data Flow

For simplicity upstream data flow could be separated to two main sections.

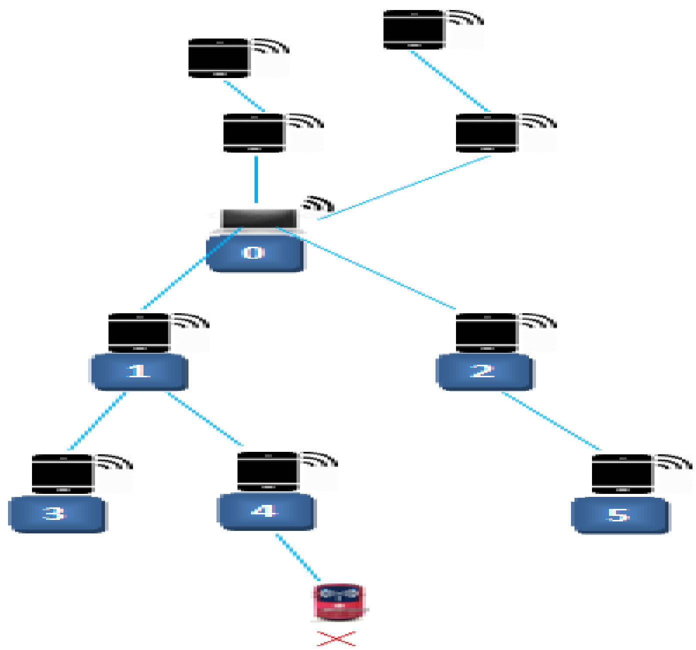

FIGURE 3.11. Sample hierarchical network diagram 7.

1. From End Device (ED) to Access Point (AP)

Regard as the network seen in the Figure 3.11, end device X has joined access point node 4 and it is con d to account sensor data at certain episodic interval. At periodic interval node X will put up an ED Sensor Report (ESR) packet and broadcast it. Below shows the structure of the ED Sensor Report (ESR) packet.

The ESR packet may receive by the other nodes in the range of X. But only node 4 will process the ESR packet coming from node X, since node X is a child of node 4.

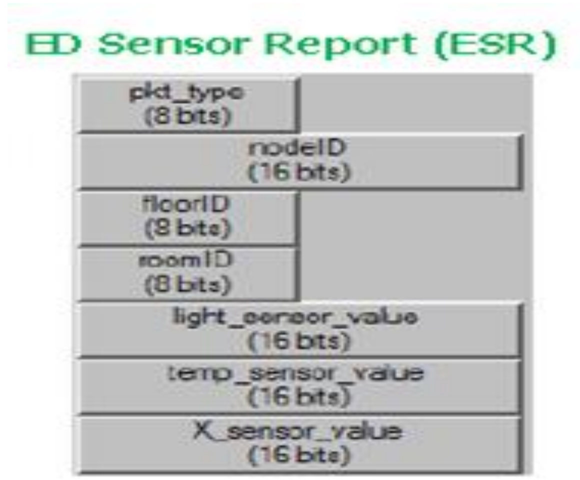

FIGURE 3.12. Structure of ESR packet.

2. From Access Point (AP) to End Device (ED)

Once access point receives ESR packet it need to be process and route back to Base Station.

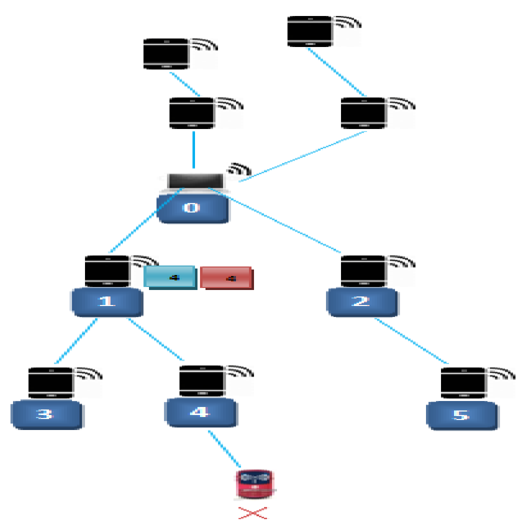

FIGURE 3.13. Sample hierarchical network diagram 8.

Consider the network shown in Figure 3.13 to understand the upstream data flow from access point to base station. In this stage access point node which is node 4 will put up a packet called Access Point Sensor Report (ASR) as below.

a. nextForwarding Node = It's Parent ID
b. currentForwardingNode = It's nodeID
c. sender = It's nodeID
d. Payload = This will complied from the ESR packet

There for when node 4 broadcasts this ASR packet, it could receive by node 1, 3, and 5 as they are in the range of node 4. When those access point nodes received ASR packet, they will check the value of the "nextForwardingNode" field. If the receiving node is not the next forwarding node, it will throw away the ASR packet, for the eight scenario, this will be the case for node 3, and 5. However, for node 1, "nextForwardingNode" field matches with the received node ID, so it will re-broadcast ASR packet again by modifying packet fields of nextForwardingNode and currForwardingNode according to its information. As seen in the 8, the forwarding nodes will uphold a "label switching table" to record following info (at node 1).

a. Sender NodeID (in this case Node 4)
b. Immediate downstream router ID (Node 4)

All this info will be used to route downstream packets. Eventually this process of forwarding goes on until the ASR packet reaches at Base Station (BS), which completes the upstream data flow.

3.1.6 Downstream Data Flow

Same as sensor data flows from end devices to base station, some packets with instructions should flow from base station to end devices. For simplicity and for analysis, let us consider the network diagram shown in Figure 3.14 and base station is sending a packet to node Y.

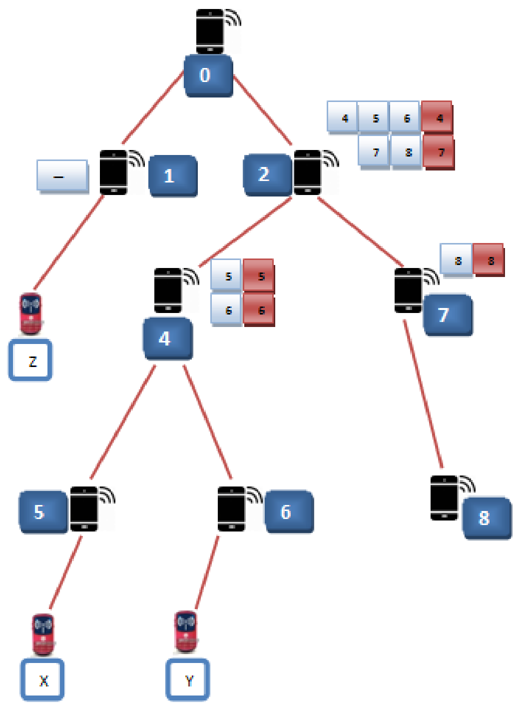

FIGURE 3.14. Sample hierarchical network diagram 9.

By looking at the label switching table created at the network formation, base station knows that the node Y is connected to access point node 6. Then with the help of label switching table, each access point will decide the next forwarding node till it reaches the final destination node which is node Y, which completes the downstream data flow.

3.2 Enhancement to the Current Protocol

To further perk up to save energy consumption and the reliability of the packet for this hieratical network routing protocol, there are few changes been introduced to some back bone packets and few additional control packets been introduced at both the end device, and access point.

3.2.1 Concept of Active/idle mode using time division multiplexing

The concept of active/idle mode is to save some part of the energy consumed my end devices when they are always awake and keep sending data to access point. For sensor networks, it is not vital to collect data very regularly and reporting them back to base station. Because if the network is designed to collect temperature, light intensity, or humidity (most of the sensor networks are design to monitor/ control these data) the data that are collecting will not change immediately, they will take some time to have good impact on the environment. And also if one access point is connected to several end devices to collect sensor data, it is not that necessary to collect data from each node and send them every time. Hence, if there is more than one end device connected to access point and the system not required very regular monitoring, we can let some nodes go to idle mode and wake them up when we needed to collect data. In this way we able to save huge amount of energy as devices are consume very less energy when they are in idle mode. And also by limiting or reducing the frequency of collecting and sending back the data also will help to save huge amount of energy for each end device.

Below shows the process active/idle mode been introduced for end device.

1. Initially after formation of the network, EDs will go to idle mode and wait for wakeup request from its AP.

2. When the time arrives, AP will send a request to selected ED to wake up. In this stage there will be a new control packet called "Wakeup Request Packet (WKRP)" is introduced. Access point will send a WKRP packet with below information.

pkt_type = 30 (which represents the wakeup request)

NodeID = ED_nodeID (which node to be wake up)

Structure of the WKRP is shown below.

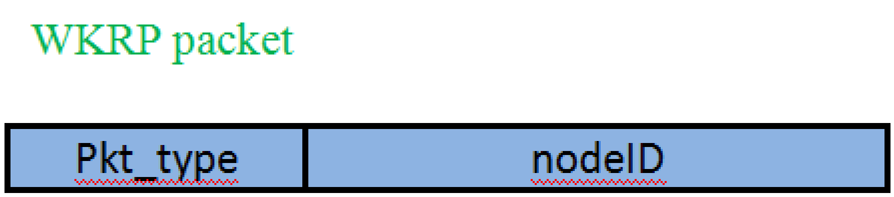

FIGURE 3.15. Structure of WKRP packet.

AP will select ED using time division multiplexing. So access point assign dedicated time slot for each end device connected to it to collect and send back the data to access point. Figure 3.16 shows the time assignment diagram for a simple sensor network.

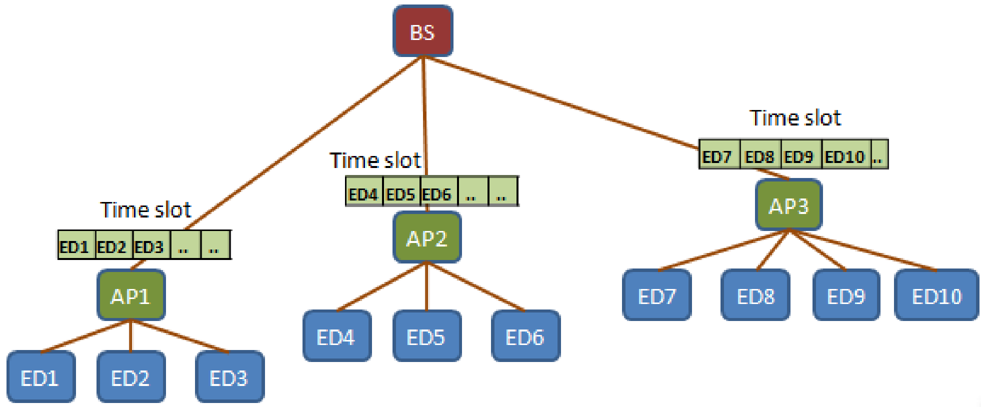

FIGURE 3.16. Time allocation to ED.

Next step is end device will send a packet called "wakeup acknowledgement packet (WAP)" to its parent node by acknowledging its presence. After acknowledgement received, access point is open for data coming from that end device. During this time end device will collect sensor data and report back to access point till it receives a "sleep request packet (SRP)" from its parent node. When the assign time ends, access point will send this SRP to its child node who is communication and wait for its "sleep acknowledgement packet (SAP)". Once this process completed, access point will move to its next child node and do the same.

Structure of the "wakeup request packet (WRP)", "wakeup acknowledgement packet (WAP)", "sleep request packet (SRP)", and "sleep acknowledgement packet (SAP)" are similar and pkt_type is changed to identify the packet type.

Wakeup Request Packet (WKRP):

pkt_type = 30

nodeID = EDnodeID

Wakeup Acknowledge Packet (WKAP):

pkt_type = 31

nodeID = parentID

Slpeep Request Packet (SRP):

pkt_type = 32

nodeID = EDnodeID

Sleep Acknowledge Packet (SAP):

pkt_type = 33

nodeID = parentID

3.2.2 Pros of Active/Idle mode at ED

1. Save energy by sending to idle mode
2. Save energy by reducing amount of data been sent to access point
3. Save energy by delaying all the control packet processes to check health of the parent node.

Presume access point has 4 end devices connected to it, the amount of energy save owing to active/ idle mode introduction is about 75 -80 % of the energy been used without this improvement.

However, there are some drawbacks and limitations when introducing time multiplexing active idle mode on end devices.

1. It is not desired to implement this method on highly sensitive sensor networks as delay in providing sensor data might cause some issues.

2. Where the system is required to act rapidly (related to medical or high risk) are not recommend using this method.

3. When one access point has huge amount of end devices connected, this might cause delay in gathering and sending data back to base station (inefficient network). (Will discuss more about in the next section)

3.3 Data Aggregation at Access Point

If the access point tends to send every data coming from each end device every time, it will use up huge amount of energy its internal energy. To cut down some of the energy been used, new enhancement been introduced to access point node, which is waiting for data comes from its all the child nodes (end devices) then send them as a burst at once. By reducing the frequency of transmitting data and considering previously introduced time multiplexing active/ idle mode (this will reduce the frequency of receiving data), we can save huge amount of energy at access point.

However, it is not advisable to wait for data from all the nodes to send data to base station when there is huge number of end devices connected to one access point as access point needs to wait very log to report back its data.

3.4 Backup Route to Send Data When an Access Point Fail

According to the current routing protocol when one access point fails or die, its child nodes required looking for a new parent and this process might take loge time when it comes to actual network scenario. Hence, if we could introduce some backup route for end devices to communicate when its parent dies and till it finds a new parent or re-form a new network, we could improve the packet loss. In an actual network scenario, this new parent searching time could be huge, and the data been collected at the end device may discard during this searching time. If the network is big, this could happen at few places then the amount of packets been lost is high.

As such, proposed enhancement for this issue is to introduce a backup route for each end device when they fail to communicate with their parent. So each end device will keep a record of its parent node and additionally alternate parent (this could be the access point which is in the range and it has the second smallest gradient value). So when at a node failure, end device will use its alternate parent to send its collected data to base station till it finds a new parent using parent discovery packet (PD).

CHAPTER 4

IMPLEMENTATION

4.1 Introduction to NS2

NS2 is a discrete-event simulator developed for networking exploration. NS2delivers substantial care for simulation of various routing protocols such as UDAP, TCP, MANET, AD Hoc and also multicast protocols over wireless or wired networks. 4.1 below shows the sample wired network created with 7 nodes using NS2 and its "Nam" graphical display. In this thesis I am using NS2 as my simulation tool to create and simulate the results to compare.

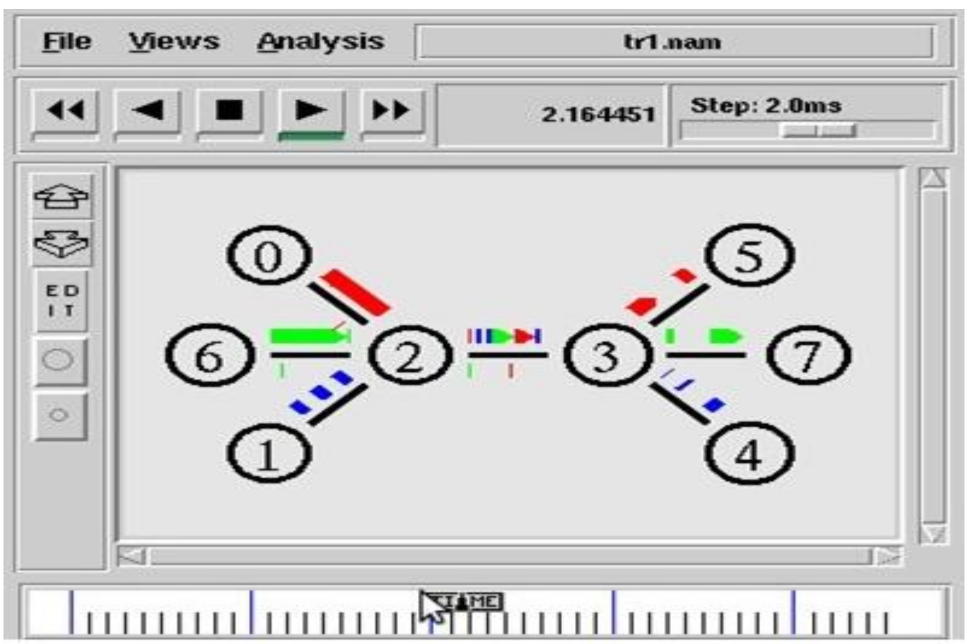

FIGURE 4.1. Nam simulation window.

4.2 Introduction to Contiki

Contiki is an open-source (OS) operating system for memory restricted, networked, schemes with a specific emphasis on low power wireless and Internet of Things (IoT) devices. The Contiki OS comprises a network simulator named Cooja, which simulates created networks of Contiki nodes. Below Figure 4.2 shows a sample network diagram created by Cooja simulator in Contiki. For this thesis I have implemented the gradient base hierarchical routing protocol in Contiki.

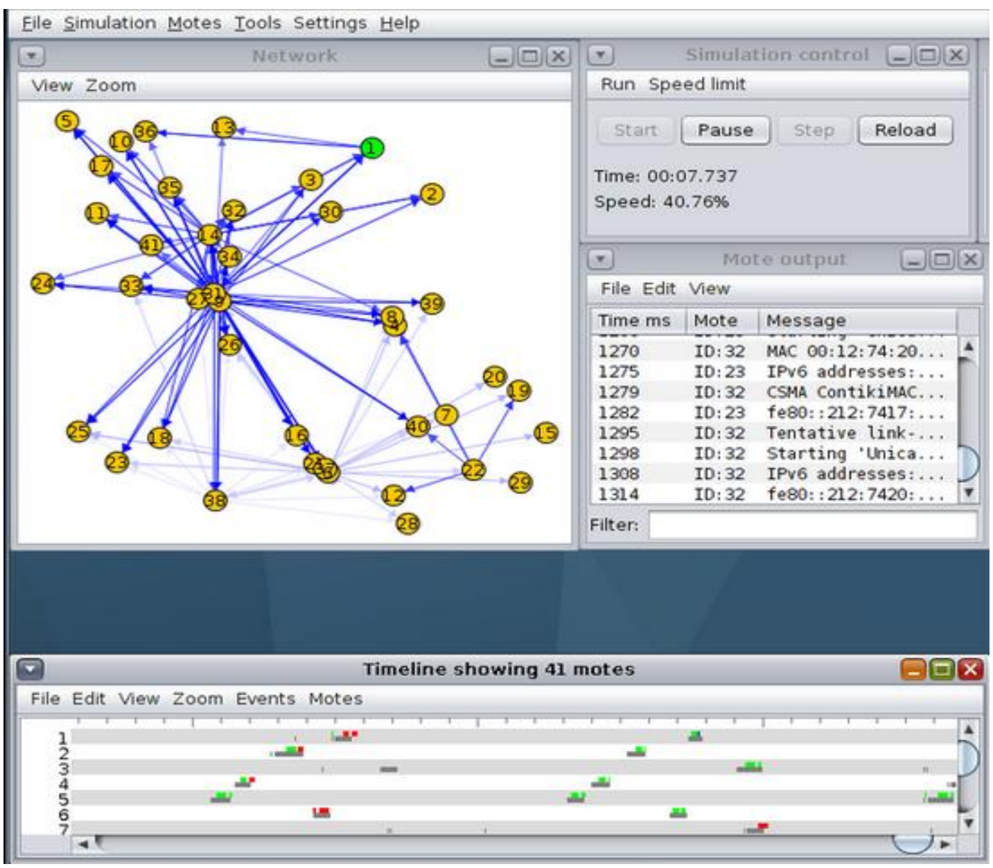

FIGURE 4.2. Contiki Cooja simulation.

4.3 Introduction to TelosB (Hardware)

The TelosB platform was designed and distributed to the university and research groups by UC Berkeley. This TelosB platform distributes low power usage permitting for long battery-life and fast sleep and wakeup state. 4.3 shows the picture of TelosB node hardware and features. In this thesis work, I have used TelosB motes to run my Contiki codes to check the actual communication happening with the implemented protocol.

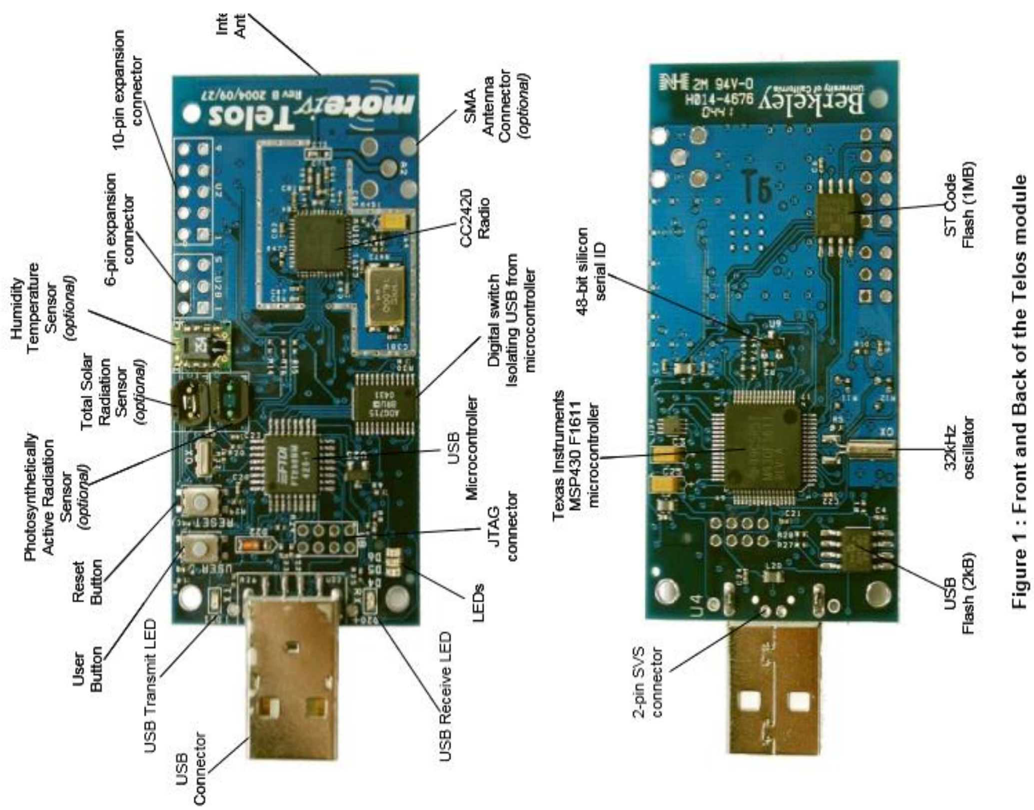

FIGURE 4.3. TelosB mote hardware features.

4.3.1 Key Features

1. 2.4 GHz, IEEE 802.15.4, and Chipcon Wireless Transceiver with 250kbps
2. Other Rf devices can be use with this hardware
3. TI MCU with8MHz, 48k Flash, and 10k RAM availability
4. Outdoor range is 125m and indoor range is about 50m
5. 3 sensors included (Light, Humidity, and Temperature)
6. Current usage is very low
7. Idle wake up time is very low
8. High security features
9. USB can be used to collect sensor info and for programming
10. Range could be expanded using SMA antenna
11. TinyOS and Contiki OS support

4.4 Validation

In Chapter 3, I proposed enhancements to the current gradient based hierarchical routing protocol introduced by Dr. Mozumdar et al. [4] that could advances the network lifetime and the packet loss of a wireless sensor network. In this section, I will demonstrate how the protocol performs well in terms of packet loss and energy consumption then refining the lifetime of WSN. From all the available simulation tools, I have chosen authenticating the behavioral pattern of a wireless network environment such as NS-2as my tool in simulating the current and proposed enhanced protocol.

4.5 Simulation Setup Scenarios

For the simulation, two network scenarios were designed within a space region of 1000 m x 1000 m. One network is created with 50 nodes and other network is with 100 nodes. 4.4 shows the simulation environment for 50 node network I have created.

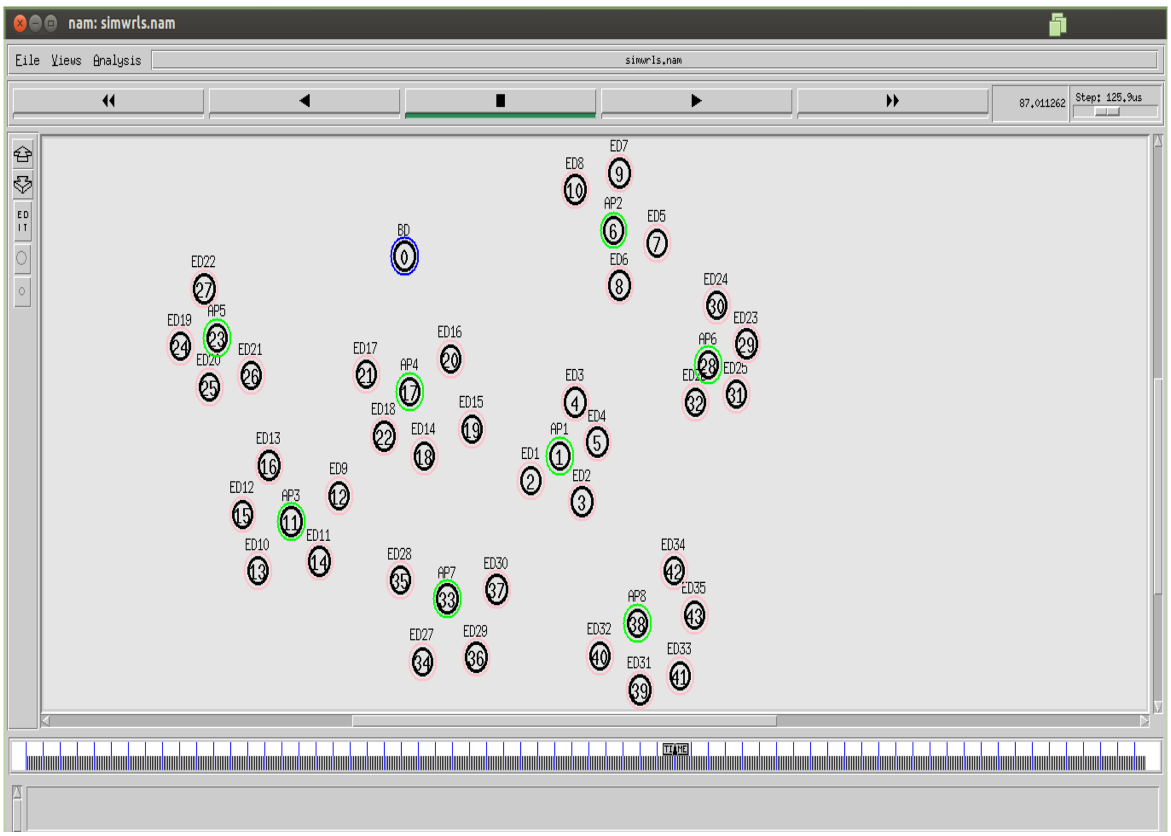

FIGURE 4.4. 50 node network setup.

With the nodes being deployed with the specific coordinates to illustrate the hieratical architecture, some parameters we set and some assumptions were made regarding node features and those are as follows.

1. Initially all the nodes are similar in nature.

2. All the nodes begin with same initial energy, energy profile was created and initial energy is set to 5J per node.

3. The base station is fixed.

4. All the nodes are static.

5. Energy consumption for control packet, transmit, and receive pre setup with the energy profile.

6. Maximum packet size is set to 300 kb.

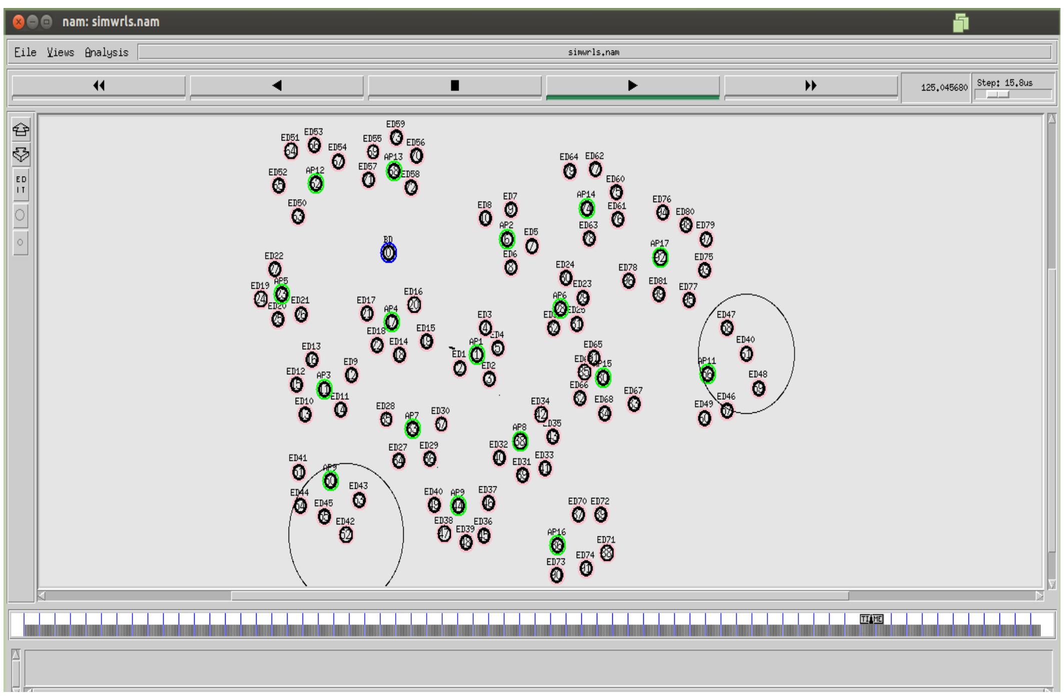

FIGURE 4.5. 100 node network setup.

Network is layout is same for both the current and enhanced protocol and individually data were collected and plotted against different parameters for both version to see the enhancement.

CHAPTER 5

RESULTS

5.1 Description

Figure 5.1 shows the initial plot I have done with total mean energy consumption against the number of nodes in the network for original protocol to highlight that when the number of nodes in the network upsurges then total mean energy consumption also elevates slightly. This could be explained easily as the network gets bigger then the network congestion is high, causing this to have data collision and higher packet loss, hence sensor nodes

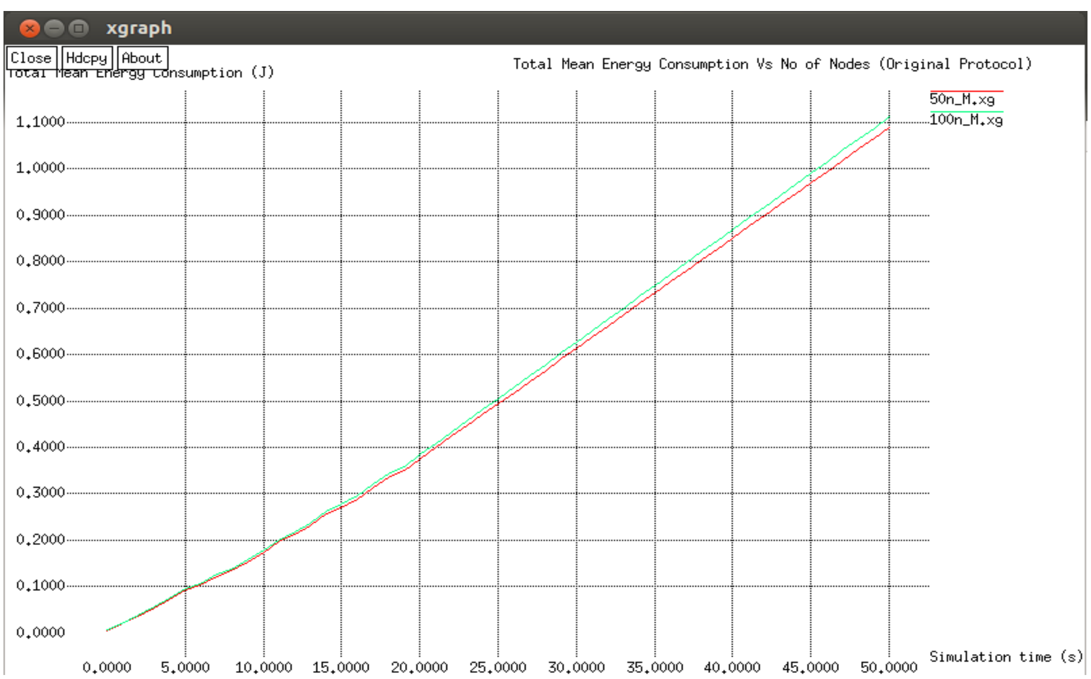

FIGURE 5.1. Total mean energy consumption Vs no of nodes.

required to rebroadcast data packets again and this data collision could increase the Power consumption which explains the Figure 5.1 graph deviation in the network with the number of nodes. Again it's similar for the Figure 5.2 which shows the total energy consumption against the number of nodes in the network.

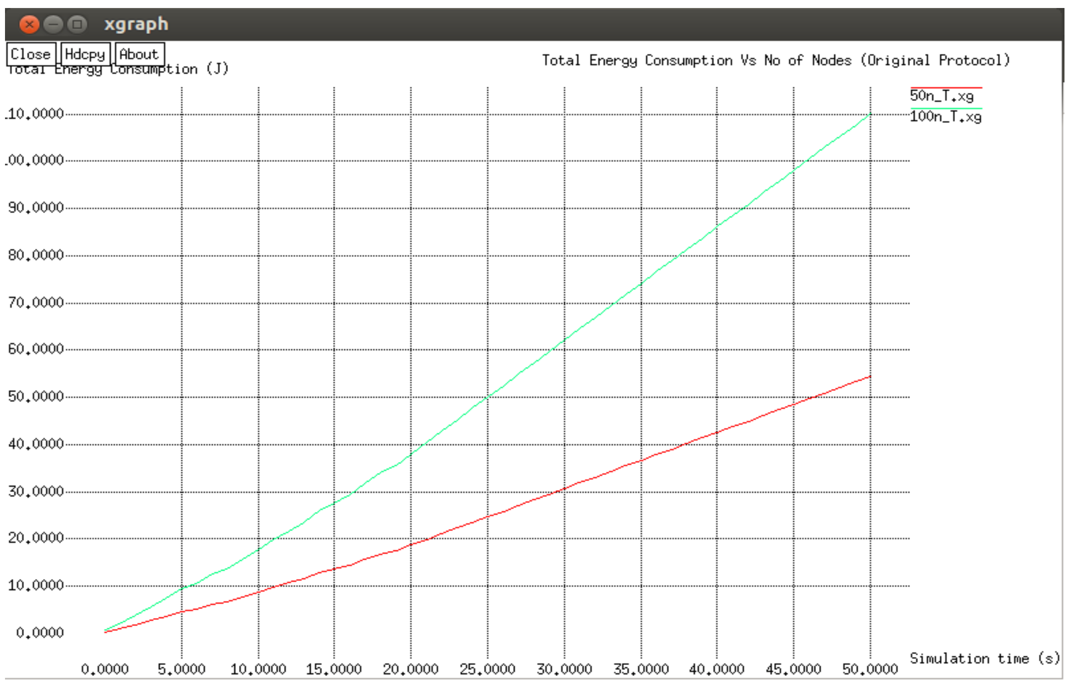

FIGURE 5.2. Total energy consumption Vs no of nodes.

Next three graphs (Figure 5.3, Figure5.4, and Figure 5.5) show the total energy consumption respect to,

1. Total Energy Consumption for 50 nodes (Enhanced protocol Vs Original protocol)

2. Total Energy Consumption for 100 nodes (Enhanced protocol Vs Original protocol)

3. Total Energy Consumption for both 50 and100 nodes in one graph (Enhanced protocol and Original protocol)

From the Figure 4.8 we can observe the improvement transpire respect to energy consumption with the proposed changes. For network consist of 50 devices, it shows that the lifetime of whole wireless sensor network extended by 5.4 times after all the enhancements been made. Enhancement could see from Figure 4.9 which is plotted for 100 node network is about 5.5 lifetime improvement. Finally Figure 4.10 shows the combined energy plot for both smaller and large network with enhanced and original protocol for easy reference.

This lesser energy consumption for enhanced protocol could derive from the below factors.

1. Active/idle mode implementation using time division multiplexing. By sending some nodes to idle state which consume very less amount of power comparing with the active state we could save hug amount of energy. This was implemented such a way that if any access point has more than one end device connected to it then the access point will assign a dedicated time slot for each end device to be active and operate. For example, let's say one access point has 4 end devices connected to it, and then only 25% of time one node will be on active mode and 75% of the time I will be in idle mode. So depends on how many nodes are connected to one access point will conclude the energy saving of the system.

However there are some disadvantages of having such a system, especially for highly sensitive applications where all the sensor nodes required reporting its collected data rapidly to make accurate decision, such an application can't use this enhancement. And also if one access point has huge amount of end devices connected, then one end point has to wait long time to be active and report its data, this could be another problem for large unplanned networks.

2. Data aggregation and reduce transmit frequency at access point. It is advisable to sand data as a burst at once when all the sensor data been collected instead of send every data packet coming from individual end device at access point. This way we able to reduce the transmission which helps the energy save.

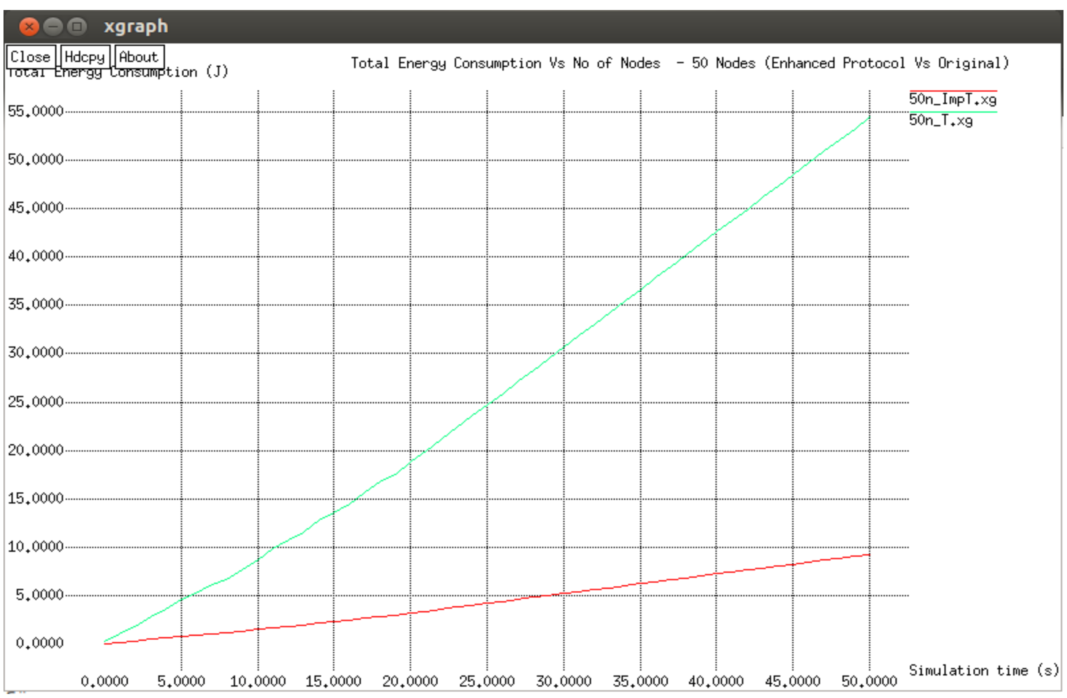

FIGURE 5.3. Total energy consumption--50 nodes (enhanced vs original).

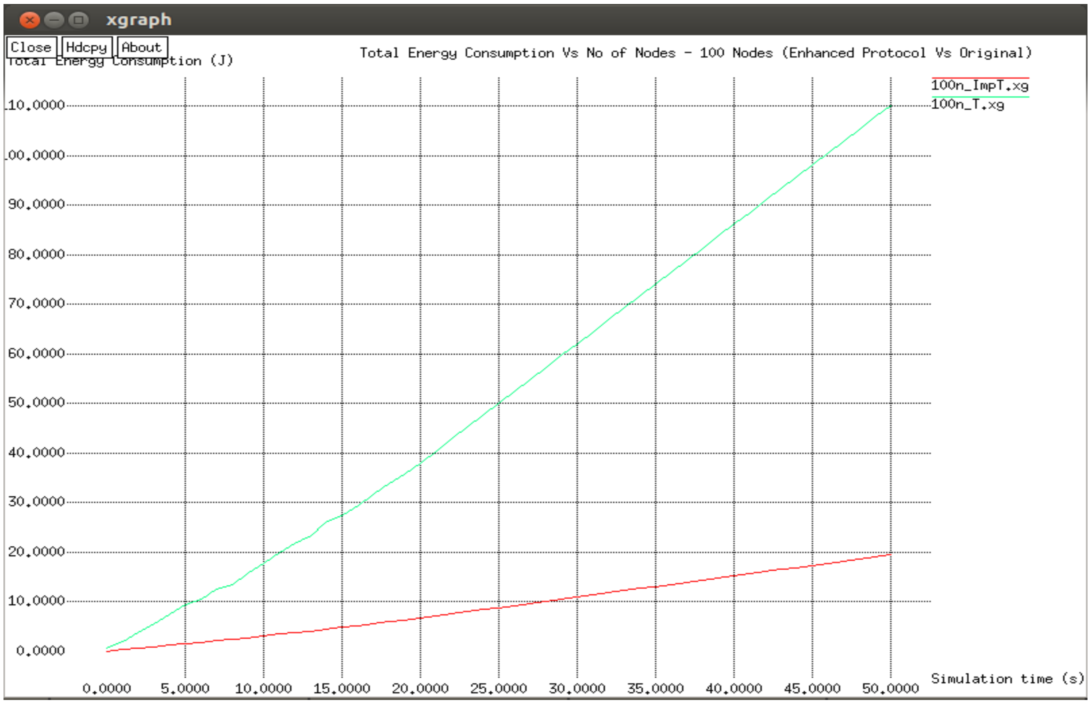

FIGURE 5.4. Total energy consumption--100 nodes (enhanced vs original)

3. Lastly some energy could be save with the less data congestion as there are less packets being collide and less re-broadcasting required as a system. With specified enhancements above, we will be reducing significant amount of data traffic in the sensor network, which contributes to a long lasting sensor network.

Figure 5.6 shows the residual energy of one end node for both enhanced and original network in 50 node network. It is easily can observe the lifetime enhancement of a single end device using this change.

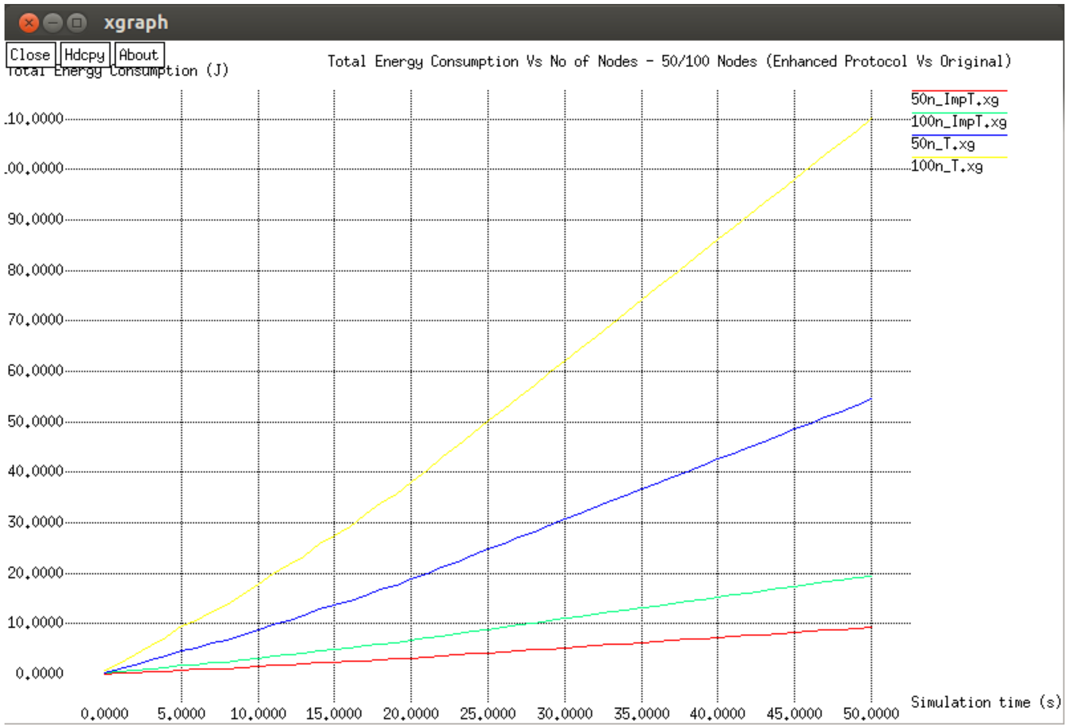

FIGURE 5.5. Total energy consumption--50/100 nodes (enhanced vs original).

Similarly Figure 5.7 shows the residual energy of one access point for both enhanced and original network in 50 node network at each gradient level. It is easily can observe the lifetime enhancement of a single access point using this changes, but the amount of enhancement is lesser than enhancement occur at end devices as access point is not going to idle mode, and saving is only coming from the data aggregation and reduce of data transmission and receiving.

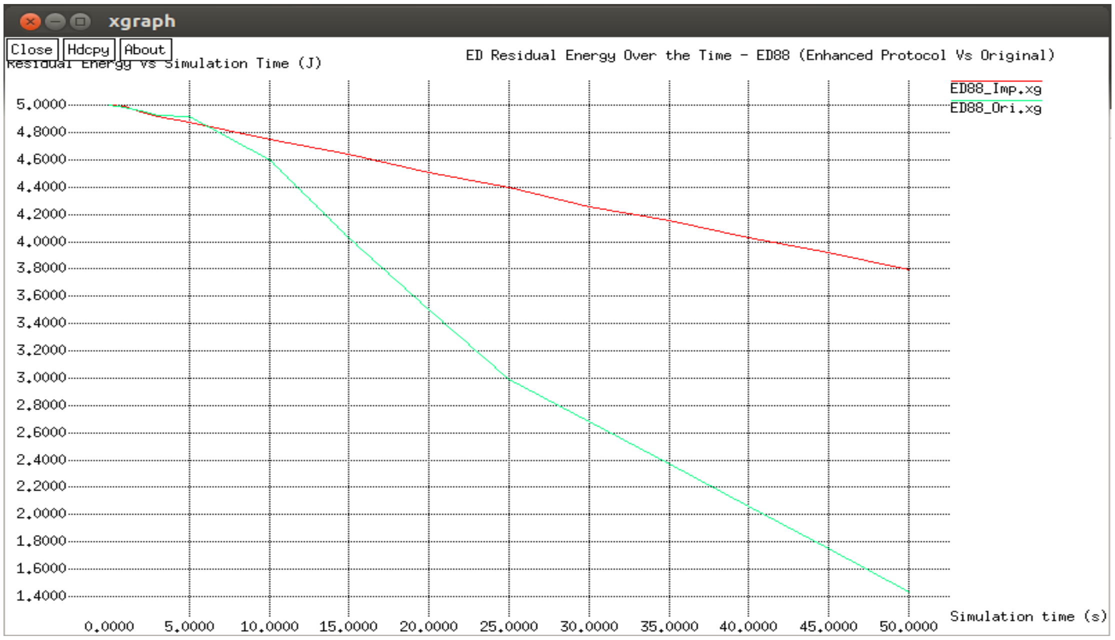

FIGURE 5.6. ED Residual Energy vs Time (Enhanced vs Original)

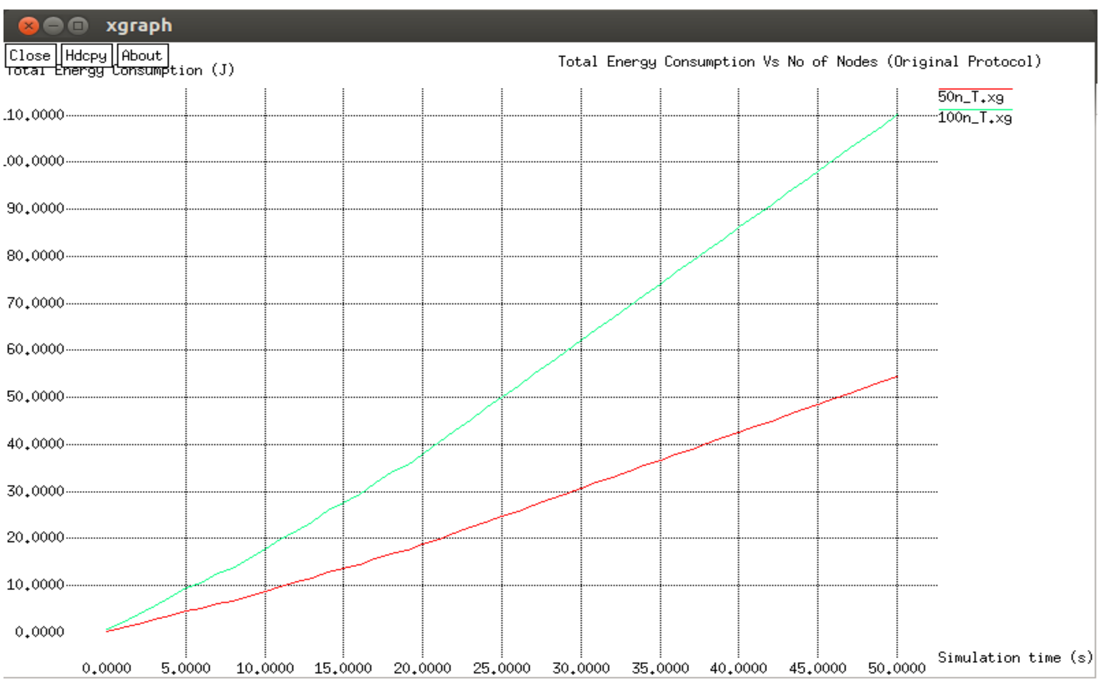

FIGURE 5.7. AP residual energy vs time for different gradient level (enhanced vs original).

Additional I have plotted graphs to express the improvement occurred with the packet loss. Figure 5.8 shows the packet loss comparison for enhanced and original protocol for both 50 node and 100 node networks and Figure 5.9 shows the enhancement for packet delivery ratio owing to these changes. We can observe that the overall packet loss is reduced owing to lesser network congestion for both 50 node and 100 node network. For 100 node network it's very important to overcome packet loss issue as always packet loss is higher when the network gets larger.

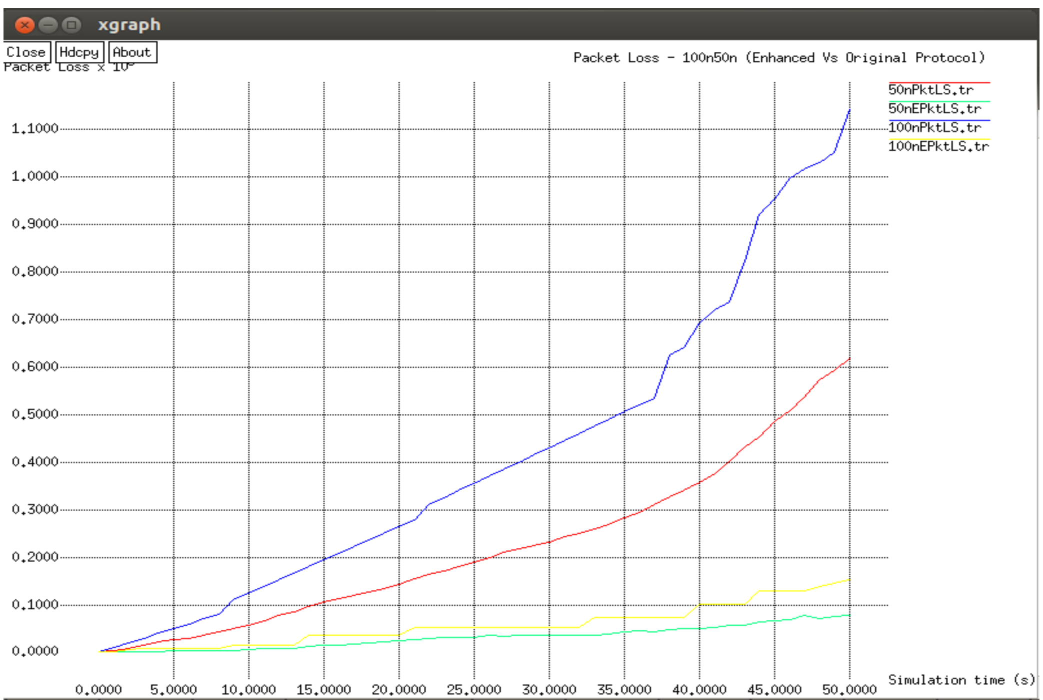

FIGURE 5.8. Packet loss, original protocol vs enhanced protocol for 50/100 node network

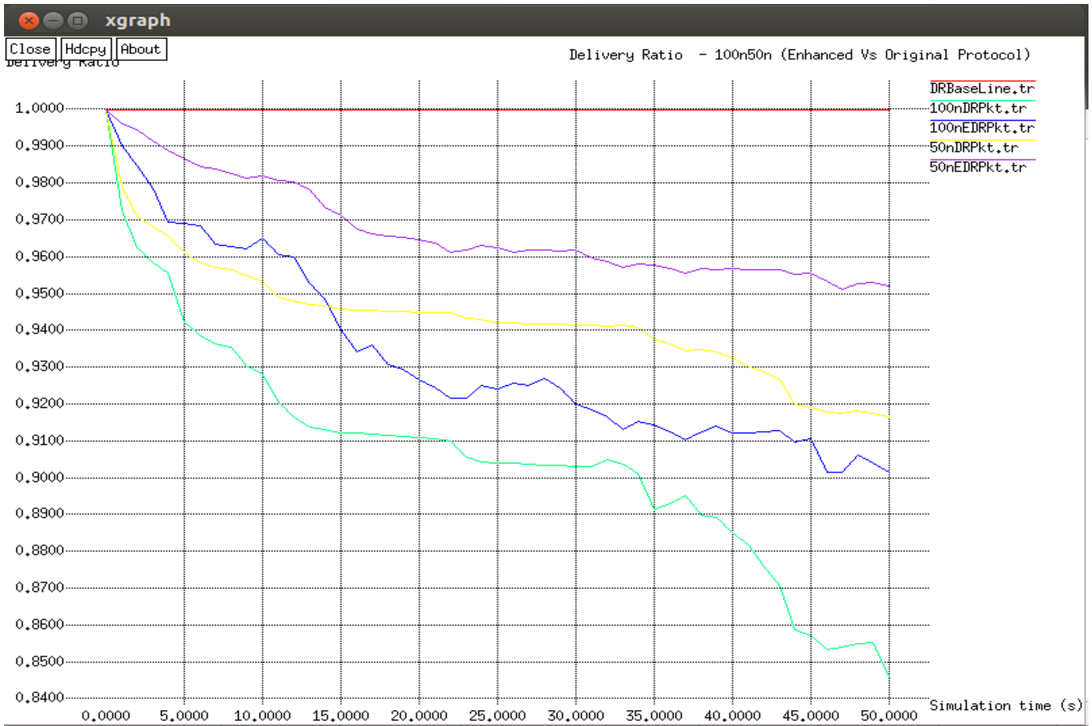

FIGURE 5.9. Delivery ratio, original vs enhanced protocol, for 50/100 node networks.

CHAPTER 6

CONCLUSION

5.1 Conclusion and Future Work

In this thesis, I recommend an encasements to energy efficient gradient based hierarchical routing method introduced by Dr. Mozumdar et al. [4] in which end devices are sending to idle mode by using time division multiplexing method. My tactic spread on a well-organized medium to large sensor networks to enhance network lifetime, and also aggregating data with lessen frequency of transmission at access points to optimizing the network life time. The imperative features which comprises of end device idle mode, reduce frequency of transmission, and backup route when link fails was analyzed and emphasized. My analysis illustrations that the energy efficiency of hierarchical wireless sensor networks can be further enhanced by using data aggregation, and sending nodes to idle mode when the application not required frequent updating and few sensor nodes are in a same area to collect similar data. Apart from this, additional routing path been introduced to reduce packet loss while link failures occur. From the study of my simulation outputs, I found out that my anticipated techniques on the base hierarchical protocol offers an improved answer to energy usage in a wireless sensor network when relate to original hierarchical technique. Then I have extended the authentication of my proposed techniques to further assess third and second and first level hierarchy nodes behavior, and seen the network lifetime enhancement which indicates better energy efficiency in the wireless sensor network.

As for future improvement of EEHW protocol, the ideal level of hierarchy could have if we upsurge the number of nodes to have four, five, and six and so on, can be explored. This thesis work also could extend to find the optimum number of end devices could connect to one access point to have efficient communication in the network without having greater packet loss and delay. The authentication of my proposed technique could also be implemented in another simulation tool (Omnet or PoNet) to have a healthier opinion and thoughtful of outcome study.

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