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AN ENERGY EFFICIENT LINEAR WIRELESS SENSOR NETWORK (WSN) ROUTING ALGORITHM

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ABSTRACT

Many new algorithms have been proposed for the problem of routing data in sensor networks due to challenging nature of routing in sensor networks. This paper presents the development and implementation of an energy efficient linear WSN routing algorithm. A testbed comprising 200 TelosB sensor nodes was set up in River bird environment. The network comprises of the sensor nodes, cluster heads and the sink linearly placed at 10meters apart from each other. The transmission codes were written in C-languages to determine optimum communication modes between nodes and balance uneven energy consumption along the layers. The protocol simulation engine used in this work is Castalia 3.2 and River bird. The performance of the developed linear WSN routing algorithm was done in relation to the existing routing algorithm; LEACH and CTA. The evaluation was based on four important metrics namely: network life time, signal strength threshold, throughput and latency metrics. The result of the analysis shows that the linear WSN routing algorithm results in longer network life time of about 1.8 times that of LEACH and 1.25 times that of CTA, better received signal strength threshold of about 1.5

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times that of CTA and 4 times that of LEACH, lower throughput of about 0.67 that of LEACH and higher latency of about 1.5 times that of LEACH and 0.8 times that of CTA.

Index words: Routing Algorithm, Energy Efficiency, Wireless Sensor Networks, TelosB node.

1. INTRODUCTION

Routing in sensor networks is very challenging due to several characteristics that distinguish these from contemporary communication and wireless ad-hoc networks. Classical IP-based protocols cannot be applied to sensor networks because it is not possible to build a global addressing scheme for the deployment of sheer number of sensor nodes [1]. Almost all applications of sensor networks require the flow of sensed data from multiple regions to a particular sink. Also, generated data traffic has significant redundancy in it since multiple sensors may generate same data within the vicinity of a phenomenon. Such redundancy needs to be exploited by the routing protocols to improve energy and bandwidth utilization. This makes sensor nodes to be tightly constrained in terms of transmission power, on-board energy, processing capacity, data storage and thus require careful resource management.

Due to differences between WSN and other wireless networks, many new algorithms have been proposed for the problem of routing data in sensor networks. These routing mechanisms have considered the characteristics of sensor nodes along with the application and architecture requirements. Almost all of the routing protocols proposed in the literature are two dimensional routing protocols [2] that perform their route discovery and maintenance using different strategies such as flooding, and multi-dimensional propagation of request messages from the

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source to the destination. However, the flooding process is costly in using important resources which are scarce in the wireless environment such as on-board energy, node processing capacity and storage. In addition, it causes delay in path acquisition and maintenance. Routing protocols that are designed for linear sensor networks will not be used for such a costly process as route discovery. In fact, these can exploit the linearity of the network to possibly eliminate or drastically reduce the route discovery process. Thus, Energy efficient routing algorithm is proposed for long distance infrastructure monitoring.

Energy conservation is very important in Wireless Sensor Network and so low power transceivers are used in the communication unit of the sensor nodes [3]. Routing is responsible for almost all the energy consumption in WSN and therefore sensing energy is negligible since it is very minute compared to energy spent in communication. As a result, energy efficient routing algorithm is very important for continuous and efficient communication. This paper, therefore deals with developing an energy efficient routing algorithm for long distance infrastructure monitoring. The development of the routing algorithm was based on the estimation of the link quality of the testbed environment. This research work is significant because it is meant to replace the manual method of deploying personnel to monitor the infrastructure thereby reducing the risk of losing the personnel's lives and cost of deployment.

The routing algorithm developed would minimize the energy consumption of the network thereby prolonging the lifetime of the sensor nodes. Also the research would make the sensor network topology and management easier since the range of the sensor node has been established

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empirically such that the optimum number of sensor nodes needed to monitor an infrastructure of length H would be known.

2. Literature Review

Many new algorithms have been proposed for the problem of routing data in sensor networks. These routing mechanisms have considered the characteristics of sensor nodes along with the application and architecture requirements. Rosuting protocols can be classified as data-centric, hierarchical and location-based although there are few distinct ones based on network flow or Quality of Service (QoS) awareness [1]. Depending on the application, different architectures and design goals/ constraints have been considered for sensor networks. Since the performance of a routing protocol is closely related to the architectural model, capturing architectural issues and highlighting their implications is necessary. Three main components in a sensor network are the sensor nodes, sink and monitored events. Apart from the very few setups that utilize mobile sensors [4], most of the network architectures assume that sensor nodes are stationary. On the other hand, supporting the mobility of sinks or cluster-heads (gateways) is sometimes deemed necessary [5]. Routing messages from or to moving nodes is more challenging since route stability becomes an important optimization factor, in addition to energy and bandwidth. The sensed event can be either dynamic or static depending on the application [6]. Dynamic events in most applications require periodic reporting and consequently generate significant traffic to be routed to the sink.

In data-centric routing, the sink sends queries to certain regions and waits for data from the sensors located in the selected regions. Since data is being requested through queries, attribute based naming is necessary to specify the properties of data. Sensor Protocols for Information via Negotiation (SPIN) [7] is the first data-centric protocol, which considers data negotiation between nodes in order to eliminate redundant data and save energy. Other examples of data centric routing algorithm include Directed Diffusion [8], Rumor routing [9], Gradient-Based Routing by [10], Constrained anisotropic diffusion routing (CADR) [11] and so on.

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The main aim of hierarchical routing is to efficiently maintain the energy consumption of sensor nodes by involving them in multi-hop communication within a particular cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the sink. Cluster formation is typically based on the energy reserve of sensors and sensor's proximity to the cluster head [12]. Low-Energy Adaptive Clustering Hierarchy (LEACH) [13] is one of the first hierarchical routing approaches for sensor networks. Other hierarchical routing protocols include: Power-Efficient GAthering in Sensor Information Systems (PEGASIS) [14], Hierarchical-PEGASIS [15], the **A**daptive **T**hreshold sensitive **E**nergy **E**fficient sensor **N**etwork protocol (APTEEN) [16] which is an extension of TEEN and so on.

Most of the routing protocols for sensor networks require location information for sensor nodes. In most cases, location information is needed in order to calculate the distance between two particular nodes so that energy consumption can be estimated. Since there is no addressing scheme for sensor networks like IP-addresses as they are spatially deployed in a region, location information can be utilized in routing data in an energy efficient way. For instance, if the region to be sensed is known, using the location of sensors, the query can be diffused only to that particular region which will eliminate the number of transmission significantly. Energy-aware location based protocols include: Geographic Adaptive Fidelity (GAF) [10], The Small Minimum Energy Communication Network (SMECN) [17] an extension to MECN, Geographic and Energy Aware Routing (GEAR) protocols [18].

Although most of the routing protocols proposed for sensor networks fit into the classification above, some pursue different approaches such as network flow and QoS. In some approaches, route setup is modelled and solved as a network flow problem. QoS-aware protocols consider end-to end delay requirements while setting up the paths in the sensor network. Examples of this protocol include: Maximum lifetime energy routing [19], Maximum lifetime data gathering [20], Maximum Lifetime Data Routing (MLDR), Sequential Assignment Routing (SAR) which is the first protocol for sensor networks that includes the notion of QoS in its routing decisions [21], Energy-Aware QoS Routing Protocol [22]. However, there are some hybrid protocols that fit under more than one category.

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3. Linear Routing Algorithm Development and Implementation for WSN

B. Architecture of the Linear Routing Algorithm

The long range of the infrastructural network prohibits each sensor node from communicating directly with the data sink because of the high cost of the long range radio transmission. It therefore requires the implementation of relay in order to efficiently transport sensor data to the data sink. However, the directional transmission along the sensor nodes will create significant latency if the chain is long. Therefore, the number of relays needs to be limited so as to control the overall latency in data gathering. To balance between the number of relays and the overall latency, it is natural that a hierarchical architecture be adopted for the long distance type sensor networks. In this paper, a novel routing algorithm that is suitable to facilitate energy efficiency considering the quality of the link and delay in gathering of sensor data from long distance type sensor networks was developed. Figure 1 shows the architectural block diagram of the proposed algorithm. To maximize the lifetime of such sensor networks, sensor node deployment strategy that allows the sensor nodes in each cluster to remain alive for approximately the same time duration was employed.

In the algorithm, the long stretch of the sensor nodes demands that network architecture be effective to reach out to the edge nodes of the network which usually are far away from the data sink with a restricted route to reach the data sink. Therefore, a hierarchical architecture shown in Figures 2 and 3 was developed such that the network would be scalable in order to suit for a wide variety of applications that may require the long distance type sensor nodes deployment. The architecture consists of three layers namely: Sensor Nodes, Cluster Heads and Base Stations. The Sensor nodes (SNs) form the first layer, the Cluster Heads (CHs) form the second layer while the Base Stations (BSs) form the third layer. The SNs perform data sensing tasks and

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report to local CHs. CHs aggregate the data streams from the related SNs and then forward the aggregated local-view data stream to a BS. The hierarchical architecture can be easily expanded to include more BSs in the highest layer for a long distance sensor networks. Additional layers can also be added between CHs and BSs based on specific application needs.

Therefore, the proposed architecture is easily scalable to increase the size of the network. In this case, the network consists of 200 nodes. Both SNs and CHs are assumed to be battery-powered and thus have limited energy supply while the BSs have no such constraints. Also, the SNs, CHs and BSs in this scenario are generally assumed to be stationary once these have been deployed. To ensure that the proposed architecture is not only scalable in future, but also energy efficient, codes such as sensor nodes battery, topology listings and sink listings codes were written in C language to determine the optimum communication mode(s) between the nodes, balance the uneven energy consumption along the layers, design a set of network protocols which enable the network to accomplish the initialization and operation stages based on the selected communication modes and sensor deployment strategy.

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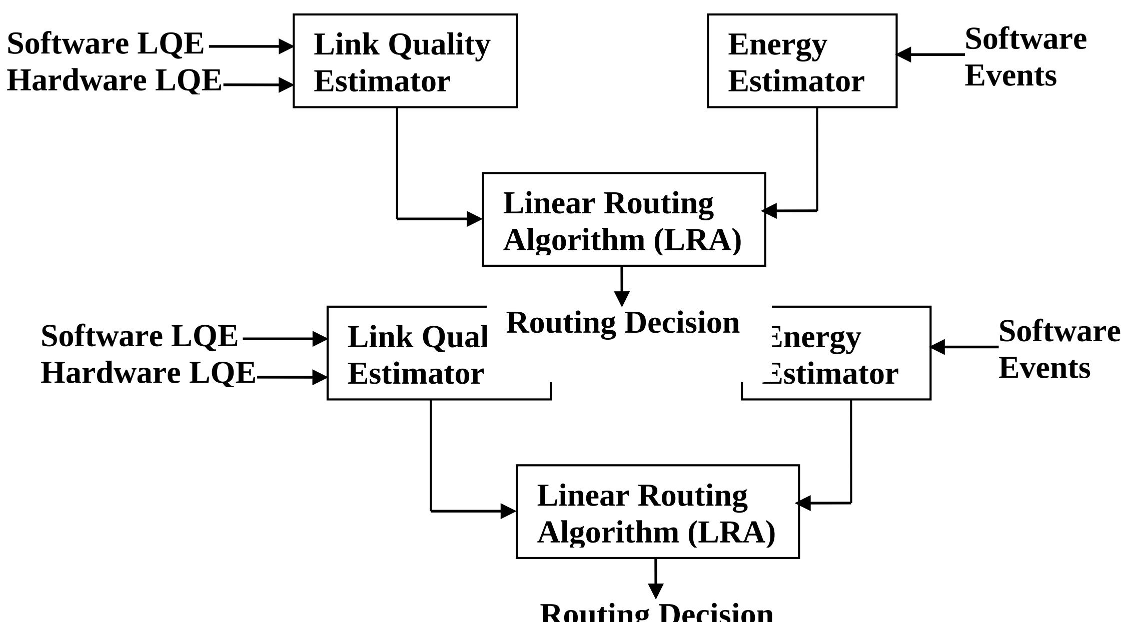

Figure 1: Architectural Block Diagram of the l thm

C. Implementation of Linear Routing Algorithm

The challenge involved in the development of the linear Routing Algorithm is the exact measurement of energy. The hardware platform of TelosB sensor node from Crossbow Technologies does not provide any hardware based energy measurement and hence energy estimation was done using software. The energy used by the sensor node was recorded at run time by tracking the time spent in different operating modes by different hardware component such as microcontroller, radio, LED, sensors and memory by the simulator.

The protocol simulator engines used in this work are Castalia 3.2 and Riverbird GmbH computer software. The simulator system comprises of event script generator and simulation process engine which is a discrete event simulator that simulates the routing algorithms in the given topology and link event sequence. In other words, it can simulate *N* instances of the routing algorithm running in parallel, one on each node. Castalia 3.2 [23] is an advanced radio pluggin for both OMNET ++ and Riverbird in Linux and windows operating systems. Castalia 3.2 as a pluggin in Riverbird [24] was configured to run the simulation testbed based on the Cygwin under Windows Operating System (OS). Essentially, Castalia is a simulator for Wireless Sensor Networks (WSN), Body Area Networks (BAN) and generally networks of low-power embedded devices. Castalia 3.2 can also be used to evaluate different platform characteristics for specific applications, since it is highly parametric, and can simulate a wide range of platforms. Castalia3.2 has many features which enable the simulation of the Linear Routing Algorithm and comparison of the performance of the Collection tree Algorithm (CTA) and Low Energy Adaptive Clustering Hierarchy (LEACH) Algorithm using some metrics.

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4. Simulation Analysis of the Routing Algorithm

In this section, computer simulation was used to evaluate the performance of the developed energy efficient Linear Routing Algorithm (LRA) as well as Low Energy Adaptive Clustering Hierarchy (LEACH) and Collection Tree Algorithm (CTA). The simulation system was designed specifically for the purpose of evaluating the performance of the routing algorithms in a linear forwarding topology for WSN. At its heart is a discrete event simulator that simulates the three routing algorithms. The simulation includes the forwarding tables and all routing algorithm communication, considering the sensor nodes network traffic. The system simulates network characteristics such as throughput dynamics, latency metrics, Network life time and received signal strength, all as composite metrics for WSN analysis. The core of the simulation system is the generator program that generates an event script (a sequence of edge weight changes) for the simulation. The Riverbird software then simulates the routing algorithm on the network using the generated event script from Castalia. The output of the simulator program is a sequence of data sets which was plotted on Excel worksheet.

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In the Riverbird Software, a linear topology of wireless sensor nodes was set up as in Figures 2 and 3 based on the parametric listings in the pluggin. In the work, three concurrent experiments were configured, to handle its simulation run. Each run simulates a single routing algorithm for 86,400 seconds (one day) at a rate of 10 iterations of the update algorithm per second. The sensor nodes are assumed to be placed at 10 meters apart. Cluster heads are introduced to facilitate the relaying of sensed data to the sink. At the beginning of simulation each upstream node receives generated sensed data and the routing algorithm developed forwards the data to the preceding cluster head which consequently relays the traffic to a sink. Each sensor sends 1500 messages (maximum transmission unit) to the cluster head in this context. Then, the three Routing Algorithms are compared to ascertain its justification in the context of energy optimization as a routing scheme using the aforementioned metrics. The LRA algorithm develops route poison which makes the nodes to continue transmission even if there is sensor node or cluster head failure. The algorithm does that by dictating the node that has problem and provides an alternate route for the transmission.

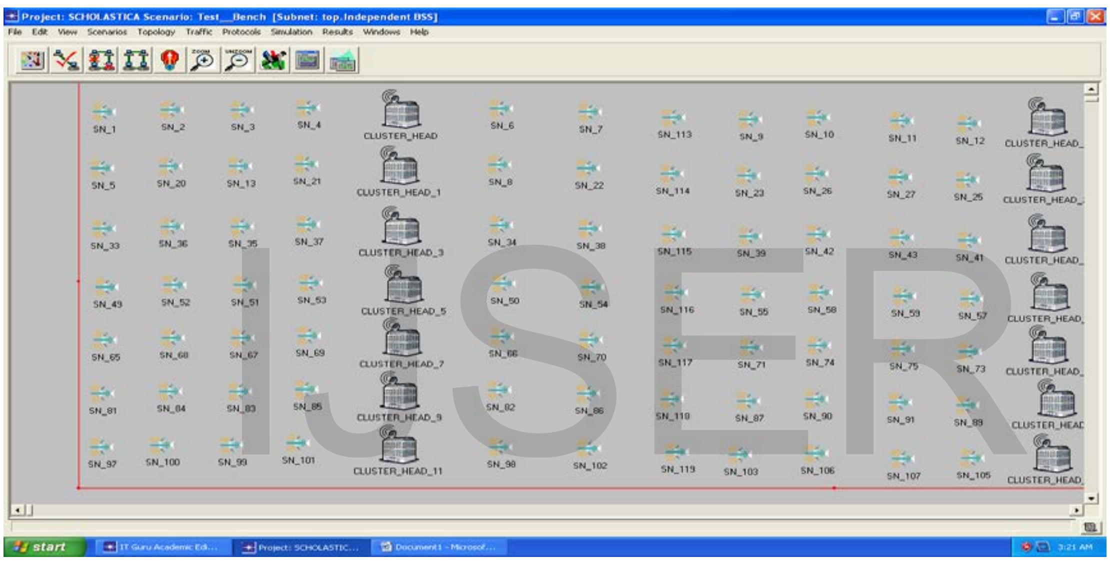

Figure 2: Simulation Environment powered by Event Script Engine

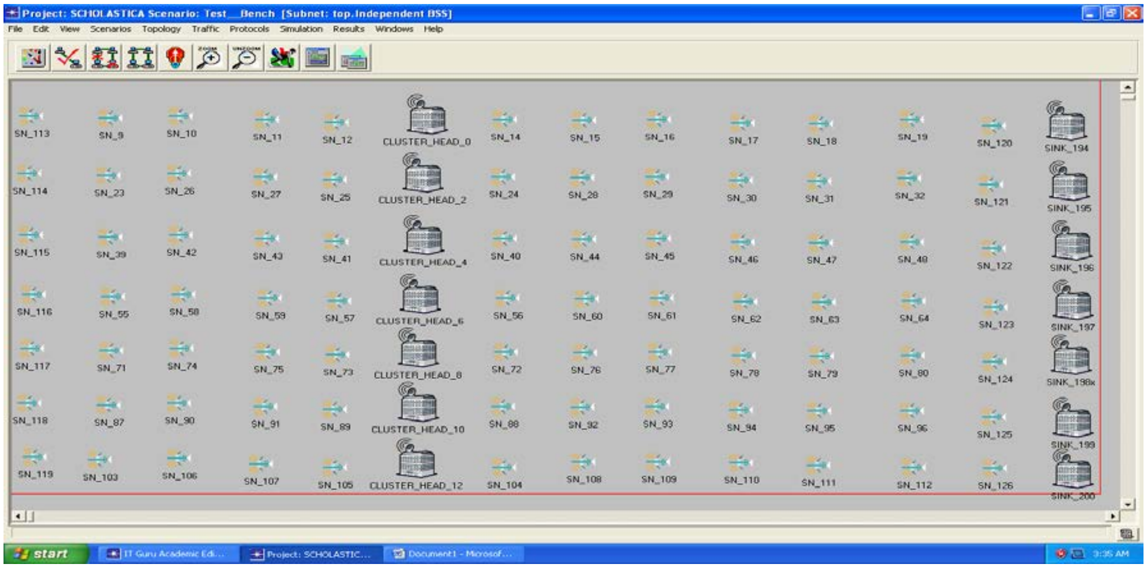

Figure -3: continuation of Simulation Environment powered by Event Script Engine showing sensor nodes, Cluster Heads and Sink

5. ANALYSIS AND DISCUSSION OF PERFORMANCE EVALUATION OF THE ALGORITHM USING SOME METRICS

5.1 Performance Evaluation of the Routing Algorithm

In this section, the performance evaluation of the Linear routing algorithm relative to the existing routing algorithms LEACH and CTA was presented.

The objective is to evaluate the claims that the LRA routing algorithm:

i. Sends optimal routing updates while minimizing the average energy dissipation at large,

ii. Facilitates ease of deployment with good convergence time, hence very energy conservative.

iii. Supports scalability in node deployment while maintaining excellent throughput as the network grows.

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iv. Contributes extensively to the linear topology network life time, hence energy efficient

v. Have optimized latency effects for time sensitive applications causing data from linear sensor topology to reach sink in extremely short time.

The evaluation is based on simulations of the enlisted protocols implemented in the discrete simulation environment shown in Figures 2 and 3. A simulation response for route poison development which is energy dissipative is shown in Figures 4, 5, 6 and 7. These scenarios show a case for perceived route poison, poison detection, poison normalization and consequent update to the sink via the closest cluster head.

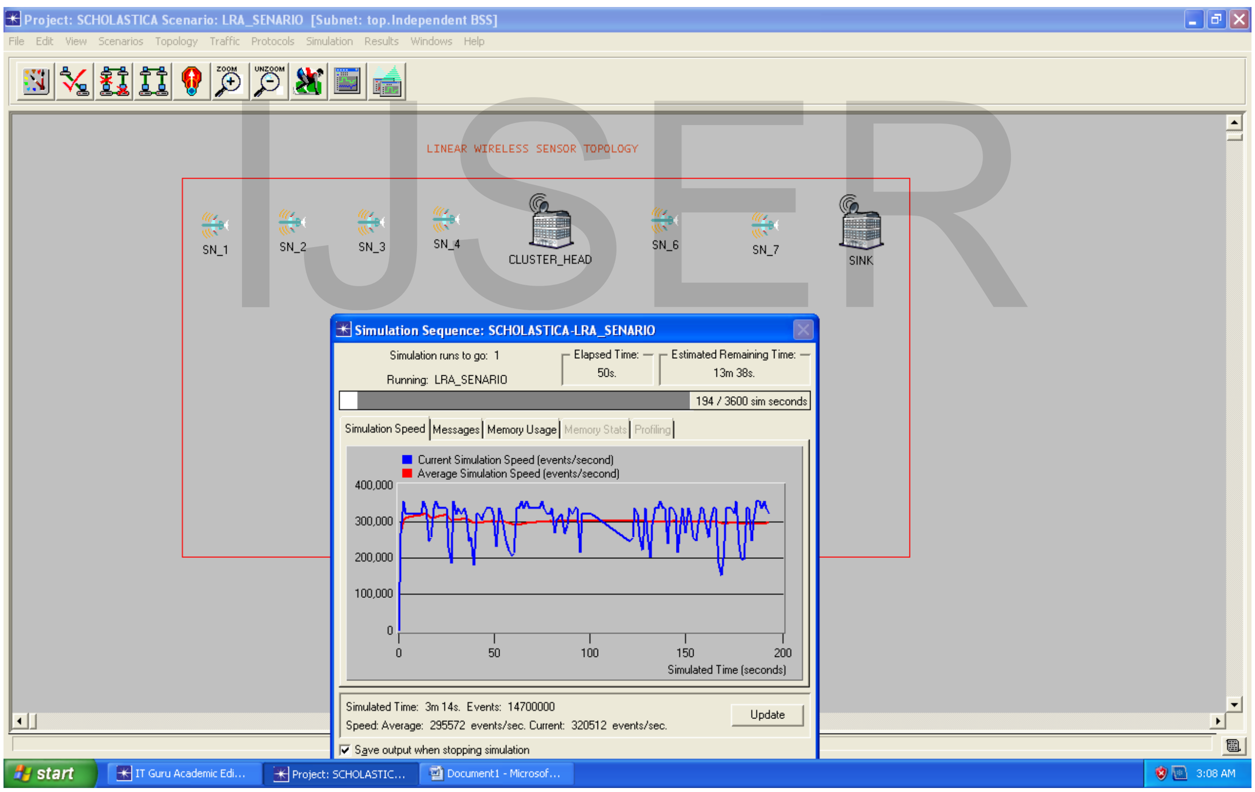

Figure 4: Simulation Scenario for Route Poison Sensing

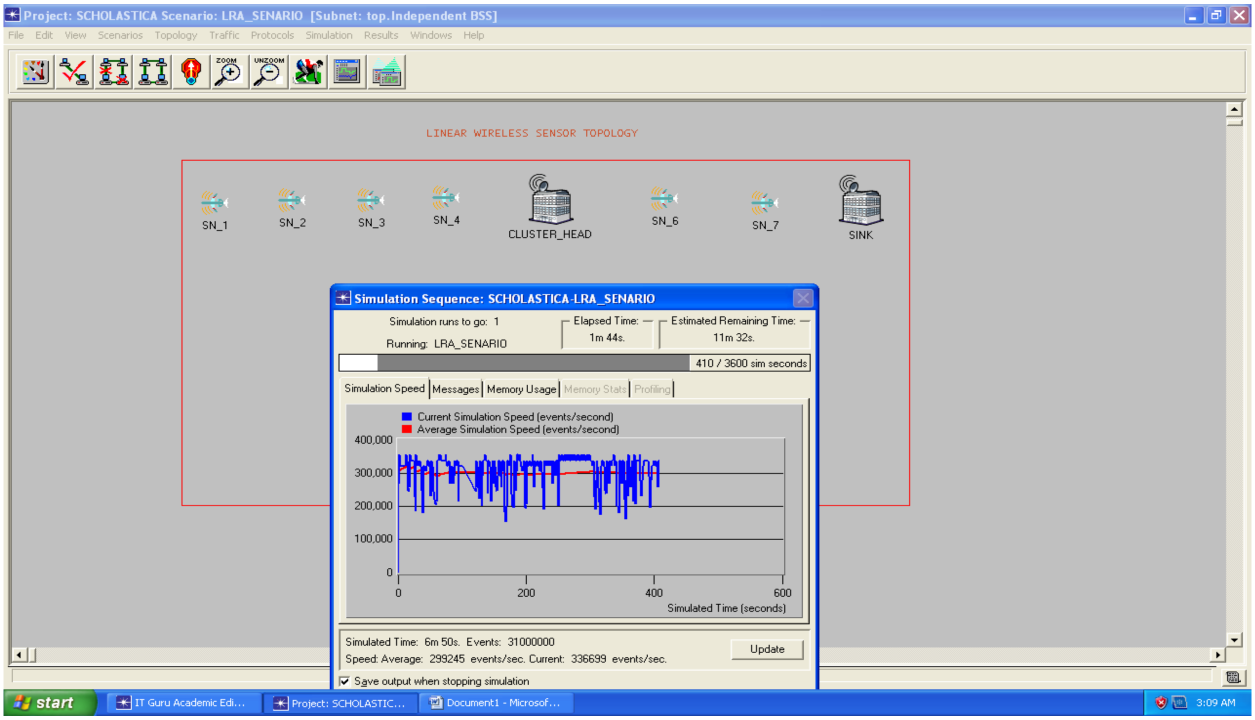

Figure 5: Simulation Scenario for Route Poison Detection

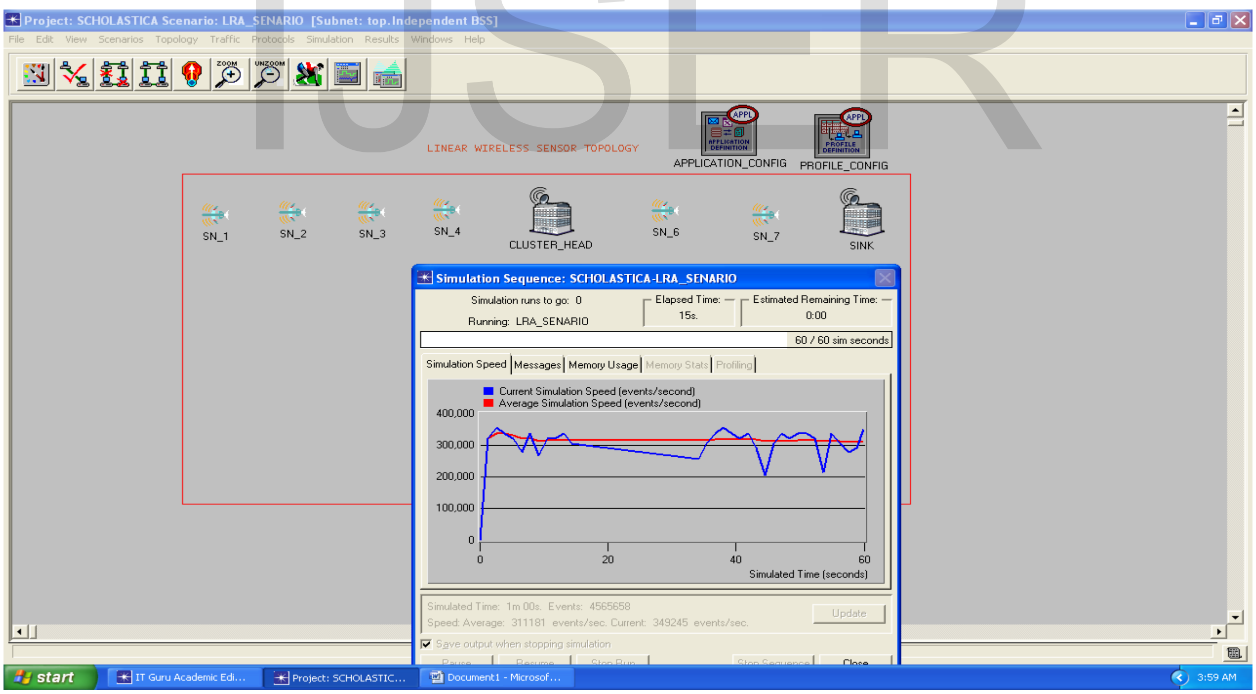

Figure 6: Simulation Scenario for Route Poison Normalization

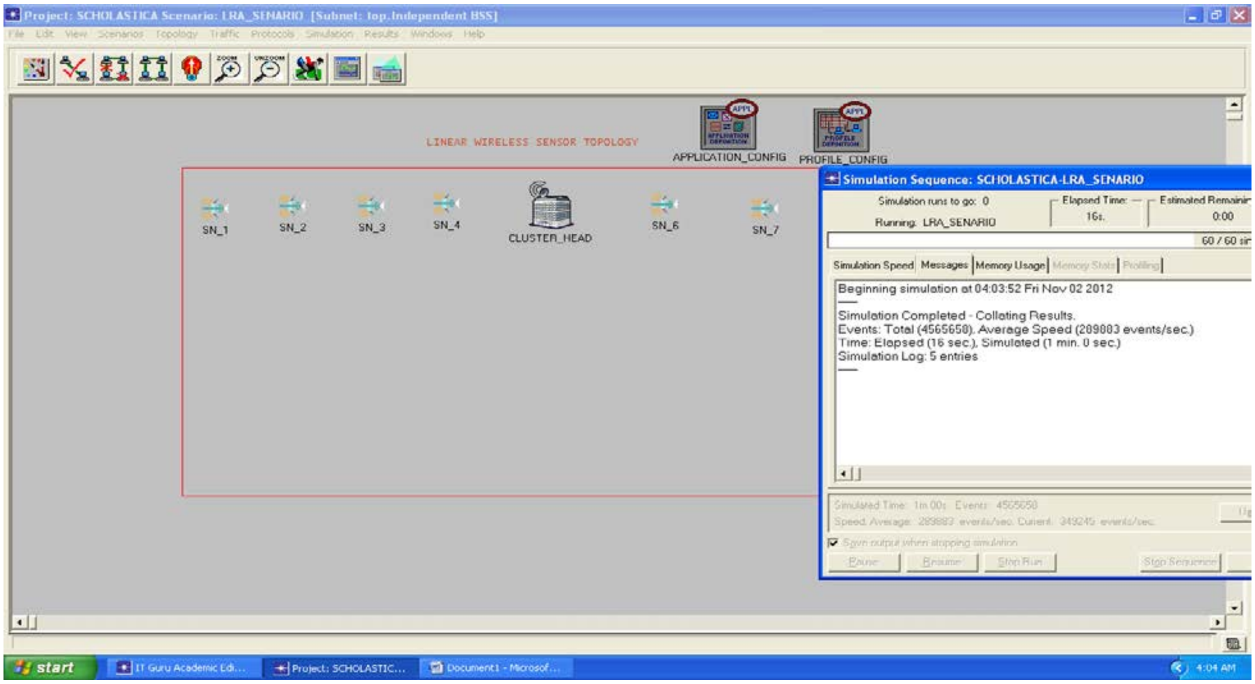

Figure 7: Successful Simulation compilation

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5.2 Discussion of Performance Evaluation of the Algorithm using some Metrics

A. Throughput Dynamics Discussion

Figure 8 shows the response of throughput dynamics for the compared algorithms. Essentially, throughput is the data quantity transmitted correctly starting from the source node to the destination sinks within a time *T* (sec). The node rate is measured by counting the total number of data packets received successfully on the node, which leads to the calculation of the received bits number which is divided by the total time of simulation execution. The network rate is defined as the average of all nodes rates implied in the data transmission. From the plot depicted in Figure 8, the throughput of LEACH is approximately 1.5 times that of the LRA and CTA. Although the introduction of traffic dynamics control such as route poison and multihop schemes try to improve on the throughput, it is still low when compared to LEACH. This is due to the many routes the signal transverse before arriving at the sink.

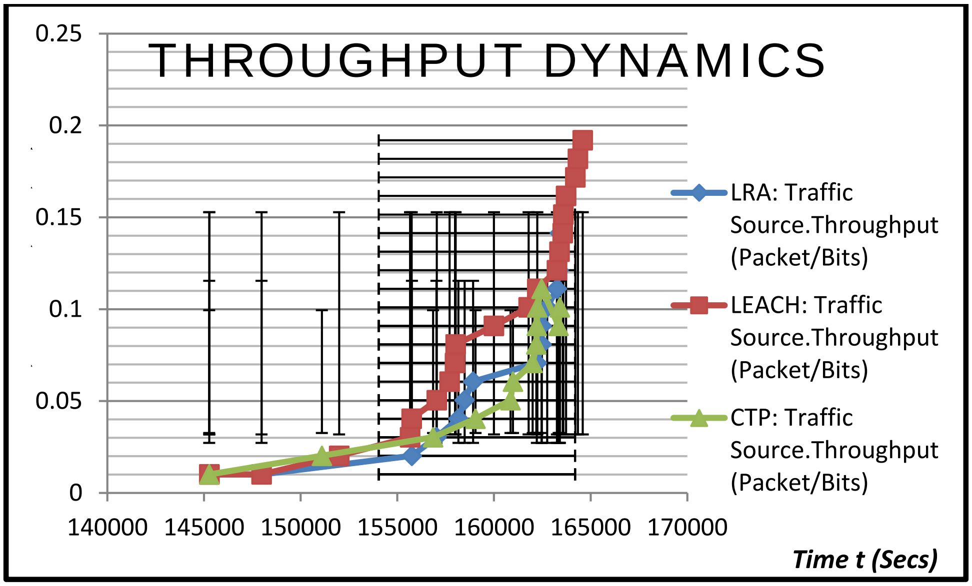

Figure 8: Throughput dynamics Against Simulation Time

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B. Network Life Time

Figure 9 shows the network life time observed in the simulation. In the linear deployment in Figure 2 and 3, a 200-node network was used. In these simulations the nodes were linearly placed throughout the 100m X 100m area and the work made restrictions on the distance between the nodes and the cluster heads. Figure 9 shows the average energy dissipated per round as a function of the number of nodes and cluster heads which aids in determining the life span of the network. The plot shows that LRA, in all cases have a higher Network Life Time compared with LEACH and CTA for the sensor nodes deployed. The energy efficiency/ Lifetime of LRA is 1.8 times that of LEACH and 1.25 times that of CTA. Each node at the simulation time assumes 2J of energy and a maximum transmission_data of 1500 bytes are sent consequently to the sink. Each node uses a probability distribution function to determine its cluster head status at the beginning of each round which lasts till the end of the simulation time. For the energy gain in the algorithms, this work tracked the rate at which the data packets are transferred and the amount of energy requirement to get the data transferred to the sink. When the nodes use up their limited energy during the course of the simulation, these can no longer transmit or receive data.

In this simulation, energy is consumed whenever a node transmits or receives data. In LEACH and CTA, it was observed that using single hop transmission scheme to communicate to the cluster head saps the energy. Also, the aggregate signals sent to the sink greatly reduce the energy life span. From the plot, LRA delivers most data per unit energy, thereby achieving energy efficiency which improves the network life span. LEACH and CTA as shown in the plot are not as efficient as LRA in the context of linear topology.

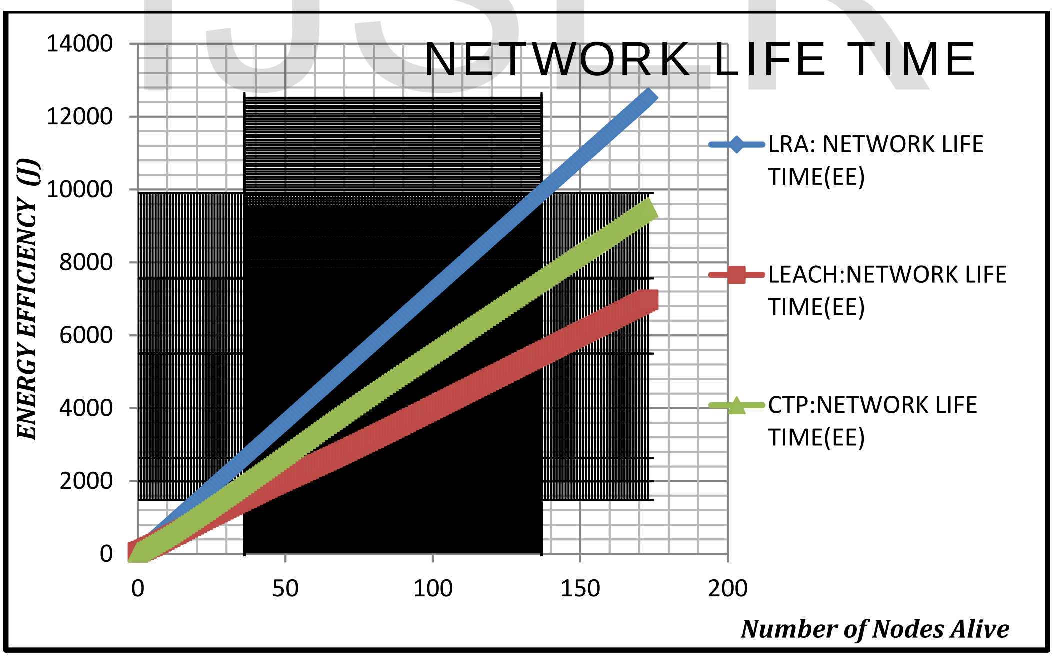

Figure 9: Network Life Time Responses

C. Signal Strength Threshold Discussion

The plot of Received Signal Strength Indicator against the number of Sensor in Figure 10 shows that the Signal Strength of the LRA is high compared to LEACH and CTA. The signal strength of LRA is 1.5 times CTA and 4 times that of LEACH. This infers the goodness of the communication link of the system and shows that LRA avoids retransmissions, hence, energy efficient.

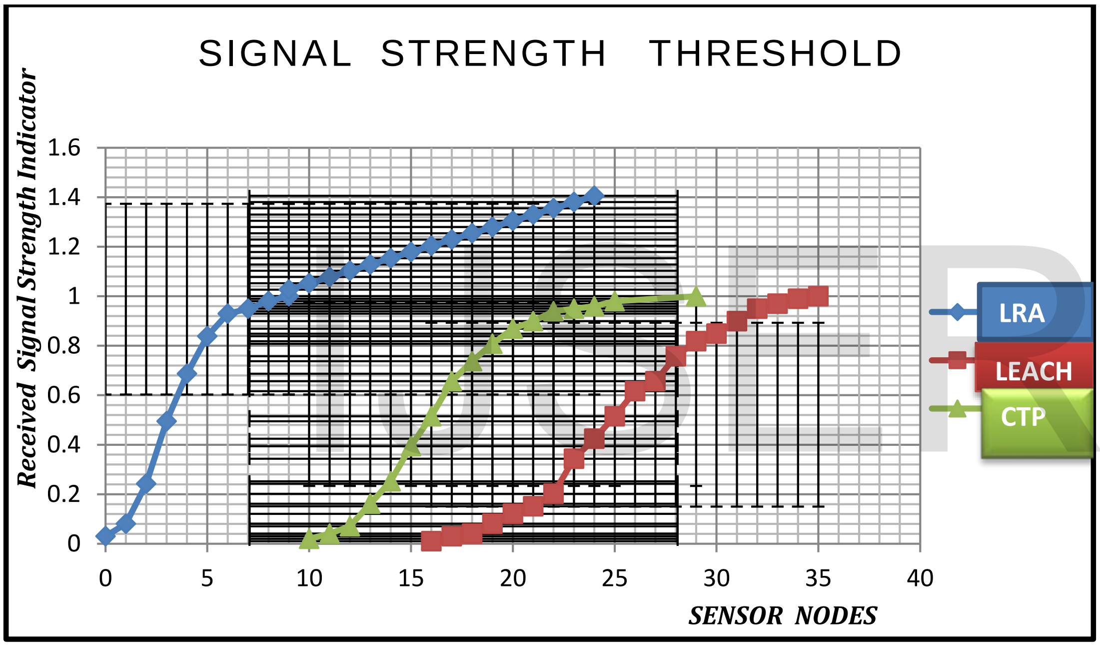

Figure 10: Signal Strength Thresholds of the Algorithms

D. Latency Metrics Discssion

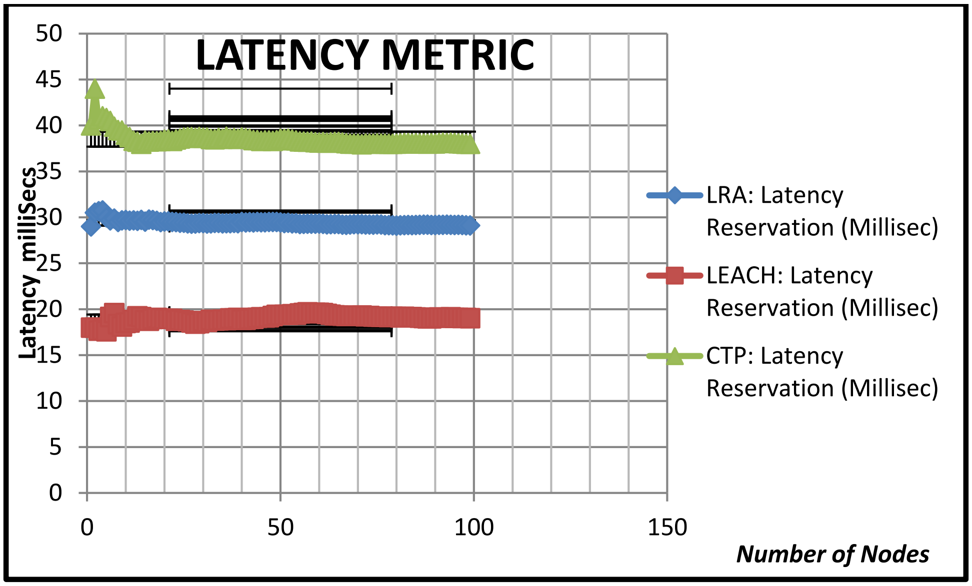

Figure 11: Plot of Network latency against Total number of sensor nodes

From the plot of latency against the total number of sensor nodes shown in Figure 11, it is observed that LEACH has minimum latency compared to LRA and CTA. The latency of LRA is 1.5 times that of LEACH and that of CTA is 2 times that of LEACH. This is because of the multihop transmission and the duty cycling used. The sensor nodes might delay from waking up and the procedure of transmitting from one node to the other before reaching the sink also causes delay, although the route poison incorporated in the Algorithm which senses, detects and normalizes a route problem without sending packets to the cluster heads, try to alleviate the latency problem. Automatic detection of the route problem and immediate action and normalizations try to reduce delay in the transmission of data in LRA. The minimum delay in LEACH occurs because it uses direct transmission and transmits randomly to the sink. This limits the transmission range and depletes the energy of the sensor nodes faster.

7. CONCLUSION

Link estimation is a critical part of almost every sensor network routing algorithm. Knowing the link quality of candidate neighbour lets an algorithm choose most energy efficient next routing hop. Since energy is a major constraint in wireless sensor networks it becomes very important to use energy efficient routing algorithm in wireless sensor networks. With the thorough study of the link quality, a routing algorithm based on link quality and energy efficiency was developed.

An energy efficient routing algorithm for linear long distance infrastructure monitoring developed was evaluated using River bird and Castalia 3.2. The developed algorithm (Linear WSN Routing Algorithm) was compared with Collection tree Algorithm (CTA) and Low Energy Adaptive Clustering Hierarchy and analysis were done. The analysis shows that the Linear WSN Routing Algorithm results in better Received Signal Strength Threshold of about 1.5 times that of CTA and 4 times that of LEACH, Longer Network Life Time of about 1.8 times that of LEACH and 1.25 times that of CTA, lower Throughput of about 0.67 that of LEACH, higher Latency of about 1.5 times that of LEACH and 0.8 times that of CTA.

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