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Energy Efficient Synchronization Based Routing Algorithms for Wireless Sensor Network with mobile sinks

By

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Declaration

I declare that this thesis is entitled " Energy efficient synchronization based routing algorithms for wires sensor network with mobile sinks is my original work and has been read and approved as meeting the primary research requirements of the School of Computing in partial fulfillment for the award of the degree of Masters in Computer Networking, Jimma University, Jimma, Ethiopia. And all source and references used for this thesis work have been properly acknowledged.

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Dedicated

My appreciation and special thanks goes to my family and my wife for endless support and sacrifice throughout my life.

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Acronyms

ALURP	Adaptive Locations Update Routing Protocol
ARPA	Advanced Research Project Agency
AVRP	Anchor Based Voronoi- Scoping Protocol
BAST	Biased Sink Mobility and Adaptive Stop Time
BEENISH	Balanced Energy Efficient Network Integrated super Heterogeneous Sensor Network
CBDC	Connectivity Based Data Gathering With Path -Constraint
CH	Cluster Head
CPU	Central Processing Unit
DAEES	Deadline-Aware Energy Efficient Query Scheduling
DARPA	Defense Advanced Research Project Agency
DDRP	Data Drive Routing Protocol
DEEC	Distributed Energy Efficient Clustering
DMSF	Dominating Based Minimum Weight Sum First
DSN	Distributed Sensor Network
DTS	Data Transmission Scheme
DTSPA	Dominating Travelling Sales Man Approximation
ED	Efficient Data Gathering
EDC	Efficient Data Collection
EE-CDRDG	Energy Efficient Clustering With Delay Reduction Data Gathering
EEDR	Energy Efficient Data Routing
EEMMS	Energy Efficient With Multiple Mobile Sinks
EESBPR	Energy Efficient Synchronization Based Routing
GPS	Geographical Positioning System
ID	Identification Number
IP	Internet Protocol
JSim	Java Based Simulator
KB	Kilo Bytes
LBD	Line Based Data Dissemination

LEACH	Low Energy Adaptive Cluster Hierarchy
LPDG	Location Prediction Based Data Gathering Scheme
LPTA	Location Prediction and Time Adaptive protocol
LTS	Long Term Support
M/S	Metter per second
MAC	Media Access Control
MAh	Mili Ampere per Hour
MANET	Mobile Ad-Hoc Network
Matlab	Matrix Laboratory
MEMS	Micro- Electro Mechanical System
MIT	Massachusetts Institute Technology
MiXiM	Mixed Simulator
MS	Mobile Sinks
MULE	Mobile Ubiquitous Local Area Network Extensions
MWSN	Mobile Wireless Sensor Network
NED	Network Description
NICTA	National information and communication Technology of Australia
NS-2	Network Simulator Version 2
NS-3	Network Simulator Version 3
OLMS	Optimal Location with Mobile Sink
OMNET++	Objective Modular Network Test-Bed in C ++
OPNET	Optimized Network Engineering Tool
PDRP	Proactive Data Reporting Protocol
PRP	Predictive Routing Protocol
QualNet	Quality Network
RCCS	Reshuffling Cluster Compress Sensing
RSSI	Radio Signal Strength Indicator
RX	Reception
SEENISH	Sink Mobility Aware Energy Efficient Network Integrated Supper Heterogonous
S-MAC	Sensor –Media Access Control

SOSUS	Sound Surveillance System
TCP	Transmission Control Protocol
TDMA	Time Division Multiple Access
T-MAC	Timeout –Media Access Control
TX	Transmission
US	United State
WSN	Wireless Sensor Network

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Abstract

In wireless sensor network (WSN), the sensor nodes should communicate each other to exchange data. Communication protocols of WSN plays significant role on energy dissipation of the sensor network. Since sensor network consumed more energy in static sinks than mobile sinks during transmission and reception. Designing energy efficient routing protocol for mobile WSN plays an important role on energy saving of the sensor networks. The communication of sensor nodes with mobile sink can be multihop or directly uploads the data to the base station. Since, in static sink the node close the sink consume more energy, because there is traffic overhead to forwarded data on behalf of the nodes far apart of sensor nodes.

This study address the problems of energy consumption a mobile sink data gathering of sensor network, problems of synchronization among the sensor nodes and mobile sink, data delivery delay due some obstacle in the network, data redundancy and more energy consumption during routing of data to the destination.

Therefore this study is concentrated on energy efficient synchronization based prediction routing algorithms in WSN for mobile sinks is designed to minimize energy expenditure and improve life time the network. In addition to that distribute the traffic load among the nodes of the entire network based on synchronization, clustering and prediction routing algorithm methods are used to route the data from the source to the destination. The radio signal strength indicator used for clustering of the sensor nodes in to groups based on their received signal from the mobile sinks. This routing algorithm uses localization of the mobile sinks to enable scalability and robustness of the network and reduce the energy wastage of the network and prolong the life time of the network.

Therefore the experiment was conducted in Castalia simulator which is built on top of OMNET++ framework to check the performance of our proposed model over the existing routing algorithm in large scale area network. The simulation result shows that our proposed routing algorithm has better performance in reducing energy consumption and prolongs life time of the network.

Keywords*:* wireless sensor Network, mobile sink, synchronization, prediction, energy, life time

CHAPTER 1
INTRODUCTION

1.1 Background

Wireless sensor network (WSN) is composed of hundreds or thousands of tiny sensor nodes which are intelligent and self- configurable devices. they are spatially distributed in ad-hoc network form and has capacity of computing and communicating wirelessly[1]. They are capable of controlling and monitoring the surroundings conditions such as humidity, temperature, pressure and so on of environment factors. In early days WSN was used only for military applications such as tracking activities of enemy, battle surveillance which was created by US defense department project of Advanced Research Project Agency (ARPA)[2].

According to [3] the improvement and development of small chips technology called Micro Electro-Mechanical System (MEMS) is encouraged to the modern network with wireless communication technology. The relevance of WSN is widely spread throughout the world in health, environment and industrial applications on sharing information and works cooperatively among sensor nodes [4][5]. The modern WSN has highly demanded relevant application in target tracking and environment wings.

According to [7][17][53][54] the applications of the wireless sensor are environmental monitoring, military application, industrial processing, healthcare and patient monitoring, agricultural precision, target tracking, disaster, nuclear plantation, home automation ,and building management etc. sensor network is a single system which contains number of sensor nodes which are scattered on the surroundings environment. WSN has different considerable characteristics and limitation in both hardware and software. Therefore, some of the limitation and characteristics are small size, low memory, low processor capabilities with multifunctional, low cost, reliable, mobility and scalable. They are installed in harsh environment from the air plane without human intervention. The sensor network is scattered on the area according to the nature of applications which is in static or mobile format[6].

In static nature of placement of sensor network, the sensor nodes are installed in stable place or fixed place for monitoring the environment. However, in mobile placement the sensor nodes are configuring to move from position to position with dynamically changing their arrangement. In some cases the placement of the sensor network may have both static and mobile characteristics nature according to the particular applications and configured during the setup time[7]. In mobile sink, the sink is moving over the entire environment of the network to collect data from the sensor nodes. However, in static sink, the sink remains on fixed place and the sensor nodes route the data to the sink. Therefore the use of mobile sink has better advantage of coverage, reliability and balancing energy of the sensor nodes when compared with static sink.

According to [1] [3] [9] energy is the most valuable and precious material in sensor network, since sensor nodes is used battery as the source of energy. In such occasion battery life could be diminish quickly and leads for dying of the nodes. In general, the resource constraint of the WSN is critical problem to the overall performance and life time of the network.

Depending to the nature of the sensor network, nodes could use energy for sensing, communication, and data processing. Therefore, according to[8] communication of sensor nodes consumes more energy than processing and sensing. The process of collecting data from the surrounding, and interpreted the collected data on the processor finally send to the destination. Therefore, Data gathering is the process of collecting data from the source to destination as shown in network topology below in Figure 1

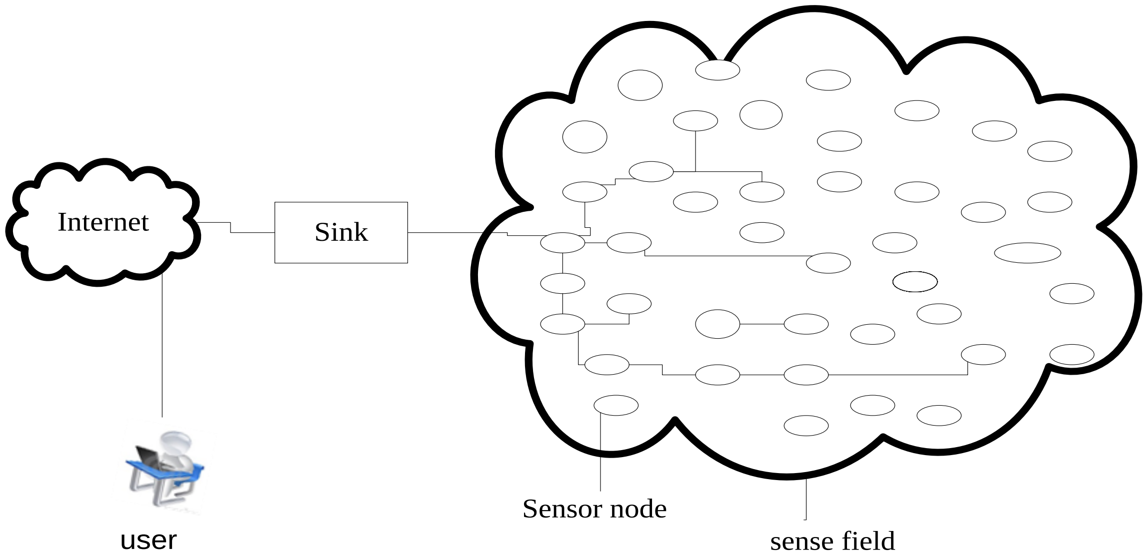

Figure 1: Wireless Sensor Network [22]

From Figure 1, the nodes are scattered on the area of interest to assemble the information from the surrounding environment and forwarded the sensed data to base station. The exchanging of information flow among sensor nodes from the source to the destination could be in either multi-hop or single hop. In single hop communication model, the sensor nodes and the base station are within the communication range. In contrary, multihop communication is passing number of intermediate nodes to reach final destination (base station) from the sources node.

For example, in Figure 1, sensor nodes are deployed on irrigation area to control the humidity and fertilizer of the farm land. The sensor nodes sense and collect information of about the irrigation which needs to add fertilizer and drink water. The information collected by sensor nodes sends to sink and the farmer takes an action accordingly. The vicinity node of the sink forwards more data on behalf of the far away sensor nodes. Thus this node has more traffic and consumes more energy to forward the received and its own data. As a result it create energy hole problem of the network which is called hotspot [9] or bottle neck of the static sensor network. Consequently partition and disintegration of the network occurred which leads short lifetime of the network[10].

According to [1]-[5][7][12][22] the researchers are investigated significant solution for energy consumption of static sensor networks by introducing mobile sensor network. And also distribute the traffic overhead among the sensor nodes of the network. In mobile sensor network, the topology of the network is dynamically changed and routing protocol has been reconstructed, Since the sink node of the network moves from position to position to collect information from the sensor nodes [11]. Therefore it is difficult to apply routing protocol static sensor network directly on the mobile sensor network without redesigning and modification.

1.2 Statement of the Problem

Recently numerous studies have been conducted in both homogeneous and heterogeneous sensor network to control and monitor the area of interest in both mobile and static sensor networks. The sensor node operates on collecting of information from the environment and forwards the collected information to the destination. In homogeneous sensor network, all the sensors nodes deployed on the environment have the same computing ability, same level of energy, same communication range of sensing and controlling activities of the physical environment. Where as in heterogonous sensors network the nodes have different computing and sensing capabilities. In heterogeneity of network the sensors nodes have various capability of collecting information and forward the collected data to the destination. In such kind of phenomenon the network may have static sensor nodes and the mobile sink with different capability of computing.

According to [11] [12] researches, conducted on the traditional data gathering sensor network, information is collected from the environment and send the collected data to the static sink. To forward the collected information the sensor nodes consumed more energy. Static sensor network consumes more energy than mobile sensor networks[13]. Because, the sensor node nearest to the static sink has high traffic overhead to forward the data that come from far apart sensor nodes. The traveling distance of the data can be calculated using hop count or Euclidean distance based on the nature and type of the network.

Another researches in [12] [14] [15] researchers invested their time on the fundamental issues of routing protocol of mobile sensor network to have an effective and suitable flow of information from the source to destination. This is mainly concentrated on mitigating the traffic overhead of the vicinity sensor nodes of the static sinks. Since topology of the network is dynamically changed due to the mobility nature of the sink, the traffic overload of the sensor network is distributed among the nodes of the network. As a result energy consumption of nodes is balanced. Whatever the type of network mobile or static, energy and routing protocol is big deal of WSN. Even though mobile sink is the most advantageous and equipped with better energy and finally leads the network to have better performance. In [5][10] has been deal with energy efficient data routing with mobiles sink to reduce the energy consumption of sensor nodes.

In [49] [52] location prediction scheme based data gathering for WSN with a mobile sink and location prediction scheme and time adaptive data gathering for WSN with a mobile sink has been also done. This is significantly reduces energy drainage and delivery delay problems. Considering the significantly improvement of routing algorithms stated in [49] [52] which suitable for small scale area of the network and improved the problem of static sink. However, still there is broadcasting location update information to announce the position of the sink. In addition to that there are also problems of scalability, energy consumption, synchronization problem, data delivery delay due to barriers of the network. Therefore such problems are insight us to spend our time on design energy efficient based synchronization routing algorithm. This leads to reduce the frequently broadcasting location update information message of the sink. Therefore, energy efficient synchronization based prediction routing algorithm for WSN with mobile sinks is proposed for large scale network. The different parameter and metrics of this study is stated in chapter 5.

1.2.1 Motivation

The reason in which we concentrated to work our research on wireless sensor is they deploying on remote area in which infrastructure is not available. The user has the ability to access the information from which sensor nodes are deployed on harsh environment such as nuclear plantation, land sliding area and disaster areas etc. at any time and conditions without exposed to threaten his/her self. This characteristic is only possible on wireless sensor network than other technologies even though WSN has big problem regarding the life time of network due to battery operated devices. Since battery is the main source of energy for sensor nodes which is used to operate their function. In the presence of resource limitation of the wireless sensor balancing energy consumption of the sensor network is mandatory by introducing mobile sink to distribute traffic overload of the network among all the sensor nodes and improved the performance of the network while routing data from source to destination. The problem of energy consumption on wireless sensor network insights us to design and implement Energy efficient routing algorithm for WSN.

Generally, the goal of our study is to shift and distributed the traffic over head burden problem of the sensor nodes among the mobile sinks in contrast to the static sink. This leads to improve and prolong the network life time, reduce energy consumption of the sensor nodes by reducing the communication range between sensor nodes and mobile sinks. The mobile sinks are moving closer to the sensor nodes to collected data from the environment's and have significantly improvement on data gathering and overall performance of the wireless sensor network. This leads to alleviating the hotspot and disintegration problem of the network by balancing the energy consumption of the sensor nodes.

1.3 Research Objectives

1.3.1 General objective

The main idea of this study is to develop Energy efficient synchronization based routing algorithm for WSN with mobile sinks.

1.3.2 Specific objectives

To achieve the general objective of the study the following specific objectives are listed as follows.

- To develop and handle broadcast location update information of mobile sink and minimize energy consumption.
- To build prototype for energy efficient synchronization based routing algorithm in WSN

- To test and evaluate the proposed algorithm in terms of energy consumption, delivery delay and life time metrics.

1.4 Methodology

To achieve objectives of this study different approaches and methods are used to come up with significant solution for the setting up problem that explained in statement of the problem.

1.4.1 Approaches

This thesis follows the methods of synchronization among the sensor nodes and mobile sink, synchronization based prediction routing algorithm, clustering of the sensor nodes using radio signal strength indicator.

1.4.2 Literature review

In order to achieve the main goal of this thesis work different researches have been rigorously reviewed and investigated in the literature review and related works to have detail understanding on energy consumption and routing algorithms in wireless sensor network. The review is conducted based on evaluating the basis of background, different applications and routing algorithms of both static and mobile sinks.

1.4.3 Parameters

To test and evaluate our prototype of this work number of parameters is used. The parameters are the simulation area 800 by $800m^2$, simulation time, communication range among the mobile sinks and source nodes, number of sensor nodes.

1.4.4 Simulation tool

Experimental setup and implementation of this algorithm is conducted on Castalia framework on top of OMNeT++ simulator to evaluate and test its effectiveness and performance of the proposed work with existing works. Comparison of this algorithm will also be conducted with the already existing routing algorithms in different parameters and metrics. The evaluation metrics we used in this study is data delivery delay, average energy consumption and life time of the network programmed using c++ programming language

1.5 Significant of Study

The significance of the result obtained from this study could improve network performance through reducing energy consumptions, delivery delay and prolong the life time of the network. Therefore, it is applicable for harsh environment that deployed to improve communication cost. As a result, in this work we proposed and contributed EESBPR routing algorithm that have capability to gather data with minimum energy consumptions and delivery delay for improve the performance of the network in terms of performance evaluation metrics such as average energy consumption, end to end delay and the network life time. Generally, EESBPR has better routing capability than routing algorithms such as LEACH and LPTA. We evaluated and compare our work with those existing routing algorithm. Finally, we come with better network performance in energy consumptions and the life time of the network.

The scientific contribution of this study is proposed and evaluated EESBPR routing algorithm that makes nodes to gather data with minimum energy and prolong life time of nodes.

1.6 Scope and Limitation of Study

The scope of this study is limited to design a model and develop algorithm for energy efficient synchronization based routing algorithm for WSN with mobile sinks only. The study focus on data gathering in wireless sensor network based on reducing the energy consumption and data delivery delay. Based on this designing suitable routing algorithm is needed to deliver the data to the destination. This only concern on efficient designing energy routing algorithms for WSN with mobile sinks to have better life time and performance of the network. There are some issues that this study is not considered such as:

- Secure communication of wireless sensor network, buffer over flow, memory sharing among the sensor nodes.
- If any malicious nodes are available in the network it is not be considered in this study.

1.7 Thesis Structure

The rest of chapters of this thesis are organized as follows, Chapter 2 deals with history of WSN, Architecture of sensor nodes investigated with various researchers, protocol stack of WSN, classification of routing algorithms of WSN in terms of mobility and static sinks, factors of that affect routing algorithms of WSN, energy model of the sensor network, management of energy in WSN, data gathering in mobile sinks, the application area of WSN and related works that have been done with various researchers under consideration. Chapter 3 explained the methodology used for the proposed work, frame work of proposed work and the designed model Proposed Routing Algorithm of mobile sinks and calculating position of sinks. Chapter 4 explains the experimental setup and simulation setups in details. Chapters 5 deals the result and simulation, analyze and discuss the simulate result and Chapter 6 described about conclusion and future work recommendation of the area.

CHAPTER 2

LITERATURE REVIEW AND RELATED WORK

2.1 History of WSN

According to [2] the foundation of the sensor network was invented since 1950s in US. In that time there were developed for military applications for detecting and targeting threats. During that time there were three different research areas of communication, sensor and computing devices which was combined them to bring sensor network. Those research areas were implemented and conducted on both software and hardware. The SOSUS was new innovation which was implemented by department of defense used to control the location and activities of soviet submarine in Atlantic and Pacific Ocean during the cold war. After sometime another network was developed which is called radar were used for air force operated by man power like wired network. Today the SOSUS is controlled by departments' oceanography and atmospheric to control and monitor the aquatic animal and seismic activities. According to [2] other improved sensor network called distributed sensor network (DSN) was investigated and developed which is the foundation of the modern technology of sensor networks.

This technology has the characteristic of the modern WSN such as low cost of sensing, processing capability and spatially distributed for data processing developed in Advanced Research Project Agency (ARPA).

In addition to that the DARPA another acoustic sensor was developed in Massachusetts institute technology (MIT) for sensing for tracking low flying aircraft which arranged in the form of array. There were used mobile node for signal processing in a single computer running with three processors, powered generator mounted on the backboard of the vehicle and those nodes communicate using microwave. In addition to that another authors in [53] the todays powerful number of small nodes, wirelessly self-configured with 16 bit of CPU, small memory size ultra-capacitor, lithium accumulator of storage and low energy consumption was launched in the early of 1980s. Therefore the modern technology of wireless sensor network was started in era of 1980s manipulated by the defense department of advanced research project agency.

2.2 WSN Architecture

The architecture of WSN has different transceivers and interfaces to create connection and communicate among the distributed sensor nodes. The wirelessly communication of the sensor network could be radio frequency or optical infrared depending on the technology of the sensor network used. According to reference [15] the sensor node equipped and integrated with the architectural body of sensing unit, processing unit, communication unit, storage unit and power unit. The sensing unit is integrated with different measurement of condition of the environment such pressure, temperature fire, vibration and so on. After the information is collected send data to the processing unit for further processing and interpreting by converting the digital to analog signal and analog signal to digital and finally send to the controller of the processing unit. According to the authors in [18] the processing unit has two major functions of operating task and controlling the other parts of the sensor node. The performance of the processing unit depends on the factors speed, data rate, memory, service loaded and preprogrammed of the processor. These all factors are evaluated with energy utilization of the processor of the sensor. In communication unit the collected data is interchange between the source and destination of the sensor network. During the communication of the network the sensor nodes have different state to have various usage of energy. The different states transmit, receive, idle and sleep modes. These states of the sensor node consume energy but their percentage is different.

Power unit is the source of energy and used to calculate how much is energy used to accomplish the task. In [19][20] [21] the amount of energy consumption is distributed among the three components such as processing, sensing and communication units of the sensor network. Considering the energy consumption of those parts communication unit has the highest percentage, since transmission and reception of the node consumed more. Power generator is the external source of the power for the battery sensor. Figure 2 illustrated that the architecture of sensor nodes and flow of information among the different architectural components.

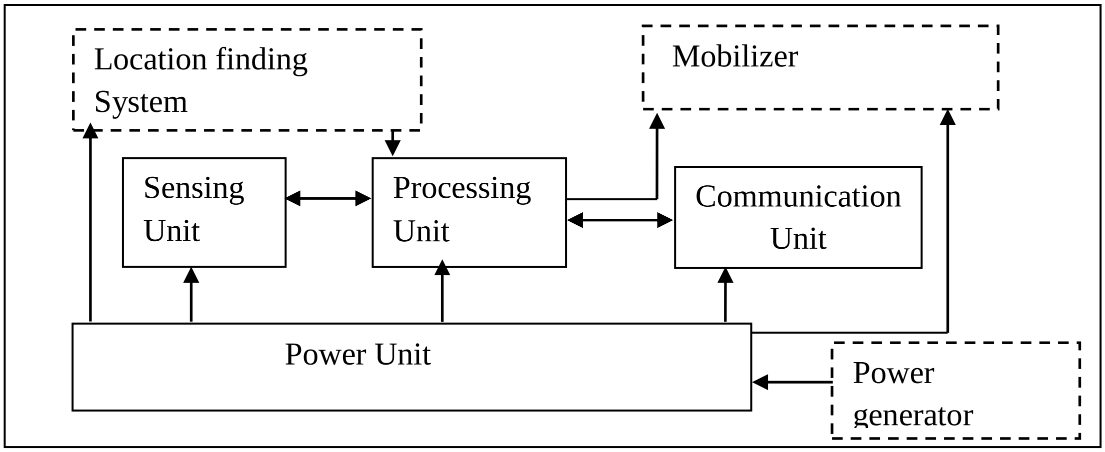

Figure 2: WSN Architecture [19]

Location finding system is a device that used by the sensor network to find the location of node, sinks and target object in the environment. Sensor nodes may use GPS and other localization algorithm applied on both static and mobile sensor networks.

The mobilizer is used to have the ability to move the node from one position to another position. The mobility may change the direction of the mobile object according to the particular application of the sensor network.

2.3 Protocol stack of WSN

WSN could not have well and pure designed protocols stack comparable to the traditional network protocol stack of TCP/IP protocol stack. According to [22][23] the WSN consisting the inherited major TCP/IP protocol layers such as the application layer, transport layer, network layer, data link layer, physical layer and task management plan, mobility management plan, power management plan on the top of traditional protocol stack. The three management plan sometimes called cross layer. The cross layer architecture of the wireless sensor network is developed on the top TCP/IP to maintain the layer structure to be more flexible and supporting network and application aware parameters. This structure leads to manage the connectivity among sensor nodes and produce high efficiency and work coordination of the sensor network.

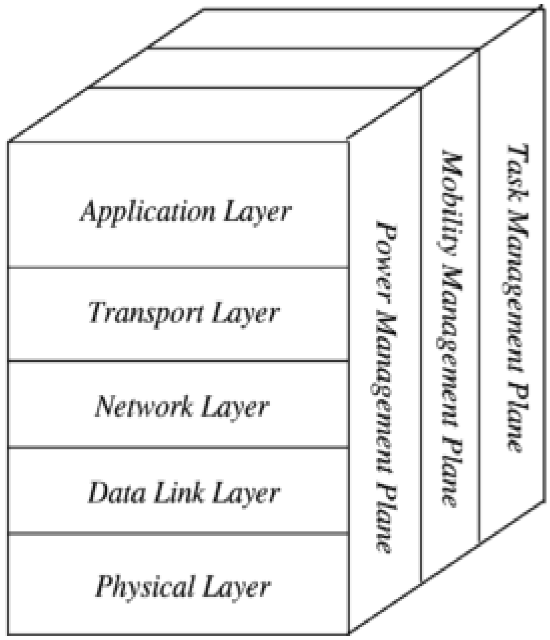

Figure 3: TCP/IP Layer for WSN[22]

The functionality of the cross layer is merging and incorporating of the common protocol to be produce combined protocol with more energy efficient and application particularity of the sensor network. Designing and combined transport and application, routing and MAC and replace the physical layer of the traditional protocol stack with wireless channel to produce more energy for the resource constrained sensor network.

2.4 Designing Routing Protocol in WSN

Designing an energy efficient routing protocol for the resource constrained WSN is the most critical issue. Since the life time of the network could significantly improve with well-designed routing algorithm of the sensor network considering the various factor of the routing protocol. The factors of designing routing protocols are highly dependent on the application area and sparse and dense deployment of the senor network according to the particular application.

2.4.1 Design Factors WSN routing protocol

According to [24] [25] some of the most common and highly influenced factors in designing routing protocols for WSN are the following:

- Node deployment, the sensor nodes can be deployed randomly from the air plan or manually. In manually deployment the routing path of the network is configured during the setup time but in randomly deployment the route path of the network is recognized an ad-hoc fashion to report the data to the destination in the network.
- Energy consumption is power source of the sensor network is limited since they are battery oriented device and more energy is exhausted in communication, processing and sensing to route the data.
- Scalability, deals with the size of the network area depending on the particular application of the sensor network. Sometime depends on the number of the sensor nodes scattered on the environment which is hundreds or thousands of nodes.
- Dynamic topology - the topology of the sensor network depends on the application area of the network which has ability to move the sensor nodes from place to place. Therefore routing reconstructing and create new topology during the time of movement of the sensor network. And the network the topology is changed due to mobile of the sensor nodes.
- Connectivity- focus on the link of the sensor nodes in the network. The neighbor of the nodes may change and the connectivity is also changed due the dynamic topology change.
- Data aggregation is the necessary in WSN to remove the redundant data from routing the same data to the destination and improve the energy efficiency of the network. According to the authors in [26] data can be aggregated based on average, maximum and minimum to improve the quality of the services.
- Transmission media, in WSN there is communication medium among sensor nodes which is implemented on the radio communication. The communication medium has different interference to make weak the communication.
- Reliability deals with the process of delivering and outperform of the data to the destination under the different internal and environmental factors. Adapting different factors and dynamically changing the topology of the network have better connectivity among the nodes to deliver data without any problem. Data reporting in WSN is the process of delivered the data to the sink. According to the study of [24] data reporting

in WSN can be categorized in to three groups according to the time and application used for.

- Time driven data reporting
- Event driven data reporting
- Query driven data reporting

In time-driven reporting it is triggered to report the collected data periodically to the sink from the surrounding environment.

Event –driven reporting the data is reported to the sink every time an event occurred on the environment.

Query-driven data reporting this is only send the report to the sink when the sink send query request to the sensor node. The entire sensor nodes wait for sink to send request and the nodes respond the requested query.

2.5 WSN Routing Protocols Classification

Unlike to the traditional and wireless communication of cellular network in [8] assigned globally IP address is difficult for sensor network because of resource constrained and application particularity of the network. Routing protocol for WSN is must be designed by considering the energy, storage and processing capability of the sensor network. Routing protocol of the sensor network assumed to be according different the application area of the network. The routing protocol should play an important role in routing the information from the source to the destination with considerable the topology of the network. Energy of the sensor network is one of the most critical issues and needs to be wisely used to extend the general life time of the network. Of this issue, energy efficient routing protocol network is basic and vital. In[24] the routing protocol of WSN is generally classified in two static and mobile sink routing according the nature of network.

2.5.1 Static Sink Routing Protocols

Static sink routing protocols are protocols that are designed for the routing the collected information from the environment to the static sink. The flow of information in this routing protocol can be travelled number of intermediate nodes in multihop or directly upload to the sink in single hop communication. Static routing protocol is categorized in hierarchical, location and multipath according to the structure, location and number path of routing relative the sink from the sensor network.

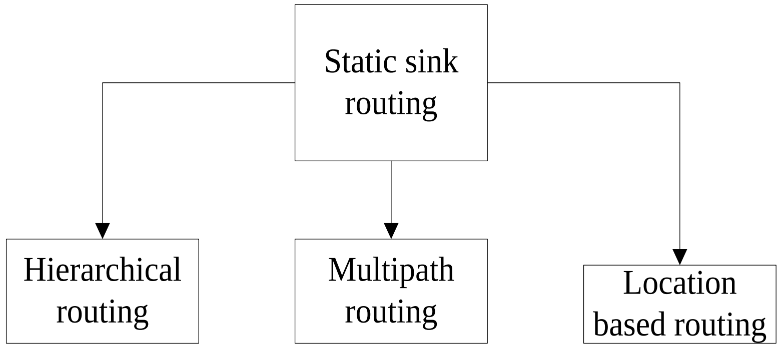

Figure 4: Static Sink Routing [24]

2.5.1.1 Hierarchical Routing Protocol of Static Sink

According to the structure of routing protocols, the routing protocol of WSN is arranged in hierarchical and flat structure. Here we only consider the hierarchical one, but the flat routing protocol is beyond the scope this study.

In hierarchical routing protocol the sensor nodes are arranged in three tier architecture, which contains the upper node, the middle node and the lower node of the network. The information flow sensor network is ascending for lower to upper of vice versa.

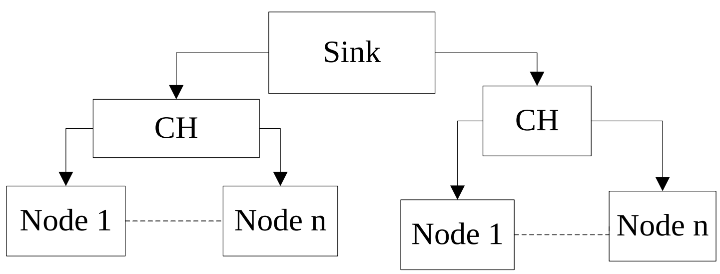

Figure 5: Hierarchical Tier Architecture [27]

According to the Figure 5 illustration the sensor nodes (node1, node2…node n) is considered as lower tier of the architecture to collect data from the environment and the cluster head(CH) is the middle architecture of the network whereas sink is upper layer of the hierarchical architecture that accept the data from the cluster head. Therefore there are number of hierarchical routing algorithm and we emphasized on some of the routing protocols here.

Low Energy Adaptive Cluster Hierarchy (LEACH) is one of oldest and most useful hierarchical routing protocols that have been proposed by Heinzelman *et al* [27]. In this routing algorithm the sensor nodes established an advertisement to become cluster head.

The sensor node collected the data from the environment send to the cluster head and makes an aggregation of data on the cluster head. According to the setup of routing algorithm LEACH have setup and steady states for each round. Therefore in setup time the network form a cluster according to the residual energy of the sensor and after setup transmitting of data is performed in the steady state. The sensor network select cluster head with formula of

$$K(\mathrm{n}) = \begin{cases} \frac{\mathrm{p}}{1-\mathrm{p}*\left(\mathrm{rmod}\frac{1}{\mathrm{p}}\right)} & if\ n \in G \\ 0 & \text{othe wise} \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

K (n) = the node which become cluster head in each round, p= percentage of cluster head, r is the current round with the set nodes of G. after selecting cluster head, the entire member of the sensor nodes communicate with cluster head according to the time slot provided for each node which called Time Division Multiple Access (TDMA) and the cluster head send the data to the base station. However, could have extra overhead in dynamic clustering and not suitable for large scale network. In [28] the authors proposed centralized energy efficient routing algorithm based on centralized clustering algorithm to improve the limitation of LEACH. The sink has an aware of location and residual energy of the entire sensors nodes during the system setup time of the network. Therefore the sink has knowledge of the setup network on intra and inters cluster communication in single hop form. Accordingly the cluster head is selected nodes which have the best energy. Another energy saved clustering algorithm was proposed in [29]. This algorithm is performed its cluster head selection based on the location and the residual energy of each sensor nodes to balance load of the cluster head and leads to prolong the life time of the network. The sensor node with maximum residual energy is nominated to be cluster head to next time. However it is centralized algorithm and needs location information of each sensor nodes.

2.5.1.2 Multipath Routing Protocols in Static Sink

Multipath routing protocol has important on having alternative routing path to the destination from the source of the sensor nodes and have an advantage of load balancing, less end to end delay, less wastage of energy. The delivery of data from the source to the destination is fast and has fewer nodes to susceptible to failure and alleviates the collision

problem of single path routing but redundant data may route. In [30] another multiple path route discovery is proposed to find the route from the source to the destination.
In this case the sink flooded the message to the entire network to initiate the route store message. The sources transmit the data by selecting the fresh interest of the intermediate node to the sink.

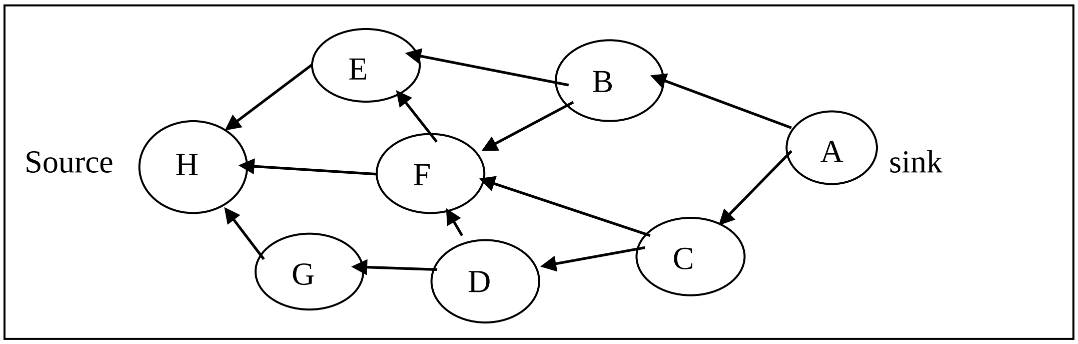

Figure 6: Direct Diffusion (Message Flooding) [30]

According to study proposed in [31] multiple paths routing to discover disjoint path from the sources to the destination is proposed in order to balance the load and localize the routing algorithm. The sink requests the route message among the multiple paths to balance and distribute the traffic load of the senior nodes. The sensor nodes discovered route requested message of the sink with in the interval time otherwise it discard route discovery requested.

On the other hand, study in [32] an energy efficient collision aware multipath routing algorithm is proposed to create collision free path among the source and destination of the entire network. The base station is aware of the location of sensor nodes with help of GPS. Each node in the network send route discovery message to the neighbor with in the communication range and the entire nodes in the network know the position of the neighbors. Therefore wastage of energy and interference of sensor nodes is decreased. Route overhearing method is used to detect collision and to check whether the route is free during route discovery.

2.5.1.3 Location Based Static Sink Routing

The location of the sensor network could be identified with the received signal strength indicator. The radio received signal strength indicator is also used to calculate the distance of the sensor network with neighbor by exchanging of packet information in addition to the GPS and other localization routing algorithms. Authors in [31] greedy perimeter stateless protocol is proposed which adopts the greedy algorithm. Perimeter and greedy methods are used to detect the location information of the nodes by forwarding the packets to the target node. The decision of destination and the next position of hop are made during forwarding packet without topological information. Another work in [33] geographic adaptive fidelity routing algorithm is proposed by partitioned the entire network in to number of equal sized cluster grids. The nodes of the entire network of this routing algorithm elect their leader to control sensor nodes. The responsibility of the leader is to make the sensor to sleep and active modes. The active sensor nodes reading the data and discover the route to send the collected data to leader. The leader node transmits the collected data to the base station. Sleep nodes conserve energy. Authors in[34] an energy efficient geographic routing algorithm is proposed with considerable routing decision factors such as distance, signal interference and cost functions. Distance and signal interference is used to find the distance of the source and destination of the node. Since as distance between source and destination increased, power is waste due signal interference noise. Therefore, the route decision is made according maximum power dissipation and interference power of the sensor nodes. Authors in [35] Location based energy aware and reliable routing protocol is proposed. The location information of the sensor network reads from the GPS and the information is store on the table with distance and ID of the neighbor nodes. Therefore, the routing decision is made according to the selected distance from the source to the destination which is stored on the routing table information and it follows shortest path to forward the data to the destination.

2.5.2 Mobile Sink Routing Protocol

In static sink routing protocol, the data is forward from the source of the network to the static sink. During the routing communication of static sink the sensor nodes nearest to the sink waste more energy than other nodes in the network due high traffic overhead. Energy is the most significant and more valuable resource for wireless sensor network to prolong the life time of the network.

According to the survey paper [35] [36] mobile sink routing protocol is an remarkable solution for problem of static sink routing protocols. Thus the traffic overload of node is distributed to the entire nodes of the network since the sink is mobile to pick up the data from the sensor nodes. The routing protocols of static sink cannot be used directly to the mobile sink without any modification. Some of classification of the mobile sink routing protocols are illustrated in this section.

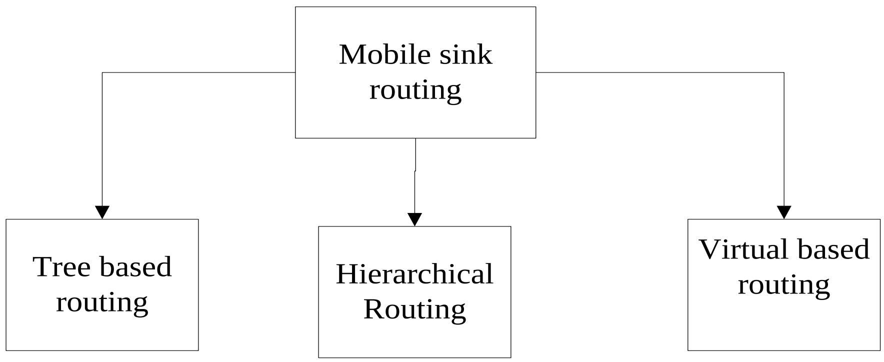

Figure 7: Mobile Sink Routing [36]

2.5.2.1 Tree Based Mobile Sink Routing Protocol

In tree based routing protocol, the structure of network is similar to the tree that put sink at the top which considered as root and the other sensor nodes are treated as the leave of the tree. Therefore the sink of the network is mobile for easily managed the environment. For example, in [37] scalable energy efficient asynchronous data dissemination routing algorithm is proposed based on tree constructed and select accessed node. The sensor node communicates directly with the accessed node and the accessed node knows the position of the sink even the sink change its position and finally send the collected data to the sink. The sink mobility reconstructs and reconfigure with minimum delay and energy wastage through distributed tree. The other study in [38] distributed dynamic shared tree with multiple mobile sink protocol is proposed to deliver the data to destination by creating groups of sinks. The groups of the sinks are master and slaves. The tree is constructed according to the structure of master and slave sinks. The sensor nodes reading the data from the environment and the slave sinks are forwarded the collected data to the master sink in the network. Master sink is the root of the tree and the number of slave sinks is connected to the master sink of the routing algorithm. The data is delivered from the source to master sink and from the master sink to slave sink and finally reach on the destination.

2.5.2.2 Virtual Routing Protocol

Virtual routing algorithm works based on virtual rendezvous point. Data dissemination in mobile sink is an efficient strategy in WSN with rendezvous area. The sink is settling on the rendezvous point to collect data from the sensor network and the sensor acts as sink to store and retrieve the data in its absences, which means if the sink is not arrive at rendezvous point.

According to the study in [39] two tier architecture data dissemination routing algorithm is proposed with building virtual grid for multiple sinks. The mobile sink broadcast query to the neighbor with node ID and distance to the grid point. The nearest node forward the query to the source within the virtual grid and the source use the reverse path to forward the data. Therefore different paths are used to detect the event of the network. Another grid based energy efficient routing algorithms is proposed in [40]. Location aware permanent grid algorithm is implemented on the nodes and the data is transmitted to the sink by selecting node header for the sensor network. But the node header is select from the grid similar to [28] to greedy geographic algorithm to send the data from source to destination or sink.

2.5.2.3 Hierarchical Mobile Sink Routing Protocol

Hierarchical routing protocol in mobile sink is similar to the hierarchical routing protocol of static sink with additional feature of mobility. The sink is moving from position to position to collect data from the environment. Here the structure of the sensor network is has as higher, middle and lower layers. The collected information is transmitted from leave to the middle layer and finally reached to higher level of the network. According to the hierarchal structure the sink acts at the top of the network and the middle part is cluster head used to aggregate the forwarded data from the sensor nodes or lower layer. According to the study in [41] registered clustering with mobile based routing algorithm is proposed to route the data from source to the sink. The sensor network broadcast packet location finding information and residual energy of the every sensor nodes in the network to select cluster head. Cluster head is selected according to the residual energy of the sensor nodes. Once cluster head is elected the cluster head broadcast an advertisement to sensor nodes to join to be cluster member. Mobile sink is moving the in network area with random way mobility model. The mobile sink change it position and broadcast location update information of the sink when it arrived to the new location. The cluster head registered the new location of the sink and generate routing path to send data to mobile sink after the sink changed its positions. Additionally energy efficient clustering routing algorithm for mobile sink is proposed in [42],accordingly the sensor network elects cluster head with better residual energy. The mobile sink broadcast the current location information to the entire sensor nodes of the network. There are number of equal distributed clusters to balance the energy hole of the network. Intra cluster routing algorithm is used for distribute the load and improve energy usage of the network to send the collected data to the sink.

2.6 Energy Model of Sensor Nodes

Energy is the most expensive and valuable part of WSN, since sensor nodes are small in size, computational capacities, low power supply, processing capability, buffer size and communication capabilities. In sensor network battery power is the source of energy. According to the work in [43] a sensor node have functionality radio transceiver, transmitting, sensing, processing and communicating capabilities. Of all functions of the sensor nodes the communication has high percentage of energy wastage. The sensor node dissipates more energy during transmit and receive **k** bits of data wirelessly than the other components. Therefore, the radio dissipation model is illustrated in Figure 8.

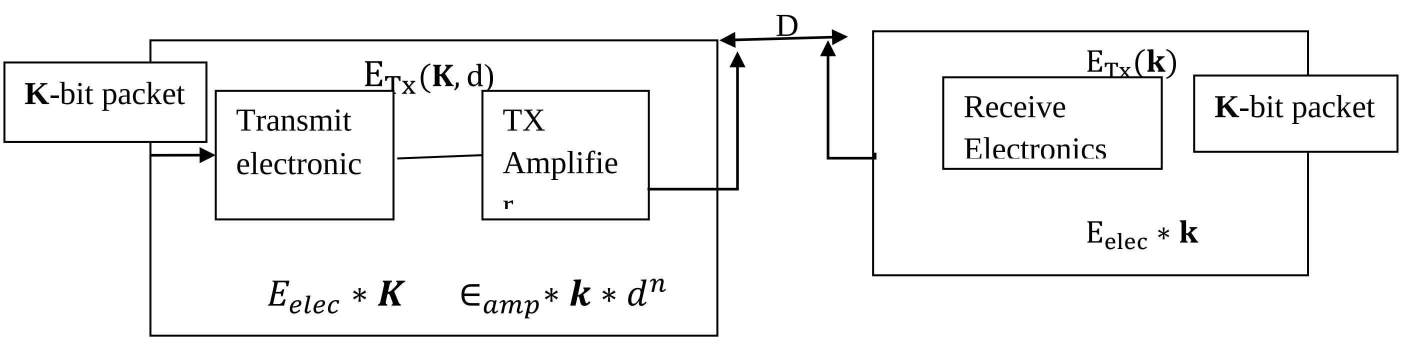

Figure 8: Radio Energy Dissipation Model [43]

The energy dissipation of the radio hardware is modeled and is compute the energy ingesting for diffusion and accept data with power amplifier with the communication range of transmitter and receiver. The data propagation distance sensor network from the source to the destination nodes in free space is (d^2 $power\ loss$) used for short distance propagation and multipath fading ($d^4\, power\, loss$) for long distance propagation. Therefore energy consumption of nodes to transmit k-bit of data from source to destination can be expressed mathematically with formula:

$$E_{Tx(k,d)} = \begin{cases} kE_{elec} + k \in_{fs} d^2, \ d < d_0 \\ kE_{elec} + k \in_{mp} d^4, d < d_0 \end{cases} \qquad \text{……………………. (2)}$$

Where, E_{elec}, represents, energy consumption of radio devices with some interferences factors signals and others. And $\in_{fs}$, $\in mp$ represent the free space and multipath fading transmitter amplifiers respectively. Then $d_0 = \sqrt{\frac{d^4}{d^2}}$

d_0 = threshold energy

d^4=multipath fading

d^2=free space loss

The life time of the network is directly depends on the energy of senor nodes.

2.7 Energy Management in WSN

The wisely usage of energy is the main significant and vital in wireless senior networks technologies since they battery oriented devices and require for different applications. There are number of investigations in [44][45] have been conducted on energy reducing mechanisms like aggregation, changing state of sensor nodes and introducing mobility models. Even though there have been a number of studies that have been investigated on reducing energy consumption but still it needs further exploration on efficient usage of energy in order to improve and extend the performance and life time of the sensor network. According to reference [45] energy management of WSN is classified in to duty cycling, data report and mobility node approaches based on the usage of energy.

2.7.1 Duty Cycling

Duty Cycling is the most effective way to save energy and improve the life time of the sensor network by altering states into sleep, idle and wakeup state mechanisms. In sensor network reducing radio transmission is saving energy. According to the study [46] the Duty Cycle based algorithms can also classified in to topological control protocols and

MAC protocols with low duty-cycle. In topological control protocol used to control the dynamic change of the protocols by keeping the operation, connectivity and coverage of the network stable even during changing the states of the sensor nodes in sleep and wakeup modes. On the other hand in MAC protocol, the sensor node switched their state from sleep state to wake up or from wakeup to sleep. Time division multiple access is used to reduce the energy expenditure and prevent collision of the sensor nodes with protocols of sensor-MAC, T_MAC and data gathering MAC according to the study in [46].

2.7.2 Data Driven Methods

According to the study in [46] there are different energy saving mechanisms which are data compression, data prediction and data aggregation methods for avoiding data delivery from sensor nodes to the sink. In data compression the data is compressed and coded at the source node before sending to destination. Data aggregation is another mechanism of reducing energy wastage through filtering and summarized the redundancy data with some mathematical and statistical methods.

Data prediction can be applied on both sink and the sensor nodes with stochastic, time series forecasting and algorithm depending on the particular applications.

2.7.3 Mobility based methods

Mobility is reduce energy wastage of the sensor network by distributed the energy consumption among the entire sensor nodes of the network and prolong the life time of the network. The mobility of the sensor network is depends the application of the sensor network used. Here either the sensor nodes or the sink or special nodes make mobile. In mobile sensor node the sensor nodes are moving around the area of deployment to collect data and send to the static sink or mobile sink according to the nature of the network. Mobility model of the network is depends on the application area. Generally mobility mode can be classified into[45][47] as:

- Uncontrolled mobility: The sensors nodes are moving randomly with different characteristic of motion such as vary speed, vary direction and trajectory. The movements of nodes are undetermined with regular data routing from source to the destination since the movement is uncontrolled.

- Predictable mobility: the motion of the nodes is constant or unchanged. The sensor node predict the time of data transfer with the predefined trajectory of the mobile node. This improves the efficiency of energy by make the sensor node active when it sends data otherwise become to sleep mode to save energy.
- Controlled mobility: The movements of the nodes are controlled by the user. This type of mobility model better used to improve connectivity and data distribution.

According to study in [15] the data collection using mobile sink extends the life time of the network 5-10 times better than the static sinks. By considering the latency of data arrival to the mobile sink there are several approaches that describe in [48] [49][50]. Another approach of mobility is relay node based mobility is an approach the rely nodes is moving to collect data from the source and send the data to the static sink similar to data MULE [51] .

2.8 Data gathering in mobile sinks

According to study in[52] data gathering using mobile sinks have better on reducing energy wastage and highly delivery of data to the destination with in limited interval of time. Data gathering is the process collecting data, process the collected data and finally send the processed data to the destination. The main objective of data gathering is addressing the collect data from the source to the base station of the network. Concerning of the implementation and routing of the mobile sink depends on the deployment and dynamically change of topology of the network. In mobile sinks, the traditional data gathering and routing algorithm designed for static sink cannot apply directly; it needs redesigning new routing algorithm which fit with mobility of sinks.

2.9 Application WSN

According to drastically technology advancement and easily usability of the sensor nodes, WSN used for different application in both industrial and academic areas. According the studies in [7][17][53][54] the accessibility of WSN is increased from time to time and some of the application areas are environmental monitoring, healthcare, target tracking, disaster monitoring, military application, industrial applications etc.

- Environmental monitoring: WSN is comprehensively used for monitoring and controlling the activities of operated on the physical environment and conditions like temperature, humidity, pressure, vibration and so on.

The important environmental monitoring ranges from agricultural precision, animal monitoring, soil makeup, controlling of forest from fire, climate changes etc. The use of WSN in agricultural precision helps to monitoring the availability of water, fertilizer, temperature, humidity, irrigation control etc. [25].

- Health monitoring: the sensor nodes are deployed on human body to control the status of the patient and send the status to the doctor remotely. The various health monitoring devices used start from simple heart beat to the expensive device of monitoring implantation.

- Disaster monitoring**:** is another important application of WSN is used monitoring and controlling natural event like volcanic eruption, earthquake and human event of fire, nuclear plantation and other harmful events.
- Military application: WSN is used for detecting and gathering of information about the enemy movement, explosion and other phenomenon.
- Industrial applications**:** used to monitor the manufacturing, processing system safety, controlling of security, lightning and so on.

2.10 Related works

According to the study in [55] proposed the placement of the mobile sinks with energy constraint scalability of the wireless sensor networks using method of balanced graph partitioning by dividing the network in to small scale networks, partitions in order to balance energy among the sensor nodes of the network. They claims only optimize the place of the mobile sinks to minimize the energy and prolong the life time of the network. However, when the sink moves from place to place the same data can be collected within the same area or on different sinks may collect same data from different area.

According to the study in[56] another designing an optimal placement of the mobile sinks with hierarchical network for efficiently data gathering and energy saving was proposed . The optimal position of the mobile sink is computed mathematically according to the residual energy of the sensor to find the best location of the sink based on the clustering.

They also discussed that the clustering mechanism which operated to be select cluster head by checking the status of the packets across the network. The nodes with maximum residual energy would be selected as a cluster head to prolong the life time of the network. Therefore the sink communicates with cluster head by moving and selecting new location to wards to the cluster head. This leads for efficiently usage of energy and improve performance of the network. However , the sink moves toward the cluster head to collect data from it, in this case there may be data loss when the sink is not arrive within the time interval at specified place due to some obstacles and the cluster head could be die.

On the other hand in[51] analytical model and clustering architecture of the sparse sensor nodes were proposed for data gathering from the senor node within the communication range. The mobile entities collect the data from the sensor nodes and send to the wired access point. The mobile entities are moves in random walk, this result significantly improves energy saving and lifetime of the network. Another work in [27] was proposed to tackle delivery delay of problem of MULES by improving the overall performance of data gathering in wireless sensor network. In addition to that in[23][47] Anchor based Voronoi-Scoping protocol and TRAIL data gathering protocols were proposed in [57]. These two protocols are designed specifically for efficiently data gathering and improving performance of the network by reducing the data delivery delay. Taking the general consideration in to account, those protocols have their own specific advantage and draw back. Anchor based Voronoi-Scoping routing protocol is suitable for heavy load network, in which the voronoi divided the network in to different cluster with anchor nodes. The sensor stored all routing information of the anchor nodes to avoid the large data transmission overhead of the dynamic routing path information. The sensor nodes communicate only with the vicinity anchor and the anchor node communicates with the sink. The Voronoi-Scoping association of mobile sink and anchor nodes refreshes the structure periodically due to the movement of sink and AVRP builds up a delivery structure.

In the study [58] TRAIL protocol was proposed for light loads traffic network based on the trailing movement of the sink and the data gathering is routed through trailing. In this protocol follows random walk movement to detect the mobile sink. Once the sink is detected request data transmission from the sensor node to the sinks trail for update the next data gathering route.

According to the study in [17] proposed efficient data driving routing protocol to reduce the overhead of sensor node for data gathering integrated with random data forwarding. This routing protocol first used gratuitous route learning for broadcasting message to the sensor nodes from the mobile sinks. And each packet caries recorded distance from the sensor nodes to the targeted mobile sink (destination). Therefore continuous route learning is experienced to give more detail information about the sensor nodes with some extra control overhead and high packet delivery to the mobile sink. However more energy is consumed to learn and discovery the route and maintain the route, which leads to become low life time of network. On the other hand, in [4] adaptive local update routing protocol is proposed based on the local flooding method to update the local area information while the sink moves. When the mobile sink moves with in the destination area it updates the location information of the local area of the network only rather than to the entire network. So it consumes less energy and minimizes the probability of collision in wireless transmission. In this case the sensor node sends their collected data to small area near the sink, and then the sensor node within the small area forwards the received data to the sink directly since they are in the destination area.

On the other hand, when the mobile sink moves to the next place it broadcasts location update to the whole network again and the sensor send the collected data to the newly updated location and new destination area. However an overhead problem is happened based on the broadcasting to update the new location especially when the mobile sink moves fatly and node at far distance may not receive location information quickly since the mobile sink is moving fast.

In the study of [10] proposed query based data gathering for delay sensitive application with mobile sinks based on query deadlines. The communication is performed with multihop route by considering the delay and minimum energy consumption with shortest path route from the source to the destination. Query scheduling algorithm is used for the mobile sink to sends query to the targeted sensor node with deadline response of the message. Therefore the response of the message should be reach to the sink within the specified time before to the deadline. This improves the throughput and balance of energy consumption of the network with optimized the number of hops and response time. The sink move back and forth to the two route ends. The query release sensor send query to the targeted sensor node and the targeted sensor node process that query reply a response message to the queried mobile sink to collect query with short path and deadline.

In the study [1] proposed hybrid approach, which combine data forwarding mechanism with mobile sink by designing several rendezvous points in order to avoid buffer overflow and energy consumption. The mobile sink visits all the rendezvous points and the senor node forward the buffered data to the mobile sink when the sink is within the rendezvous points. Therefore the sensor nodes collect high and low sampling rate of data on the clustered sensor nodes. The clustering is consider as rendezvous point and the allotment mechanism is used for storing high sampling rate temporary on the buffer of the low sampling rate of the same cluster. This sampling rate data is buffered until the mobile sink come in one hop communication range of the rendezvous point. The transmission of the rendezvous point is restricted within deadline based on the algorithms of dominating based minimum weight sum first and dominating traveling sales man approximation for minimizing data sampling rate with missed deadline and maximized data sampling rate without missed deadline respectively. This only consider for sensor nodes with high data sampling rate to store temporary on the lower data sampling rate sensor nodes. However, still there is data loss until the mobile sink reached within the communication range especially in large scale sensor network. Another works biased time stop adaptive sink mobility algorithms was proposed in [48] by considering the region where high density deployed of sensor nodes is called pocket. To achieve the accelerated of the network coverage and fairness service time of each region, the sink node moves probabilistically with favoring on the less visiting areas and adaptively waits longer time in the network area which have higher density and more data traffic. However, the mobile sink moves to visit all the vertex of the graph may cause time delay problem especially for large scale network. In the study [49] proposed location prediction and time adaptive data gathering with a mobile sink to decrease energy consumption and location update of the mobile sink. During the usage of single mobile sink the data delivery latency is decreased when comparing with static sink especially in small scale network. The overall performance of the network is improved to some extent but the mobile sink waits more time on the more data generated area. Therefore, there is still delivery delay as the number of sensor network increase and when mobile sink spent its time on the more data generated area. In addition to that the sensor node consumed more energy to receive and buffer the data until the sink reach at specified place. The other hand, the study in [59] proposed to mitigate the data delivery problem on large scale deployed wireless sensor network with path constraint. The mobile sink moves along the give fixed trajectory to collect data from the randomly deployed sensor nodes with constant speed. The sink moves back and forth to reach at the end point of the network with single hop or multihop communication and finally the node send the data to the mobile sink. In multi-hop communication is assigned sub sink, the member nodes send their data to the sub sink and the sub sink send to the mobile sink directly in order to improve the data collection and reduce the energy consumption. To solve such problem integer linear programming language method is used to find the optimize connection of the sub sink with its members and increases the amount of data collected to send to the mobile sink. In addition to integer linear programming language, genetic algorithm is also used to solve the maximum amount of shortest path problem by the partitioned communication in to zones without considering the knowledge of geographical area of the network and utilizing energy effectively. However, the main drawback, it needs another data routing for area where the mobile sink is not reached.

According to study in [11] proposed the an algorithm based on the connectivity based data collection to extend the life time of the network based on path constraint of the mobile sink and increase the time and energy constraint of the mobile sink by clustering the sensor nodes into fully connected single cluster. In multihop communication, gateway is designed for nodes which are out of the communication range of the mobile sink in order to extend the life time network and balance the energy consumption of the sensor nodes. To communicate the sensor node with the mobile sink use shortest path with Djikstra algorithm to balance the energy consumption and connectivity of sensor nodes with in multihop communication. However, buffer overflow and data delivery delay problem could be occurred due to the restricted path to forward the generated packet to a single mobile sink. In the study [60] an efficient reshuffling cluster compressed sensing is proposed to improve the problems of the LEACH by balancing energy consumption and reduce data volume of the network. By adopting LEACH (Low Energy Adaptive Cluster Hierarchy) algorithm to form cluster and selecting cluster heads from the sensor nodes having largest residual energy to balance the energy consumption and prolong the life time of the network. The cluster member's collect the raw data and send to the cluster head. After the cluster head receive the raw data, it sorts the data in ascending order and preprocessing the signal with linear projection and finally sends the compressed data to the sink. The sensed data are reshuffle only one time and put on stable time to reduce the energy consumption and to have an accuracy of the reconstruction. The sensed data does not dynamically change to reduce the computation overhead for real time application utilization with the theory of compressed sensing. Even though the data is compressed to send to the sink there is energy consumption and hot spot problem on vicinity of the static sink, because of traffic overhead problem on the vicinity node of the static sink is high. According to the study in [61] an energy efficient routing algorithm data forwarding to the destination based on clustering is the proposed for the sensor nodes. In this case members of the cluster select their cluster head based on the better residual energy of the sensor nodes, and the cluster head the data from the members and send the collected data to the base station with reduced delay and minimum energy consumption. However, a single mobile sensor node when the sensor node failed another mobile sensor node comes therefore there is data loss due buffer overflow of the cluster head and leads to die the cluster head of the network.

In the study [16] a balanced energy efficient network integrated super heterogeneous protocol is proposed based on the different energy level of the sensor nodes (normal with lowest initial energy level, advanced, super and ultra-super highest level of energy). Hence this protocol works by forming a cluster and the probability of the sensor node to be cluster head is based on the ratio of the residual energy each node to the average of energy of the network. This works the same principle as LEACH and DEEC works by selecting the node with high residual energy as cluster head (CH). In addition to LEACH and DEEC an improved BEENISH algorithm is designed dynamic adjusting CH selection for long stability and elongation of the network life for both protocols of mobile sinks than static sink by reducing the energy consumption of sensor nodes. However there are still problems of data forwarding latency and data delivery ratio. On the other hand the study in [62] proposed trajectory planning and load balance network with joint optimization, to solve problem of load balancing of mobile sink. Therefore, the joint optimization select minimum energy consumption rendezvous point based on the approximation algorithm. The mobile sink is collected the data with delay bound based by exploring the trajectory of the sink to optimize its performance. The correctness of the algorithm is proved mathematical by analyzing the trajectory planning and load balancing to improve the performance the algorithm. This proposed work assumed that location of each sensor is localized to be known by the mobile sink using distributed localized algorithm which fully designed to make the network more effective and efficient. However, there is buffer overflow problem of the senor node.

In [63] the authors proposed localized algorithm with distributed two tier geographic architecture with hash table for efficiently data collection according to the event driven which occurred on the environment. The mobile sink moves only when an event is occurs on the environment otherwise it stay in fixed place. This distributed algorithm is suitable for event detecting application in wireless sensor network to identify intrusion detection and collect the detected event and send to the mobile sink. Furthermore hash table is used to reduce energy consumption of sensor nodes to route the data to the mobile sink. Hash table based data collection protocol is used to collect the data by selecting location announcer nodes to announce of location of the mobile sink with virtual grid when an event is occurred. However, data delivery delay and energy consumption problem may be happened since the sink is only collect data when it is on single hop.

According to the study in [15] distance aware routing algorithm for multiple sinks is proposed. This study is reviewed more detailed on energy efficient data collection in wireless sensor network. To route data from the source to the destination residual energy and distance are considered as main factor of sensor nodes. In this study the routing algorithm classified in to routing setup phase, steady phase and maintenance phase. In routing phase the mobile sinks are moving on the boundary area of the field to collect data from the environment. To route the data from source to the destination distance and residual energy of the neighbor is calculated. Therefore the source selects the shortest path with maximum residual energy. The mobile sinks are only collecting the data when they are parking at the sojourn point. This results balance energy consumption and increase the life time of the network. However, still there is energy consumption due to periodically broadcasting location update message and data delivery delay is not specified. On the other hand, in [64] an energy management algorithm with mobile sinks for wireless sensor network is proposed to balance energy consumption among the sensor nodes. The objective of this study was not only to balance the energy of sensor nodes but also balance the workload of the sensor nodes too. The mobile sinks are connected with local road map to monitor the remote deployed sensor node with constant speed. Therefore more than one mobile sinks are moving at the same road to collected data from the environment. This data collecting is performed depending on the residual energy of the sensor nodes. The mobile sinks collect data give priority the sensor nodes which minimum energy. However, Moreover as far as moving on the same path there will be data redundancy.

According to the study in [9] predictive routing protocol was proposed based on the concept of milestone. During the mobility of the sink the milestone node holds about the future location of information of the mobile sink. The information is flooding to the neighbor nodes to update the previous location of the mobile sink. However, the problem is flooding of update location information periodically to the entire sensor node of the network increases the energy consumption and creates an overhead problem. In addition another study in [65] master based data transmission was proposed from the source node to the destination. In this case the sensor nodes are grouped in the regions according to the location information. The grouped sensor nodes in the region select master nodes to communicate with the mobile sink when it arrives at that region. The selected master node from the leaf nodes is swapping its function with an agent node to prolong the life time and improve performance of the network. the master node consume more energy and the agent nodes charged to the master until some threshold level after that master node broadcast leaving message to select new one. However there is considerable data delivery delay when the mobile sink is not arrived within the time and energy is consumed by frequently broadcasting message.

According to the study in [52] location prediction based data gathering protocol using a mobile sink is proposed for collecting of data from the sensor nodes. The mobile sink is moving on predefine trajectory with a constant speed to minimize energy consumption. The predefined trajectory and constant speed makes easily for the mobile sink predictable with loose time synchronization. Single mobile sink is suitable for small scale network to monitor the environment. However, still there is energy consumption due broadcasting message for location update and data delay. In addition to there may be route breakage due some obstacles especially in case of large scale network area. Additionally in [50] was proposed on vertical line that divided the sensor in two equal parts for the source nodes and mobile sink. The line at the center acts as rendezvous region for data storage. The ordinary data that generate at the boundary sends to the nearest inline and the sink send query to the inline to access the data. The query is flooded along the virtual line until it reaches to the inline of requested data. The first inline node send the query data to the inline and the repose query send in reverse path to the sink. The objective of this study is to address the hotspot and scalability problem. However, the main drawback is that when using the line that acts as rendezvous point there may be high data latency at node near the boundary of the network.

Table 1: Comparison of Related Works

Reference	Objective	Approaches	Limitations
DDRP[17]	Reduce protocol over head	Broadcastin g based route learning	Energy consumption to learn route discovery based on broadcasting
ALURP[4]	Minimize energy-consumption and avoid collision	Local flooding based	Routing overhead when sink moves fast
DES[10]	Reduce energy consumption	Query based algorithm	Data drop when deadline expired at the intermediate nodes
ED[1]	Avoid Buffer overflow	DMWSF& DTSPA	Data loss when node is out of communication range.

BAST[48]	Reduce energy consumption &data latency	Adaptive stop time and biased sink mobility	Time delay of sink
LPTA[49] and LPDG[52]	Reduce energy consumption	Prediction, Prediction and time adaptive	Data loss, delivery and energy consumption and scalability
EDC[59]	Reduce data delivery delay	Integer linear programmin g	Needs additional routing for mobile sink un reachable area, since path is constrained
CBDC[11]	Prolong life time of network	Connectivit y based clustering	Buffer overflow and data delivery delay
RCCS[60]	Balance energy	Reshuffling based clustering	Hot spot problem
EE-CDRDG[61]	Reduce data delay& energy consumption	Clustering	Buffer overflow problem
SEENISH [16]	Reduce energy and data delay	Clustering approach	Data loss
PDRP[58]	Improve Performance and routing overhead	Voronoi-scoping and trail	Energy consumption in routing update periodically
EEDR[15]	Balancing energy and prolong life time	Distance aware	Energy consumption and delivery delay
EMMS[64]	Balance workload	Local road map based connection	Collision and data redundancy
PRP[9]	Data delivery delay	Milestone	Energy consumption due periodically broadcasting

		based	
DTS[65]	Improve performance	Selecting master node based	delay delivery and still energy is consumed due to frequent broadcast update message
OLMS [56]	Reduce energy consumption	Clustering based of nodes	Data loss due to head traffic of cluster head
LBD[50]	Reduce hot spot and scalability	Line based	High data latency

2.11 Summary

This chapter deals with the background history of the wireless sensor network and the application of the sensor network during the innovations time. After some time the sensor network is became integrated with advance and modern technology for different application areas in this time. There is also architecture of WSN like that of the traditional TCP/IP protocol stacks with additional features of power management, mobility management and so on. The sensor network has factors of scalability, density, energy, topology management, coverage area, reliability etc. depending on the specific application of the network. Therefore, designing energy efficient routing protocol is necessary for sensor network. Generally the routing protocol of wireless sensor network can be classified into static and mobile routing protocols. Therefore, energy drainage is the main major issues since it is battery operated devices. There are also energy management mechanism like duty cycle, data aggregation, mobility and related works with both static and mobile sensor networks routing algorithms.

CHAPTER 3

SYSTEM MODELING AND DESIGNING

3.1 Overview

This chapter explained the methods which considered the scenarios of efficient energy usage in wireless sensor network, the proposed framework for the model with mobile sinks, EESBPR routing, calculating future position of sink throughout this research.

3.1.1 Assumptions

This chapter contains design and system model of network which is considered some assumptions that follows throughout this thesis work.

- All the sensor nodes are randomly deployed in the range of interest.
- Once the sensors are statically deployed, they could not move from one position to another except the sinks.
- The sensor nodes are energy constraint which is only functional until the energy is run out.
- The sink is moving around the area to collect data from the sensor nodes according to the predefined trajectory.
- All the sensor nodes are location aware to identify the geographical location of all the neighbor nodes with help of geographical positioning system (GPS.
- The energy consumption of GPS is considered as negligible when compared with the energy consumption sensor nodes during communication and sensing.
- The mobile sinks have unlimited energy, unlimited communication capability and unlimited computational capability such as memory, processor than sensor node and can communicate with the sensor in direct or multihop. The mobile sink can only accept data when it is on the parking position.
- The mobile sink could not accept any data while moving on the given trajectory.

3.2 System Model

3.2.1 Network Architecture

In this section, we explained the details of design framework of network topology of the sensor network and demonstrate route of data on the area of interest in wireless sensor network. To tackle the energy expenditure, the delay and other problems of the network with mobile sinks which described on the statement of the problem. Therefore, in this network model, there are **N** number of sensor nodes that deployed on the region of interest to monitor the ambient environment and **S** number of mobile sinks that are mounted on robots, animals which are moving around the environment to collect data from the environment of the network area by periodically changing their location. While the sinks are moving on the predefined trajectory of the network have the following properties: number of parking points, velocity of the sinks, moving duration of the sinks and sojourn time of the sinks. In this case every sensor nodes of node (i) and node (j) are the set nodes which is members of the network of N which is (i, $j \in$ N) are randomly distributedly scattered on the space and creates self-configured network topology in specified environment according to the diagram as shown in below.

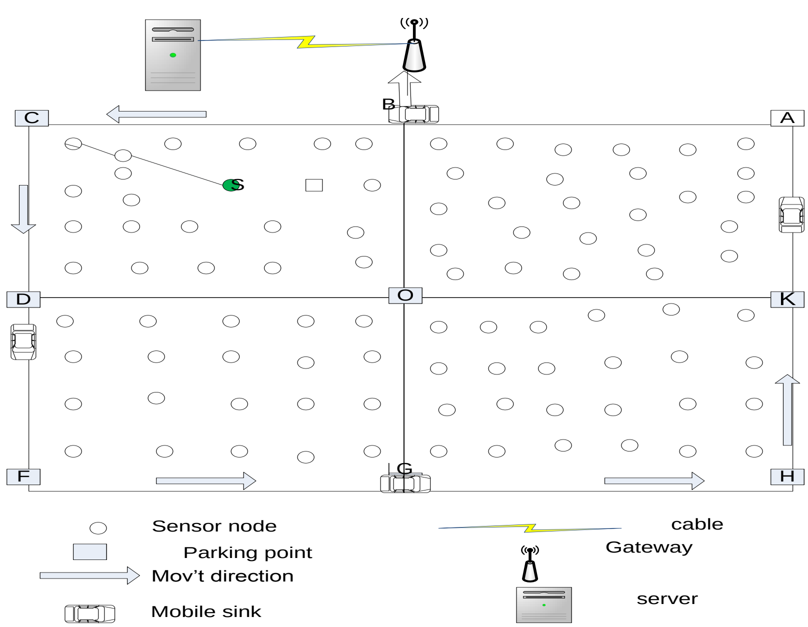

Figure 9: System and Network Model

In Figure 9, above the sensor nodes are scattered randomly on the space from the air plane to monitor and control the environment without human intervention. Once the sensor nodes are deployed on the area in static form to control the environment and collect data, process the collected data and finally send to the mobile sinks. During communication of sensor networks, the data is forwarding from source node to the destination node may follows number of intermediate nodes.

Basically, the communication nature of the sensor nodes and the mobile sinks may follow two ways by considering their communication ranges.

- Single hop communication, the source node can directly upload the collected data to the sink, since the source node and the sink is within the communication range of each other.
- Multi-hop communication is another type of communication mode, in which the data is travel number intermediate nodes to reach at the destination node from the source. Such mode of communication goes more than one sensor nodes to arrive at the destination. Based on the mode of the communication the sensor node can also perform two operations. Therefore, a sensor nodes can acts as event detector or router

- The first case is sensor nodes acts as event detector, which detects an event from the ambient environment and collects information about it. E.g. temperature, fire etc.
- The second case is the sensor nodes acts as router, that route the collected data from the environment and forwarded that data from the source to the next node or destination.

During monitoring and controlling the environment, the sensor nodes detect an event, process that event on the processing component and transmit the processed data to the sinks. This network model consists of heterogeneous sensor networks on a given environment. Those heterogeneous sensor nodes are the static sensor nodes which called ordinary sensor node and the mobile sensor nodes which called mobile sinks. Therefore in this study both static sensor nodes and mobile sinks are considered.

The sensor nodes are deployed on the rectangular area as shown in the Figure 9 of the network model to monitor and collect information from the environment. The mobile sensor nodes are moving to around the area to capture the collected information from the static sensor nodes. Therefore, the network model of our system is divided in to different partitions of clusters with equal sized for two main reasons.

- For making easily management of the sensor nodes and mobile sinks by reducing the number of travelled distance of the data to reach at destination and reduce controversial of selecting of next hop the sensor nodes for large scale network area.
- To decrease the energy consumption of sensor nodes by reducing distance of data travelling to reach the final destination and reduce packet delivery delay of the data to arrive at the mobile sink.

Every node on the entire network is assumed to be location aware with low power consumption geographical positioning system (GPS) which makes easily to identify the location the neighbor of sensor nodes. Accordingly the mobile sinks are revolving on the predefine trajectory of the rectangular area of the network in order to collect the data from the sensor nodes. The mobile sink collect can also collect data only when it is setting on the parking point. The general, representation of network model with undirected graph of G is, G= {N, S, k, P} Where N is the set of static sensor nodes which randomly scattered on the monitoring environment, S is the number of mobile sinks that are moving on the predefined trajectory of the monitoring environment with k the communication link among mobile sinks and the sensor nodes, and p of the parking point of the mobile sinks.

According to this network model, the mobile sinks are moving in anticlockwise direction on the rectangular area of the predefined trajectory with constant velocity to make easily predictable. To avoid collision during routing each mobile sinks assigned TDMA time slot their members of sensor nodes. The topology setup of the network is dynamically changed as far as the sink is moving from position to position periodically, but the entire sensor nodes are aware of the location of the mobile sinks and parking point of the sink on the specified point and waiting time at each point to accept data from the members of the sinks before moving to the next position and the waiting time is expired. We assume that the mobile sinks turn off their radio during moving.

Therefore, during the communication link is available among source sensor nodes and the mobile sinks with weighted graph cost value. For example if two sensor nodes, node (i) and node (j) are within the communication range, then the communication distance between node (i) and node (j) d (i, j) will be less than the communication range (R) which is d (nodei, nodej)≤R. in this case either node j or node i be nearest to mobile sink of k. Otherwise the communication will be with q which is directly communicate with one of the mobile sinks and neighbor of either of the sensor nodes of node i or node j.

3.2.2 Proposed Routing Algorithm

In this section we found designing and implementing **EESBPR** routing algorithm is necessary for wireless sensor network to reduce the energy consumption of wireless sensor nodes and increase the life time of the network. In wireless sensor network, the communication component is consumed more energy than the sensing and processing components, since more energy is consumed during reception and transmission of data packets.

According to [66] the sensor nodes use radio energy of (AA) battery power with capacity of 300mAh as a source of energy. The main reason why we focused on energy here is that it is impossible to change the battery of each and every sensor nodes manually since they are deployed on the harsh environment and time consuming and costly.

Thus in [66] the life time of battery can be stay from 4 days to several years depending on the particular application of the wireless sensor networks which continually operating. Therefore designing an energy efficient routing algorithm is one of the best options to prolong the life time of the networks. In WSN the sensed data should be transmit within the time bound from source to destination in order to reduce the drop of data and delay packet besides to the energy consumption. As a result this affects the performance of the network in general. Subsequently, therefore we designed synchronized based routing to predict the position of sinks by calculating distance among the parking positions. The nodes are grouped in number of clusters according to the number of mobile sinks and sensor nodes are joined to the sinks as members based on their rank as stated in equation (4). When the source nodes want to send data to the sink first check the residual energy and distance of the neighbor nodes, if the neighbor node has better residual energy send the data otherwise find other neighbor with better energy. This process is continued until the data reached at the final destination or sink.

All clusters have the same distance from the center point to all directions and each sinks has their own cluster members (partitions).

Generally, designing and implementation of the proposed algorithm, EESBPR, has five phases:

1. **Clustering phase**: the number of sensor nodes is partitioned in to groups of clusters according to the number of mobile sinks to minimize the distance and moving time of the data from the source to the sinks which leads to reduce both energy consumption and delay.
2. **Sensor member's selection phase:** in this phase each mobile sink broadcasts a beacon message to all sensor nodes. After the sensor nodes received that beacon message from the sinks, then sensor nodes are started ranking of sinks according to the received beacon message of received signal strength indicator (RSSI) with (MSi, RSSIi). Then compare the received beacon message with RSSIi>RSSIi+1 then sensor nodes joins to MSi. In addition to that according to [67] The RSSIi only cannot be accurately estimating the distance of mobile sink and sensor nodes because there is presence of channel fading and attenuation.

Therefore the round trip time is needed to calculate the exact distance of the node in addition to RSSI. Hence we adopt the formulae's of [67] to calculate the rank of sensor nodes to be a member of a mobile sinks based on RSSI and round trip time and compare and sort in ascending order. Afterwards the sensor nodes sends a join to the sink which has the highest rank of the mobile sink according to the order of the received radio signal strength and waits for an acknowledgment from the mobile sinks based on the distance calculating and round time trip (TORT). To calculate traveling of packets from source to the destination with round time using mathematical formula of:

$$T_{TOT} = \frac{T_{RTT} - T_{TPP}}{2} \qquad \text{(3)}$$

Where, T_{RTT}= total round trip time

T_{TPP} = Time to Process Packet

According to the time of trip there is also jitter (JT) of clock of transceiver and microcontroller in which the request sensor nodes and wait for acknowledgement of the mobile sink can be expressed with mathematical formula

$$T_{TOT} = \frac{T_{RTT} - T_{TPP} + JT_{tc}}{2}$$ -- (4)

$$T_{RTT} = T_{TOTR} + T_{TOTA} + JT_{tc}$$ -- (5)

Where, T_{TOTR}= Time of Trip (Journey) for Request

T_{TOTA} = Time of Trip for Acknowledgment

JT_{tc}= Jitter caused by clock of transceiver and microcontroller

Therefore, the mathematical expression of calculating the rank of each mobile sink with radio signal strength and round trip by the sensor nodes is indicates as shown below.

$$\mathrm{rank_i} = (\max(\mathrm{RSSI}_i, RSSI_{i+1}) + {}^{D_{RTi}}/_{\max_{i=1}(\mathrm{RSSI_i})}$$ --------------------------------- (6)

According to equation (4) of the sensor node join to the highest rank of $\mathrm{rank_i}$ having higher value of radio signal strength, this indicates that the distance between the sensor node and the mobile sink is shortest. D_{RTi} The duration of round trip of mobile sink with index of i. Therefore association of the mobile sink and sensor node is created and communication will be start after time synchronization is takes place.

3. Synchronization phase: in this phase we considered the time synchronization the mobile sinks broadcasting hello message which contains (current time, starting location, velocity, waiting time and parking points) of the sinks to sensor nodes. Then the sensor nodes modify their local time to the global time of mobile sinks in order to communicate easily and predicting the position of the sink. In addition to that there is also time synchronization triggered event sensing of the sensor nodes by periodically changed its state from active to sleep and sleep to active stats. If there is data to receive and transmit the sensor node becomes active otherwise sleep to save energy.

4. **Moving and wait phase** in this case the sinks are moving on the predefine trajectory to change from one position to another with parking position of P_S (P1, P2……..P_n), where n is the number of parking position of the sinks and waiting time ($T_{w)}$ of the sinks. We assume that the radio is turns off during the sinks are moving. The mobile sink can only accepted data when the sink is sojourn at the parking point until the waiting time is expired and moves with constant velocity (v).

5. Data gathering phase, the sinks collect the data from the nodes on the parking point until the waiting time expired and move to the next position. For more emphasize how mobile sinks and sensor nodes are communicating based on the logical clustering and routing of data from the sensor nodes to the mobile sink with synchronization time to predict the next position of the sink. We assume that the synchronization clock skew error has not significant effect on the result.

Algorithm 1: Pseudo Code Clustering Of Nodes and Sinks

Input sensor nodes(N),mobile sinks (S), beacon message

Output clustered nodes

1. ***sinks broadcast*** *beacon message* ***to sensor nodes by setting*** *RSSI* ***value***
2. ***all sensor nodes receive the*** *beacon message* ***of sinks***
3. ***calculate rank of sinks using the received RSSI of sinks***
4. ***for*** *(i=0;i<S; i++)*
5. ***If*** *(RSSIi> RSSIi+1)*
6. *Node send join message to sink with value of* ***RSSIi***
7. ***Else***
8. ***Node*** *send join message to* ***sink*** *with value of* ***RSSIi +1***
9. ***Node*** *wait to received membranes acknowledge from sink*
10. ***End if***
11. ***End For Loop***

As we stated in Figure 9 of the system model the mobile sinks are broadcast beacon message containing radio signal strength indicator on the first round to make the sensor nodes into groups. After the sensor nodes receive that message they store the radio signal strength indicator and arrange RSSI value in ascending order and send join message to the sink and wait to acknowledge be a member from the sink. A node joining to sink that has highest value of RSSI means, that sink is found in better communication range when compare with other sinks. Once all the sensor nodes are joined to the sink having better RSSI then clustering of nodes are finished and the nodes communicate with parent nodes which the mobile sink as illustrated in Algorithm 1 in step 1 to step 9.

Once the sensor nodes clustered and identifying to which cluster belongs to, the mobile sinks broadcast information’s which contains the starting point, current time, number of parking position, the waiting time of the sink at each parking point to collect data, velocity of the sinks , mobile sinkID the network. Then after the sensor nodes received all the information of the mobile sinks, sensor node modifies their local time to the time of the mobile sinks. The reason why the mobile sink broadcast message is to establish time synchronization to the nodes of the network with unique sinks id. After synchronization of the mobile sinks and sensor node has been made, communications of the sinks and sensor nodes is started. In this case we assumed that the sensor nodes are intelligent enough and the sinks are moving in counter clockwise direction.

3.2.2.1 Calculate future position of mobile sinks

In the proposed algorithm of the mobile sinks are regularly moves to update the location and parked on the specified points of the predefined trajectory to collect data from the network.

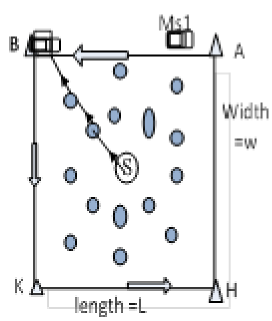

Figure 10: sample of mobile sink location update

To calculate the next position of the mobile sink which starts from point A (x, y) and ends at point B(x, y) can be mathematically expressed in terms of x-y coordinators as shown in Figure 10:

$Ms_{nxt}(x,y) = Ms_{cur}(x,y) + \overrightarrow{\Delta(x,y)}$ ………………… (7)

Where $Ms_{nxt}(x,y)$ = updated location of the mobile sink

$Ms_{cur}(x,y)$ = current position of the mobile sink before moving and

$\overrightarrow{\Delta(x,y)}$, is the difference value of x and y coordinators and the arrow in dictates moving and direction.

In this case time taken to move the sink from points A (x0, y0) to B(x1, y1) can be calculated with Euclidean distance between the points divided by constant velocity of the sink.

$T_{ms} = \frac{\sqrt{(x_0 - x_1)^2 + (y_0 - y_1)^2}}{V}$ ………… …………………………….......................... (8)

Where,T_{ms} is moving time of sink from point A to B with Euclidean distance of x and y coordinators, V is velocity of the sink.

By considering the moving time of the sink and the current time of the sink, the senor node can be predict the time when will be arrived at the next parking position using mathematical formulae:

$T_{pred} = T_{curr} + T_{ms} + \delta$ ……………………………………………………….. (9)

Where T_{pred} is the estimated time where the mobile sink arrive at the parking point

T_{curr} Current time of the mobile sink (the time at which the sink is start moving)

δ =is the drift time of packet to reach at each nodes

Tms is the moving time of the sink to reach at the parking point.

To route the data from the source to the destination the sensor nodes

When a node gets data from another node, then node compared the travelling time data to reach at destination with waiting time of mobile sink. If the travelling time is less than the waiting time the sensor nodes forward the data to the sink otherwise find another relay node and send to it. When the node received the data packet has the same sequence number is existing take the existed and discard the new one. If it is not available on the routing information store the data packet sequence number. if node A needs to send data to node B first check the distance and the residual energy of node B and compare with other node C, then if the distance and residual energy of node B is good send to B otherwise send to C. each data packet has a time which stay at each node. If that time is expired the data packet is discarded. For this case we adopt the Djikstra algorithm to find the shortest path from the source to the destination. The pseudo code for EESBPR Routing Algorithm is implemented of the sensor network is as follows.

In **Algorithm 2**, the mobile sinks send the synchronization message contains velocity, waiting time, number of parking point, initial position of the mobile sinks to the sensor nodes. After the nodes receive this message and modifies their local time to the time of sinks and send an acknowledgement to the sinks. Since the sinks are mobile the sensor nodes take the responsibility to check and calculate the position of the sink to forward packets. If the sink is parking with in the communication range of the source node then source node send packet otherwise calculate the next parking position as illustrated in the algorithm 2 in steps 1to step 21.

Algorithm 2: Pseudo Code for EESBPR Routing Algorithm

Input set parking =false;

Output received data

1. *Mobile sink* ***broadcast message****(current Time, initial position, waiting time, number parking point, velocity)*
2. *Sensor* ***nodes*** *receive (current Time, initial position, waiting time, number parking point, velocity))from sink*
3. ***If****(received information)*
4. *Sensors local time = sink's current time Then*
5. *The sensor nodes send acknowledge to the sink after modified their local time*
6. ***End If***
7. *SinkWait_time =* ***initValu***
8. ***If*** *(distance(****s,j****)< distance(****s,k****)) then*
9. *Node* ***j*** *is in short distance*
10. ***If****(* ***j*** *is sink node && Parking==****true****) then*
11. *While(initpacketTrTime<=****initValu****)*
12. *Send data to sink*
13. *i****nitValu****=* ***initValu – 1***
14. *initpacketTrTime = initpacketTrTime-1*
15. ***End Wile Loop***
16. ***Else if (j*** *is* ***sink*** *node && Parking =false)*
17. *Sensor* ***node*** *send data to neighbors*
18. ***Else*** *data send to* ***j***
19. ***End if***
20. ***End if***
21. ***End if***

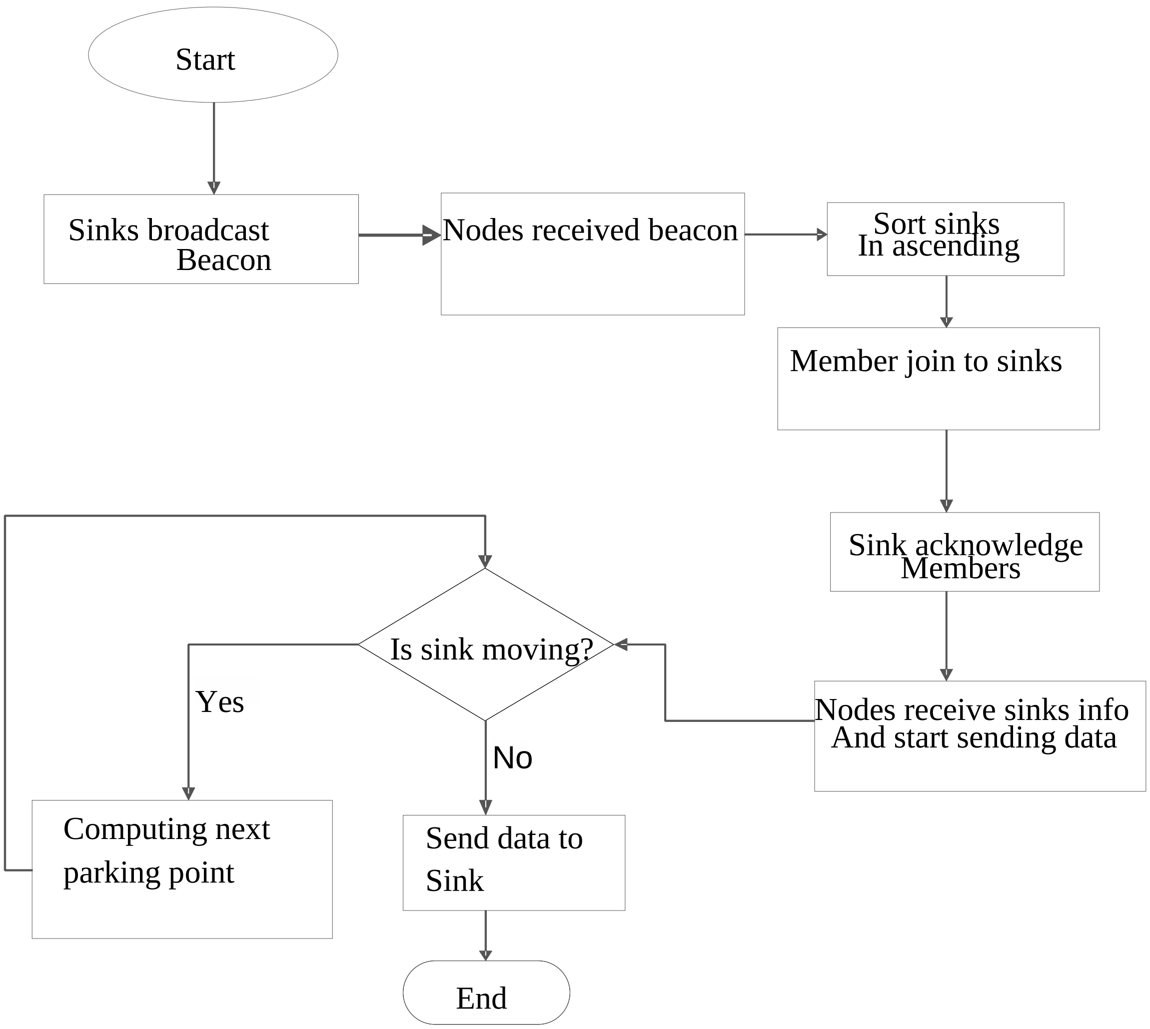

Figure 10: Flow Chart of Overall Routing Algorithm

We use this flow chart to emphasize the algorithm's 1, 2 and contains the summarization of those algorithm and how our system and network model works. This flow chart shows how the mobile sinks are moving and collecting data from the sensor nodes and the data is route from the sensor nodes to the destination. According to [68] synchronization is critical for many applications of wireless sensor network such as node localization, detecting events, medium access control, data aggregation and target tracking of monitoring environment. On the other hand time synchronization is an important for energy saving by alternating the mode of the sensor nodes to sleep, idle and active mode.

In our study synchronization is used for communication of between the sensor nodes and the mobile sinks.

According to [15] in multihop communication mode the energy consumption of sensor from source node to the relay node and from the relay node to destination should be minimized. The communication between the sensor nodes and the mobile sinks follow minimum distance with minimum energy consumption. Since wireless sensor nodes is battery operated device, energy is the important thing. In addition to checking the distance between nodes and checking the energy of the sensor node also needed to forward the data to the neighbor and destination. In order to check the energy of each node to send message calculating residual energy of the sensor nodes should be needed. If the residual energy of the sensor nodes is less than the threshold energy the node cannot exchange information. This can be calculated with the formula of:

$$E_{res} = IE - E_{TRx} \quad \text{---} \quad (10)$$

WhereE_{res} the residual energy of the sensor nodes i.e. the energy left after some operations are performed.

IE = the initial energy of the sensor node

E_{TRx}= Consumed energy by the sensor node during transferring and receiving of data. The source node sends the collected data to the mobile sink when reached at point B after p time. The mobile sinks are moving horizontally the value of x-value is constant and the value of y- is variable change and in vertical movement the value y- is constant and value x is variable change.

CHAPTER 4
IMPLEMENTATION

3.2 Simulations Setup

Wireless sensor network is one on of the most widely and recently used hot research area in network paradigm. Therefore simulation is used to test and evaluate the effectiveness and efficient of the proposed solution. Thus, in order test our proposed solution of this work simulation tool is used to check the effectiveness of the solution. Since simulation tool is the most important and most widely useful method to test and evaluate the network topology on the behalf of the real world test beds. Running wireless sensor network with real world test bed is most difficult, costly and time consuming when compared with the simulation. Because implementing and testing using simulation before applied on real environment is more effective and advantageous. Therefore, according to [24] surveyed paper there are different wireless sensor network simulation tools depending on the different applications environment of the WSN. Some of the simulators of WSN are NS-2, NS-3, QualNet, MiXiM, OPNET, OMNET++, Castalia, SensorSim, and Matlab etc.

According to the context of this thesis, the simulation framework is selected based on the modularity support, realistic wireless channels and radio support features. In addition to that the simulation to could also be user friendly interfaces and open source. therefore according to [69][70] oment++, castalia framework is used to simulate this work integrated them on ubuntu 14.04LTS operating system on toshiba core I3 laptop computer.

3.2.1 Omnet++

Omnet++ is one of the discret event environmnet seup and which has an execellent modularity supports to with generic and flexible architecture. the modularity of the omnet++ is suitable for research area with public c++ source test bed.

Omnet++ contains the nested hierarchical componentes with compund modules having simple models which describes the behavior of the each and every components.

Omnet++ is written and has well documented with both graphical environment and comand line degbugging and the community provider of the omnet++ is provided continously updated and new framework. This model contains **.ned**, h,.cc and .ini programming languages.

- **.ned Langauge :**

NED stands for network description language which contains the structre of the model which defined and is going to be simulated. The NED is used to defined the structure of simple modules and assembled them in to compound modules. In addtiton to that it also used to defined the gates and channels for simple modules through the compund models. Simple modules contains algorithms and the lowest level of hiearchy frame work of the modules. The simple models is implemeted using c++ of omnet++ class simulation library[70]. The modules can exchange message with the destination modules or may follow a series of gates and connection to the other module. Each module has an input and output gates intefaces which used to send out and receive messages by createing connection of the submodules and modules of the network topology. The simulation time increase as the module send and received message form other modules and the same modules as self message to be executed later time. Such selfmesseages are scheduled the events that execute later time by the module itself. Therefore version 4.4.1 is used for implementing and development of the models of sensor network submodules and module of the system structure.

- **.h and .cc language**

Defined the behavior of each submodules and modules of the toplogy which is writeen in c++ programmiing.

- **.ini file :** is configuration file which is setsup the simulation scenarios.

3.2.2 Castalia

Castalia is simulator of WSN and body area network which developed by NICTA and generally used for low power embedded device of the networks. In this thesis work, Castalia simulation tool is used for simulating, testing and evaluate the proposed solution. The reason why choosing Castalia is that it is the most widely used open source simulation tool which is specifically designed for wireless sensor network and body area network and has the ability to evaluate and test their own distributed algorithm and protocols with realistic wireless channel, radio and specific behavior of sensor nodes. It is used on top of OMNeT++ framework. It has also highly parametric for simulating wide range platforms and characteristics of specific applications[69]. In Castalia, the sensor nodes are implemented as compound modules with sub-modules of communication modules, application, physical and sensor with low power embedded devices. Castalia is programmed with C++ programming language. The key features this simulator includes: physical process modeling, sensing devices with bias and noise, node clock drift, wireless channels, radio models, MAC and routing protocols. Castalia has a flexible physical process with different sensing devices, like temperature, vibration, and pressure with consideration of noise, bias and node clock drift [69]. The communication of nodes in Castalia is not directly unlike of OMNeT++. To communicate sensor nodes with each other the node connects to the wireless channel rather connecting with one another. This means that direct communication of nodes is impossible as illustrated in Figure 11. In Castalia simulator the node is used as composite module having different structure of sub modules as illustrated in Figure 12.

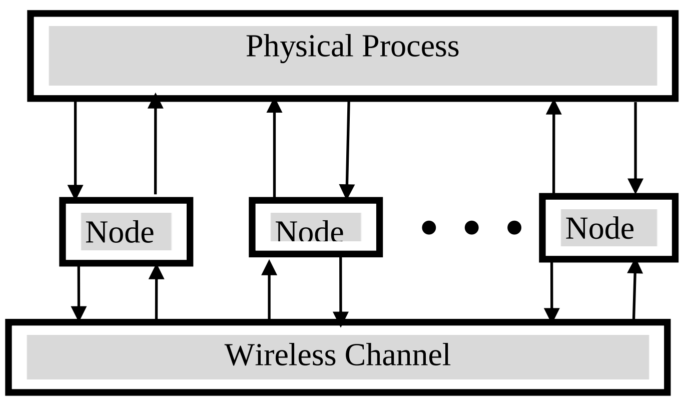

Figure 11: Communication of Nodes [69]

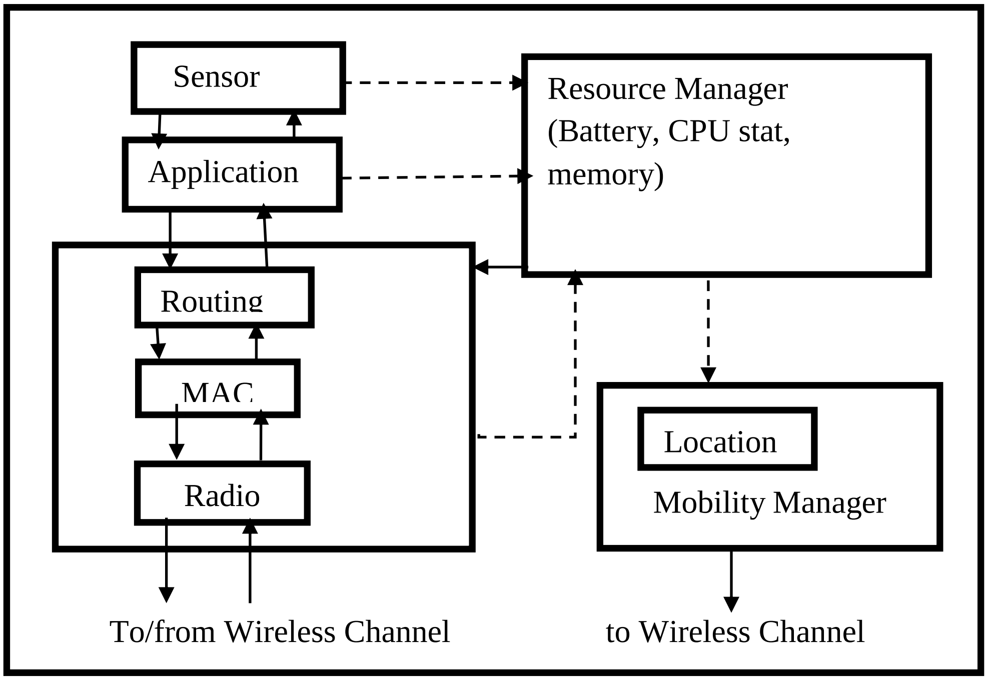

Figure 12: Structure of Composite Node [69]

From Figure 12, the sensor nodes directly contact to the physical environment and to the wireless channel. To communicate the sensor nodes with its neighbor first communicate with the channel and send to the other node. In the Figure12 above the solid arrow indicates that the flow of information the sensor nodes from one module to the other and the dash arrow indicates flow of control. The sensor nodes sense the activities from the physical environment send the message to the application manger and application manger also sends sampling data of requested message. To send requested sampling data the sensor node gets energy from the resource manager. The application manager sends the sampled data to the communication module. The communication module contains the routing sub module which routes the sampled data from the source the destination. In the MAC sub module of the communication module contains the MAC address of the data packet to be routed the application layer of the sensors nodes and Radio sub module contains TX, RX, modulation type, the RSSI and so on. Resource manager module contains the resource of sensor nodes such as CPU, memory and battery etc. Mobility manager module of the sensor nodes is used only to define the location of the sensors nodes during mobility of the nodes.

In this thesis work the simulation of wireless sensor nodes is clustered and grouped according to the number of mobile sinks. This leads to reduce the energy consumption, better network communication, efficient topology management, reduce delay and extends lifetime of the network. According to Figure 9, the sensor nodes are statically deployed on the environment but only sinks are mobile to gather data and balanced energy among the sensor nodes of the network with different parameters.

The parameters that are used for simulating the thesis work is sensors nodes, mobile sinks, velocity, parking position, path Loss, average path loss, communication range ,simulation area and simulation time are listed below in the table.

Table 2**:** Simulation Parameters

	Parameters	Value
1	Simulation area	800X800m^2
2	Sensor nodes	200-1200
3	Constant payload	250 kbps
4	Number of mobile sinks	3
5	Sinks Velocity	10m/s
6	Parking position	9
6	Path loss	2.4
7	Average path loss	55
8	Communication range	60m
9	Simulation time	5000second
10	Waiting Time	10-20 MS

1. **Simulation area** is a rectangular field in which the sensor nodes are deployed for controlling the events that occurred on the environment.
2. **Sensor nodes**: the number of sensor nodes which are deployed on the simulation area, to control the activities of the environments.
3. **Mobile sinks:** are kinds of nodes where the sensor nodes are routed the collected to the sink. The sinks are moving on the rectangular area to collect data from the sensor nodes.

4. **Velocity: the** speed of the mobile sinks which are moving on the predefined trajectory to collect data on given direction.

5. **Parking position –** the place where the mobile sinks are dwelling to collect data on the specified parking point.

6. **Path loss Exponent** – is reduction in power relative to some interference of signals during communication we set 2.4 according to the path loss of the wireless sensor network as an optimal for our simulation.

7. **Communication range** – is the maximum distance to transmit the data, it depends on the power of the radio frequency. Therefore we set the value of communication range which optimal for our

8. **Simulation time**: determines how long time is taken to end simulation for 5000 seconds with 500 second interval of 10 rounds.

9. **Average path loss (PLd0):** determines the maximum distance to receive and transmit data of the wireless channel.

10. **Waiting time:** in our study we have waiting time for the sink to collect the data on given parking point. So we used (10 – 20) second as an optimal waiting time to our study.

11. Constant payload : determines the default packet size of the with 10 packet rates

4.2 Graphical interface of simulation setup

This section briefly explains the experimental result of simulation running with visualized graphical user interface of the network setup generated images of the design model of the network. As described in Figure 13 of this experimental window contains the sensor nodes, sinks, physical environment, wireless channel and the flow of information. The flow of information shows the communication path of the sensor nodes with each other and with the physical environment. The simulation result stored in the simulation radio test folder which displayed in two mechanisms with two formats. The first one is in .txt format which is save on CastaliaTrace and **YYMMDD-HHMMSS.txt** file format the stands for(Y-year, M-month, D-day, H-hour, M-minute and S-second) respectively at which the simulation was generated. The second one is directly displays the output immediately on the console after the simulation time is finished.

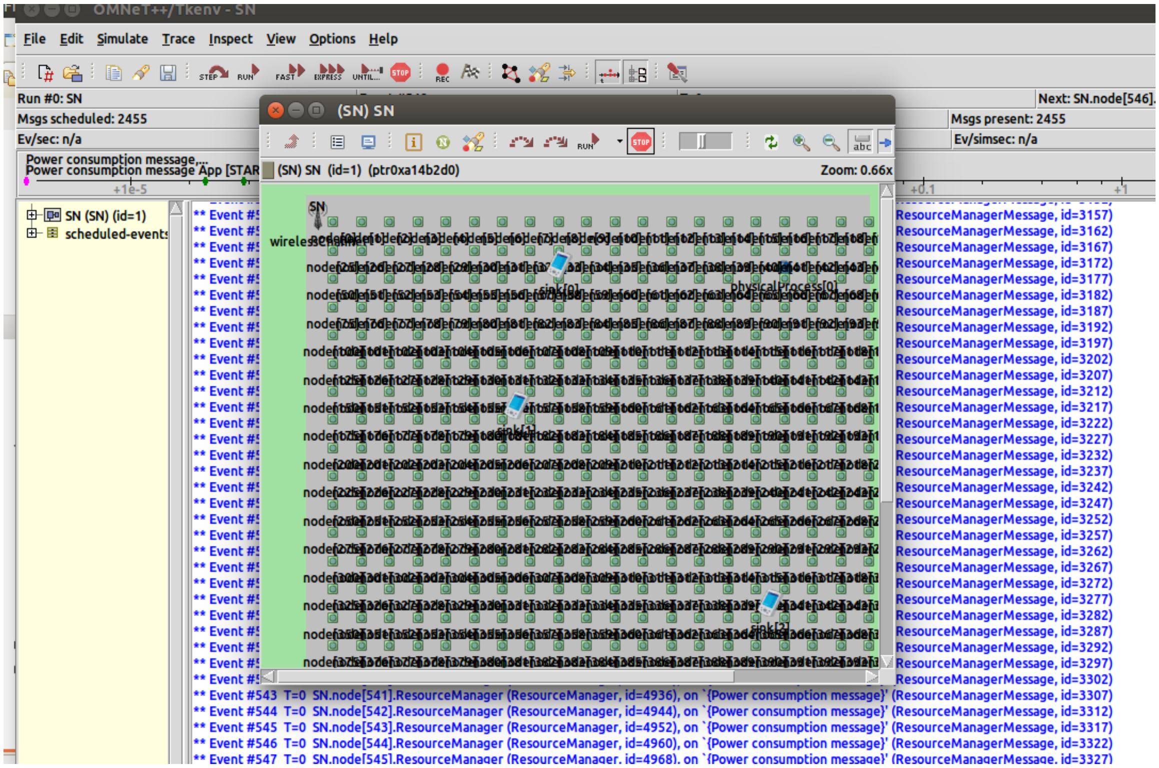

Figure 13: Screenshot Simulation Area

In Figure 13: of the simulation result of the graphical user interface the message is create on the .msg extension file and the compiler convert the message extension file in to c++ compiler understanding format. Most of the result used for analysis was collected through the YYMMDD-HHMMSS.txt that generated by simulation result on the simulation module after the simulate run finished.

In order to collect the simulated result of all the modules during the simulation, the collect trace file must set to be true on the configuration file. During the simulation run the generated message statistics of the models of the sink mobility is displayed on the trace file and the sending and received packets of the application and communication modules respectively. The results is collected from the Castalia Results of the on the console and plot the graph of the result using gnu plot of the Castalia Result of the simulation.

Accordingly, the report data from the simulation modules and display on the console output was used to plot the graph of the various statistics report generate by Castalia simulator as clearly illustrated and discussed in chapter 5.

CHAPTER 5

RESULT AND DISCUSSION

This chapter explains the results analysis and discussion scenarios of the targeted based simulation result. The performance metrics for the designed simulation scenarios were described and stated briefly on the run simulations according to the various configuration files based on the predefined parameters which were used on discussion and analyzing of the simulation results.

5.1 Performance Evaluation

This section of this chapter we describe the performance metrics which were considered for evaluating the performance routing algorithms. Therefore, in wireless sensor network routing algorithm performance mechanism depends on the defined routing metrics. In wireless sensor network needs energy efficient routing protocols in order to effectively deliver the data to the destination with considerable energy consumption. There are different performance metrics which used to evaluate performance of the protocols in wireless sensor networks. These metrics are average throughput, end-to-end delay, packet delivery delay, energy, life time, hop count, reliability and so on. From the different metrics of wireless sensor network we used average energy consumption, end to end delay and life time of the network are be considered as significant metrics of this thesis and compared with the existing (LEACH, LPTA) routing algorithms.

Thus, in wireless sensor network energy is the critical issues since sensor nodes are battery operated devices. In this thesis work we focused on energy consumption of sensor nodes during transmission and reception data, delay of data to deliver at the destination and lifetime of the network. Based on these metrics we evaluate the performance of the proposed routing algorithm and compared with the existing routing algorithms which are LEACH and LPTA.

5.2 Result Analysis and Discussion

This section presents the details analysis of the simulation results using graphically representations which generated from the experiment.

1. **Average Energy consumption:** energy is the main and critical asset in wireless sensor network. Therefore, in wireless sensor network more energy is consumed when transmitting and receiving of data than sensing and processing of the data.

   To determine the average energy consumption of the sensor nodes within given operational time can be mathematically calculated as follows.

$$AvgEconsum = \frac{\sum basepowerNode * simTime}{1000}$$

AvgEconsum = the average energy consumption, basepowerNode = the energy assigned each sensor node for receiving and transmitting, simTime = the simulation time of the network.

Table 3: Average Energy Consumption at each operation time

Simulation Time In Second	Average Energy Consumption(j) After Corresponding Simulation time			
	LEACH Routing	LPTA Routing	EESBPRouting with 2 sinks	EESBPRouting with 3 sinks
500	14.665	5.221	5.15	5.132
1000	28.754	10.29	10.49	10.542
1500	43.69	16.296	15.808	14.888
2000	58.894	22.584	20.956	22.065
2500	72.93	28.264	26.213	26.723
3000	86.891	33.42	32.163	31.588
3500	101.264	37.476	35.502	37.645
4000	117.063	48.43	44.474	42.766
4500	131.256	51.909	49.067	47.351
5000	146.303	60.136	52.103	52.502

As shown in Table 3, above, the simulation result which was collected from the simulation experiment examined the average energy consumption sensor nodes stays on operation. The simulation result shows that the average energy consumption sensor nodes of among three routing algorithms (LEACH Routing, LPTA Routing, and EESBPR routing with 2 and 3 sinks) are examined for 10 rounds with about 500 second time interval of each runs. The general summarization average energy consumption of simulation result can be graphically represented as follows.

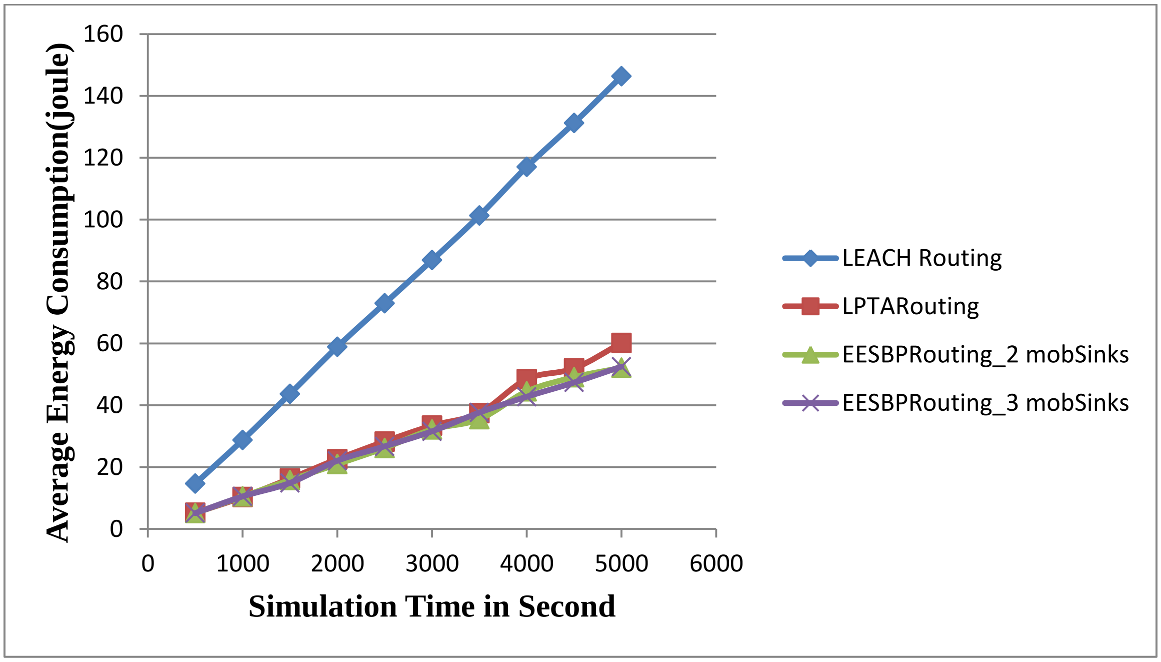

Figure 14: Average Energy Consumption in Simulation Time

As a principle the lesser energy consumption of the sensor nodes, the more life span of WSN due to the energy constraint of the sensor nodes. In Figure 14, of graphically representation of the simulation result shows the EESBPR routing algorithm has less energy consumption than LEACH and LPTA. LEACH routing protocol consumes energy than LPTA and EESBPRouting since in LEACH routing protocol the data is routed to the static sink. Therefore, the sensor node nearest the static is suffered with traffic overhead since it forward the data come from far apart. As it is noticed from the graph Figure 14 simulation result of average energy consumption LEACH protocol, LPTA and EESBPR routing algorithm with 2 and 3 mobile sink to route data is 80.171, 31.4026, 29.1926, 29.1202 joule respectively. Thus our EESBPR routing algorithm outperformed 7.03% with 2 mobile sinks, 7.268% with 3 mobile sinks than LPTA with a mobile sink and 60%

of LEACH protocol implemented on static sink. This means that the remaining energy of EESBPRouting is higher which results increase the lifespan of the network.

In Figure 15 we compute the average energy consumption as the number of sensor nodes and the communication range of the sensor node and mobile sinks. As the number of sensor node increases, the data travel number of intermediate nodes to arrive at the destination. When compared our proposed or EESBPRouting algorithm with LTPA, algorithm averagely consumed energy with value of 31.51583 joule whereas LPTA consumed 36.00283333 joule. Because our proposed algorithm reduce broadcasting location update of the mobile sink and reduce the communication range of the sensor nodes by clustering nodes in to groups. Hence, LEACH routing protocol consumed 51.50733333 joule in average. Therefore, as the energy consumption of sensor nodes reduced the life time of the network is increased. Thus we can conclude that the energy consumption our proposed algorithm outperforms better than the exiting routing protocol to route 2005 KB of data to the sinks.

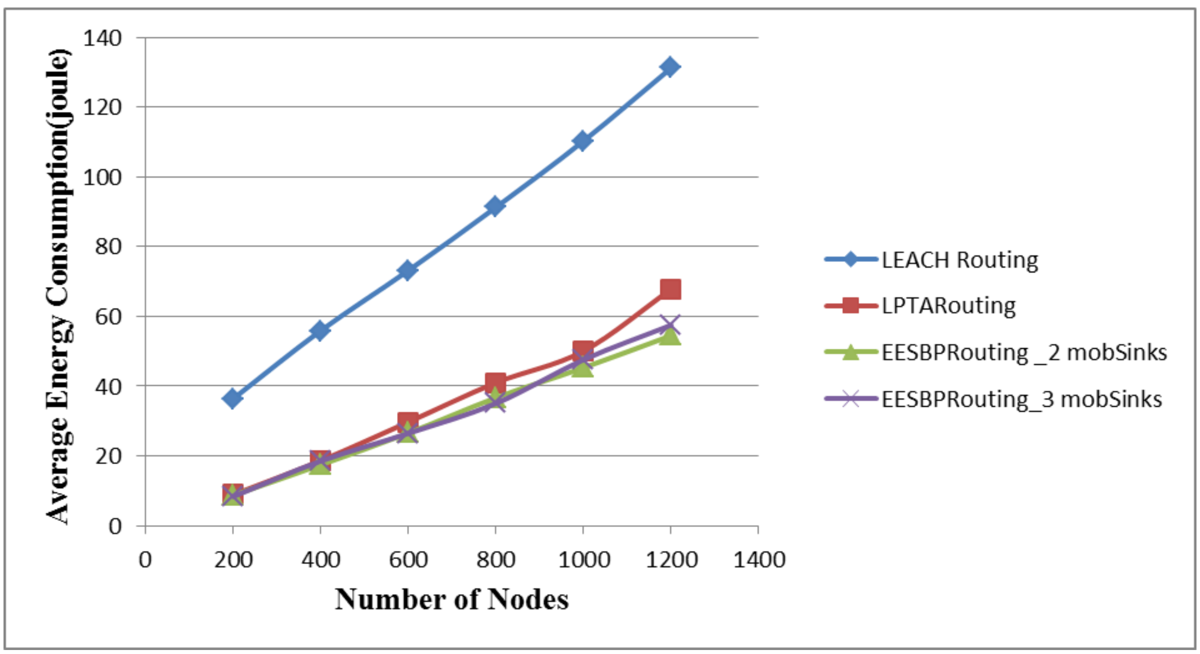

Figure 15: Average Energy Consumption in Number of Nodes Varies

2. **End to End delay**: it defines that the average time taken to transmit messages from source nodes to the destination or mobile sinks. It is measured in average time taken of the generated message at the source node and received generated message at mobile sinks.

$$\text{EEdelay} = \sum \text{time packet teken arrive at des} - \text{time packet generate at source}$$

Where EEdelay =the End to end delay of the packet.

Figure 16 the simulation result shows the performance of EESBPR with LEACH and LPTA routing algorithms in terms of packet delivery delay. As in chart the end to end delay of delivery delay of LEACH is small at 200,400 numbers of nodes. At the beginning the number of cluster head was 5%. Since the packets move number of intermediate nodes to reach at the destination. And after 400 nodes the delivery delay of LEACH routing algorithm decrease because the number of cluster becomes increased to 15% of the nodes. On the other hand when comparing EESBPR and LPTA with mobile sink at velocity of 5m/s with 200 nodes LPTA has better end to end delay. This means that the packet is delivered fast. As the numbers of sensor node increase the end to end packet delivery also increase since the data moves number of intermediate nodes to arrive at the destination. Therefore, the number of mobile sink increased the delivery delay decreased, because the communication range of sensor nodes decreased with 2 sink and 3 sink than 1 sink. Thus LPTA routing algorithm is implemented on single sink whereas EESBPR routing algorithm is implemented on 2 and 3 sinks having the velocity. At the 1000 sensor nodes LEACH algorithm has better performance delay than EESBPR with 2 sinks because the mobile sinks stays more time at one parking time. Generally as the number mobile sink the probability of packet delivery delay decrease. This mean the packet is delivered on the sink quickly.

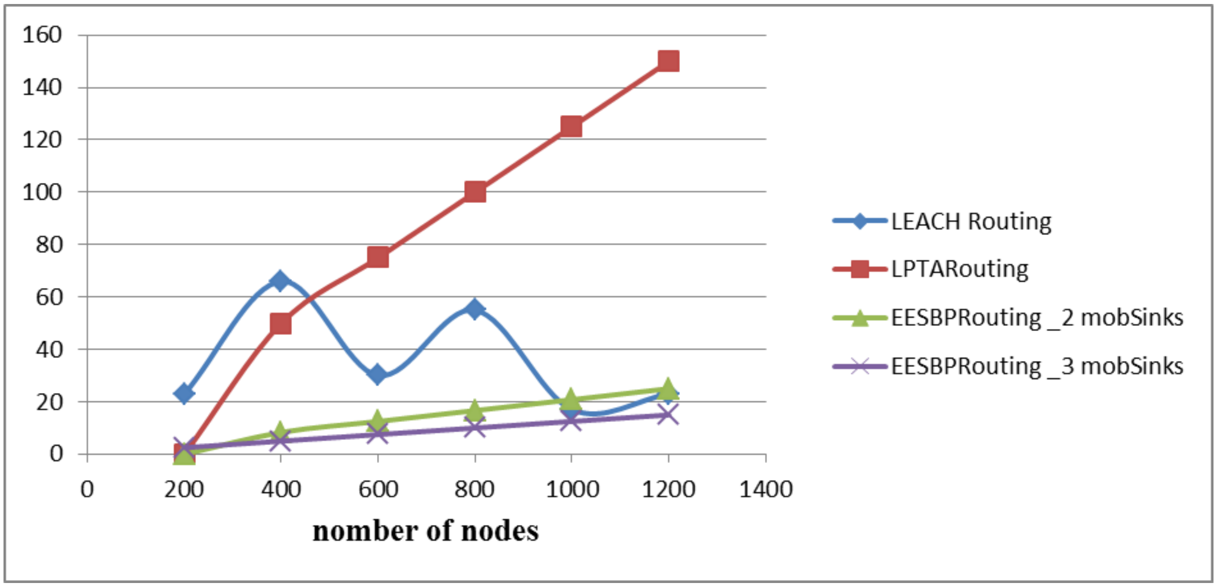

Figure 16: End To End Delay as Number Node Varies

3. **Life time:** the life time of the network depends on the specific application in which until the first node will die or some of the sensor nodes are dying. The life time is expressed in in minute, hours, day and years depending on the application of the sensor nodes used. Here we considered the minimum life time of the network relative to the initial energy of the node and simulation time is expressed in terms of days with the mathematical formula

$$\text{Lifetime} = \frac{\text{initial Energy} * \text{simTime}}{((\text{initial Energy} - \text{remainEnergy}) * 86400)}$$

Where Lifetime = the minimum estimated life time of the network

Initial Energy = the initial energy of the sensor nodes

Remain energy = the energy left after receiving and sensing of data

As Figure 17 illustrated the life time of the network from 500-2000 second LPTA routing algorithm has better life time since some the sensor nodes are at sleep mode. As stated in the chart the life time of the network depends on the energy of the sensor nodes. if the energy consumption of the sensor node increase the life time of the network decrease. When we look at the life time at each simulation time LPTA has better life time than our proposed for example in 500-2000 second. But when we look the overall lifetime of network EESBPR routing algorithm has better than LEACH and LPTA routing algorithms with values 3.86 days, 13.4 days and 16.451 days respectively based on number node varies as shown in Figure 18. When comparing the life time values of the network for LEACH, LPTA and EESBPR routing algorithms with simulation time are 3.87days, 15.934 and 17.134 respectively as shown in Figure 17. This shows that the proposed algorithm has better life time than the existing routing algorithms. But there is one fact as the simulation time increases, the more energy is used to receive and transmit message, results decrease lifetime of the network since it is battery operation devices. .

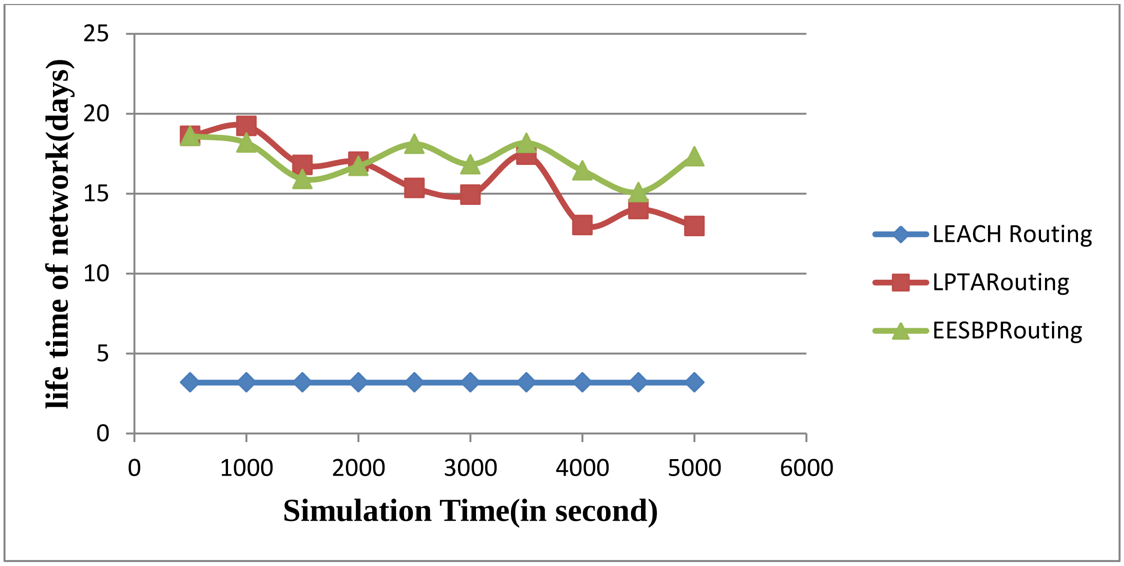

Figure 17: Life Time of Network in Simulation Time

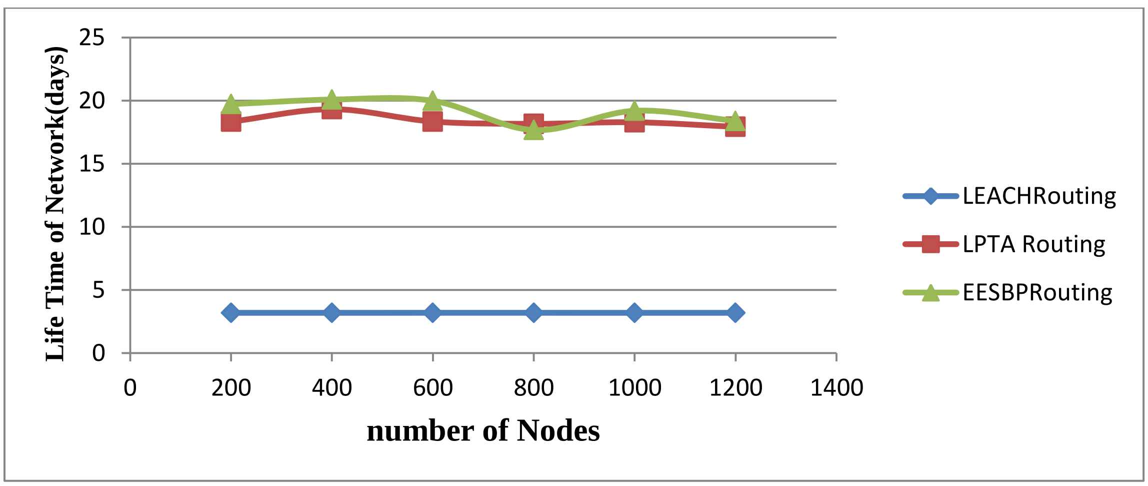

Figure 18: Life Time As Sensor Node Varies

CHAPTER 6

CONCLUSION AND FUTURE WORK

6.1 Conclusion

In this thesis we explored the background, architecture, component and factors of WSN was discussed in which WSN is defined as a composed of small sensor nodes which are deployed on the area to collect information from the environment and communicate the sensed information with each other and mobile sink wirelessly through single or multihop routing mechanisms. Thus WSN has wide application area and has been conducted various researches on both industrial and environmental areas.

The main challenging issue of WSN is reducing energy consumption of sensor nodes and results to prolong the life span of the network. Therefore to increase the life time of the sensor nodes of the network designing an energy efficient routing algorithm is necessary. There are many conducted and ongoing researches that concentrated on the energy efficient routing algorithms of mobile sink. In mobile sink, the sink frequently flooding locations update information to the entire network to have the sensor nodes latest information. This result consumes more energy. Therefore, this thesis proposed an energy efficient routing algorithm based on clustering and time synchronization and prediction of the mobile sinks to decrease data delivery delay and reduce energy consumption of sensor nodes to improve the performance of the network and simulated the proposed algorithm using c++ programming language of Castalia platform on top OMNeT++. The mercies namely average energy consumption, end to end delay and life time were used to evaluate the performance of the proposed algorithm with existing ones.

In general, in wireless sensor network it is possible to reduce the energy consumption and improve overall performance while designing energy efficient routing algorithms

6.2 Recommendations

In this section, the future research directions are discussed to be further improved the proposed algorithm for efficient data gathering in wireless sensor network with multiple mobile sinks. As shown in the discussion it is considered only average energy consumption, average latency, end to end delay and life time of the network, in the future it is better to use more evaluation metrics such as buffer management, bandwidth, and reliability of packets to have better and improved the performance of the proposed work.

In addition to that the researcher may add data aggregation on each sensor nodes and mobile sink to be more improved the overall performance of the network. In this simulation experiment it is assumed that the sensor nodes are location aware with helps of GPS or other localization mechanisms but in real world environment sensor nodes do not know their exact locations. It is also assumed that the energy consumption of GPS is negligible when compare with energy consumption of sensor nodes during transmission and reception time, but in reality it may not be.

It is also recommended apply the end to end security of data gathering from the source to the destination with mobile sinks.

It is also better if this experiment is tested in real environment and it is also better to considered the mobile sink management means when a sink leave and join to the network.

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Appendix

The appendices of this thesis consisting of the simulation result and the .Ned source code of the topology.

Sample Source code of Ned

```
Package Castalia;
import wirelessChannel.*;
import physicalProcess.*;
import node.mobilityManager.*;
import sink.Sink;
network SN
{
   parameters:
      int field_x;
      int field_y;
      int field_z = default(0);
      int numofSinks;
      int numNodes;
      string deployment = default("");
      int numPhysicalProcesses = default(1);
      string physicalProcessName = default("CustomizablePhysicalProcess");
      string debugInfoFileName = default("Castalia-Trace.txt");
      int trRange = default(60);
      double sRange = default(11111);


     @display("bgb=800,800,grey75,#008000,0;bgs=,m;i=maps/africa,#11FF00,100;is=n
     ;i2=status/green,blue,15");
      submodules:
      wirelessChannel: wirelessChannel.WirelessChannel {
         parameters:
            @display("i=device/antennatower;p=17,30");
         gates:
```

```
        toNode[numNodes];
        fromNode[numNodes];
  }



  physicalProcess[numPhysicalProcesses]:<physicalProcessName>like
hysicalProcess.iPhysicalProcess             {
     parameters:
        @display("i=misc/globe_s,black;p=677,103");
     gates:
        toNode[numNodes];
        fromNode[numNodes];
  }
  node[numNodes]: node.Node {
     parameters:
      @display("i=block/circle_vs,green;p=,,m,25,40,40");
     gates:
        toPhysicalProcess[numPhysicalProcesses];
        fromPhysicalProcess[numPhysicalProcesses];
 }
 sink[numofSinks]: sink.Sink{
 energy = intuniform(499900,500000); //0.5joules
        id = index+2;
        xpos = intuniform(0, field_x);
        ypos = intuniform(0, field_y);
  }
connections:
  for i=0..numNodes - 1 {
 node[i].toWirelessChannel-->{@display("ls=,0");}--> wirelessChannel.fromNode[i];
 node[i].fromWirelessChannel<--{@display("ls=,0");}<-- wirelessChannel.toNode[i];
  }
```

```
  for i=0..numNodes - 1, for j=0..numPhysicalProcesses - 1 {
 node[i].toPhysicalProcess[j]-->{@display("ls=,0");}-->physicalProcess[j].fromNode[i];
node[i].fromPhysicalProcess[j]<--{@display("ls=,0");}<--physicalProcess[j].toNode[i];
      }

}
```

Trace file of the simulation result of the first 200 nodes with 500 second simulation time.

```
Castalia| what:General (1)
Castalia| when:2018-04-13 22:54
Castalia| label:txPower="-5dBm",velo=5,nodes=200,sink=2
Castalia| module:SN.node[0].ResourceManager
Castalia|        simple output name:Consumed Energy
Castalia|                64.7025
Castalia|        simple output name:Estimated network lifetime (days)
Castalia|                16.6959
Castalia|        simple output name:Remaining Energy
Castalia|                18655.3
Castalia| module:SN.node[0].Communication.Radio
Castalia|        simple output name:RX pkt breakdown
Castalia|                1414 Failed with NO interference
Castalia|                718 Failed with interference
Castalia|                10998 Failed, below sensitivity
Castalia|                2127 Failed, non RX state
Castalia|                400 Received despite interference
Castalia|                5238 Received with NO interference
Castalia|        simple output name:TXed pkts
Castalia|                415 TX pkts
Castalia| module:SN.node[0].Communication.MAC
Castalia|        simple output name:Sent packets breakdown
Castalia|                415 SYNC
Castalia| module:SN.node[0].Application
Castalia|        simple output name:Global packets sent
Castalia|                995
Castalia|        simple output name:Received Packets
Castalia|                0
Castalia| module:SN.node[1].ResourceManager
Castalia|        simple output name:Consumed Energy
```

```
Castalia|                 54.2921
Castalia|         simple output name:Remaining Energy
Castalia|                 18665.7
Castalia| module:SN.node[1].Communication.Radio
Castalia|         simple output name:RX pkt breakdown
Castalia|                 1102 Failed with NO interference
Castalia|                 642 Failed with interference
Castalia|                 9670 Failed, below sensitivity
Castalia|                 439 Failed, non RX state
Castalia|                 241 Received despite interference
Castalia|                 6717 Received with NO interference
Castalia|         simple output name:TXed pkts
Castalia|                 832 TX pkts
Castalia| module:SN.node[1].Communication.MAC
Castalia|         simple output name:Sent packets breakdown
Castalia|                 832 SYNC
Castalia| module:SN.node[1].Application
Castalia|         simple output name:Global packets sent
Castalia|                 995
Castalia|         simple output name:Received Packets
Castalia|                 5
Castalia| module:SN.node[2].ResourceManager
Castalia|         simple output name:Consumed Energy
Castalia|                 47.4854
Castalia|         simple output name:Remaining Energy
Castalia|                 18672.5
Castalia| module:SN.node[2].Communication.Radio
Castalia|         simple output name:RX pkt breakdown
Castalia|                 1115 Failed with NO interference
Castalia|                 203 Failed with interference
Castalia|                 5628 Failed, below sensitivity
Castalia|                 334 Failed, non RX state
Castalia|                 282 Received despite interference
Castalia|                 4906 Received with NO interference
Castalia|         simple output name:TXed pkts
Castalia|                 832 TX pkts
Castalia| module:SN.node[2].Communication.MAC
```

Castalia| simple output name:Sent packets breakdown

Castalia| 832 SYNC

Castalia| module:SN.node[2].Application

Castalia| simple output name:Delivery Ratio

Castalia| simple output name:Global packets sent

Castalia| 995

Castalia| simple output name:Received Packets

Castalia| 5

Castalia| module:SN.node[3].ResourceManager

Castalia| simple output name:Consumed Energy

Castalia| 59.5192

Castalia| simple output name:Remaining Energy

Castalia| 18660.5

Castalia| module:SN.node[3].Communication.Radio

Castalia| simple output name:RX pkt breakdown

Castalia| 1356 Failed with NO interference

Castalia| 766 Failed with interference

Castalia| 14392 Failed, below sensitivity

Castalia| 1510 Failed, non RX state

Castalia| 404 Received despite interference

Castalia| 4848 Received with NO interference

Castalia| simple output name:TXed pkts

Castalia| 833 TX pkts

Castalia| module:SN.node[3].Communication.MAC

Castalia| simple output name:Sent packets breakdown

Castalia| 833 SYNC

Castalia| module:SN.node[3].Application

Castalia| simple output name:Global packets sent

Castalia| 995

Castalia| simple output name:Received Packets

Castalia| 5

Castalia| module:SN.node[4].ResourceManager

Castalia| simple output name:Consumed Energy

Castalia| 54.2486

Castalia| simple output name:Remaining Energy

Castalia| 18665.8

Castalia| module:SN.node[4].Communication.Radio

```
Castalia|        simple output name:RX pkt breakdown
Castalia|                1999 Failed with NO interference
Castalia|                1668 Failed with interference
Castalia|                10758 Failed, below sensitivity
Castalia|                4690 Failed, non RX state
Castalia|                362 Received despite interference
Castalia|                5079 Received with NO interference
Castalia|        simple output name:TXed pkts
Castalia|                833 TX pkts
Castalia| module:SN.node[4].Communication.MAC
Castalia|        simple output name:Sent packets breakdown
Castalia|                833 SYNC
Castalia| module:SN.node[4].Application
Castalia|        simple output name:Global packets sent
Castalia|                995
Castalia|        simple output name:Received Packets
Castalia|                5
Castalia| module:SN.node[5].ResourceManager
Castalia|        simple output name:Consumed Energy
Castalia|                53.4603
Castalia|        simple output name:Remaining Energy
Castalia|                18666.5
Castalia| module:SN.node[5].Communication.Radio
Castalia|        simple output name:RX pkt breakdown
Castalia|                523 Failed with NO interference
Castalia|                387 Failed with interference
Castalia|                8420 Failed, below sensitivity
Castalia|                1294 Failed, non RX state
Castalia|                227 Received despite interference
Castalia|                6282 Received with NO interference
Castalia|        simple output name:TXed pkts
Castalia|                832 TX pkts
Castalia| module:SN.node[5].Communication.MAC
Castalia|        simple output name:Sent packets breakdown
Castalia|                832 SYNC
```