AN IMPROVED LINK-QUALITY BASED ENERGY-EFFICIENT ROUTING FOR WIRELESS SENSOR NETWORK-BASED INTERNET OF THINGS

By

MISBAH SHAHID

NATIONAL UNIVERSITY OF MODERN LANGUAGES

ISLAMABAD

June, 2023

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MISBAH SHAHID

BSCS, University of the Punjab, Jhelum, 2019

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

In **Computer Science**

To

FACULTY OF ENGINEERING & COMPUTER SCIENCE

NATIONAL UNIVERSITY OF MODERN LANGUAGES ISLAMABAD

NATIONAL UNIVERSITY OF MODERN LANGUAGES FACULTY OF ENGINEERIING & COMPUTER SCIENCE

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Thesis Title: An Improved Link-Quality based Energy-Efficient Routing for Wireless Sensor Network-based Internet of things

Submitted By: Misbah Shahid **Registration #:** 52 MS/CS/S21

Master of Science in Computer Science (MSCS)
Title of the Degree

Computer Science
Name of Discipline

Dr. Moeenuddin Tariq
Name of Research Supervisor

Signature of Research Supervisor

Dr. Muhammad Noman Malik
Name of Dean (FE&CS)

Signature of Dean (FE&CS)

Brig. Syed Nadir Ali
Name of Pro-Rector Resources/Director General

Signature of Pro-Rector Resources/DG

June 8th, 2023

AUTHOR'S DECLARATION

I Misbah Shahid

Son of Shahid Idrees

Registration # 52 MS/CS/S21

Discipline Computer Science

Candidate of **Master of Science in Computer Science (MSCS)** at the National University of Modern Languages do hereby declare that the thesis **An Improved Link-Quality based Energy-Efficient Routing for Wireless Sensor Network-based Internet of Things** submitted by me in partial fulfillment of MSCS degree, is my original work, and has not been submitted or published earlier. I also solemnly declare that it shall not, in future, be submitted by me for obtaining any other degree from this or any other university or institution. I also understand that if evidence of plagiarism is found in my thesis/dissertation at any stage, even after the award of a degree, the work may be cancelled and the degree revoked.

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Signature of Candidate

Misbah Shahid

Name of Candidate

8th June, 2023

Date

DEDICATION

This thesis work is dedicated to my parents and my teachers throughout my education career who have not only loved me unconditionally but whose good examples have taught me to work hard for the things that I aspire to achieve.

ACKNOWLEDGMENT

"All praise to Allah, the lord of the worlds, and His Prophet Muhammad (peace be upon him), his family and his companions."

First of all, I wish to express my gratitude and deep appreciation to Almighty Allah, who made this study possible and successful.

This study would not be accomplished unless the honest espousal that was extended from several sources for which I would like to express my sincere thankfulness and gratitude. Yet, there were significant contributors for my attained success and I cannot forget their input, especially my research supervisors, Asst. Prof. Dr. Moeenuddin Tariq, who did not leave any stone unturned to guide me during my research journey.

I shall also acknowledge the extended assistance from the administrations of Department of Computer Sciences who supported me all through my research experience and simplified the challenges I faced. For all whom I did not mention but I shall not neglect their significant contribution, thanks for everything.

ABSTRACT

Title: An Improved Link-Quality Based Energy-Efficient Routing for Wireless Sensor Network-based Internet of Things

The Internet of Things (IoT) has gained implausible prominence in today's era due to its wide range of applications in various fields such as smart cities, transportation, home automation, and smart healthcare. In such IoT-based systems, wireless sensor networks (WSNs) play a major role. WSNs consist of autonomous sensor-equipped intelligent devices. These devices work together to sense and gather data required by IoT applications. In WSN-based IoT, power consumption is a challenging issue in extending network lifetime. Due to these issues, IoT applications suffer from power loss, delay, and shorter network lifetime. Existing routing protocols designed to address these issues are lacking in efficient route selection, reliable data transmission, and maximizing packet delivery ratio. In designing energy-efficient routing protocol for WSNs, optimal route selection with minimum energy depletes has become a matter of concern. This research proposes a novel routing scheme for WSN-based IoT. It helps to achieve better application performance by reducing delay and energy depletion and improving the packet delivery ratio. The proposed protocol is named as Link-Quality based Energy-Efficient routing (LQEER) for WSN-based IoT. LQEER is composed of three major steps. The first step is the network setup, where information is distributed among the nodes in the network field. The distance information of first-hop neighbors is calculated and stored in the routing table. The next step is link-quality estimation, where a standard link quality estimator is used to ensure the reliability of links between nodes before transmitting data. The third step is packet routing with energy balancing, where all the information of neighboring nodes stored in routing is then used in planning routes and data forwarding. LQEER is compared with a routing based on tree and geographic (RTG) and energy-efficient optimal multi-path routing (EOMR) protocol. NS2 is used for evaluating the LQEER protocol. Experimental results show that LQEER reduces energy consumption by 30% and 25% compared to EOMR and RTG. LQEER improves packet delivery ratio by 25% and 21% over EOMR and RTG respectively. Moreover, LQEER also minimizes end-to-end delay and gains improved network lifetime as compared to EOMR and RTG protocols.

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LIST OF ABBREVIATIONS

IoT	-	Internet of Things
WSN	-	Wireless Sensor Network
CHPSH	-	Cluster Head with Static Hub
MAC	-	Multi-adaptive clustering
BS	-	Base Station
ERSR	-	Energy-efficient Region Source Routing
RABC	-	Restart Artificial Bee Colony
EAMR	-	Energy Aware Multi-hop Routing
ESEERP	-	Enhanced Smart Energy Efficient Routing Protocol
EOMR	-	Energy-efficient Optimal Multipath Routing
RTG	-	Routing based on geographic and tree method
SFO	-	Sail Fish Optimization
EMGR	-	Energy Efficient Multicast Geographic Routing
IEGGR	-	Improved Energy-Aware Delivery Guarantee Geographic Routing
GeoM	-	Geographic Multi-cast routing
EELRP	-	Energy Efficient Layer Routing Protocol
EDGR	-	Energy-aware Dual-path protocol based on Geographic Routing
EEG	-	Energy Efficient Geographic Routing
ETLHCM	-	Enhanced Three Layer Hybrid Clustering mechanism
DEER	-	Dynamic Energy Efficient Routing
DGRP	-	Delay Aware Green Routing Protocol
FLGR	-	Fuzzy Logic based Geographic Routing
EEGR	-	Energy Efficient Grid-based Routing
CH	-	Cluster Head
SCH	-	Secondary Cluster Head
SN	-	Source Node
PDR	-	Packet Delivery Ratio
RP	-	Rendezvous Points
GH	-	Grid Head
HHC	-	Hybrid hierarchical clustering
LQEER	-	Link-Quality based Energy-Efficient Routing
est_Link	-	Link estimation

FLQE	-	Fuzzy logic-based link quality estimator
NS-2	-	Network Simulator
SPRR	-	Smoothed packet receive ratio
SF	-	Stability Factor
ASL	-	ASymmetric Link
SNR	-	Signal to Noise Ratio
LQ	-	Link quality
	-	

LIST OF SYMBOLS

A	-	Normalization symbol or smoothness factor
B	-	Normalization symbol for link quality estimation
$\mu(i)$	-	Represents membership function for high quality links
t_c	-	Time Counter
p_c	-	Packet Counter
C_N	-	Current Node
D_N	-	Destination Node
$N_{xt}N_{gh}$	-	Next Neighbor

CHAPTER 1

INTRODUCTION

1.1 Overview

Internet of Things (IoT) is a network of interrelated computing devices which perform tasks intelligently without human intervention [1]. IoT comprises smart devices called sensors. These sensors cooperate and work together to build an IoT network for sensing. Since sensors are the key components of the IoT network. In an environment, sensors sense physical environmental parameters (temperature, speed, direction, etc.) and convert this sensed data to electric signals for further operations [2]. Due to the nature of the IoT network, it has gained more importance. The gradual increase in the development of IoT has made it a vital part of daily life. Moreover, there has been a fast increase in the adaptation of new technologies as a result of linking various sensor devices, which generate a large amount of data that is processed for further cognitive tasks. These technologies have enabled communication all the time, everywhere, and for everything in an IoT environment. IoT applications have improved the quality of life of humans. IoT plays its role in different sectors, such as healthcare, smart homes, industrial automation, transportation, the military, environmental monitoring, and robotics. IoT has grown in popularity as a means of connecting the physical and digital worlds using new technologies [3, 4].

Wireless sensor networks (WSNs) are the core components of the IoT. WSN plays a major role in the growth of IoT, enabling low-cost devices with limited capabilities to connect to the internet and potentially provide life changing applications [5]. In applications such as home automation and smart cities, WSNs are considered the best solution for controlling and monitoring large amounts of data [6]. In addition, water quality monitoring, agriculture monitoring, and air pollution control [7] are well-known applications of these networks. Thus, the increasing trend of automated IoT applications using WSN has a significant impact on the quality of life of humans while providing economic benefits. As a result, companies, governments, and universities are paying attention to IoT and WSNs to assist in the development of new technologies and applications, such as smarter homes and offices, healthcare, smart cities, and environmental monitoring [8].

A wireless sensor network is a group of interconnected sensor nodes that are connected to one or more base stations via gateways. These nodes are low-powered devices with limited resources that are capable of sensing and transmitting data. The sensor nodes are distributed in a region where they work cooperatively to monitor and gather data from the environment before sending it to a base station [9]. The extensive applicability of WSN-based IoT networks in various applications, along with the quick and steady advancement of information technology development, attracts the attention of researchers in this field.

WSN-based IoT opens an interesting area of research. An important area under this study attracts toward designing an efficient routing for such a network. Since sensors are the key components in these networks and are responsible for sensing and processing data. However, sensors are resource constrained devices. A lot of energy is consumed by the sensors while processing data. It is impossible to replace or recharge the batteries of these devices and it is a costly process [10]. According to the topology of WSNs, the sensors cooperatively monitor and collect, and send to the sink in a multi-hop manner. Moreover, in these networks, the lifetime of a network is usually measured on the basis of the sustainability of the energy level in sensors. The energy of the sensors depletes during data transmitting causing death of sensors. Based on these issues, the network lifetime decreases which also leads to poor network performance. Additionally, the network performance is defined in terms of throughput, delay, and energy [11]. In resource constrained WSN for IoT applications, routing plays an important role. The routing protocols guarantee network connectivity and transmission while providing optimal paths for data forwarding. Moreover, to conserve energy in WSN, energy-efficiency is an important design consideration of the routing protocols [12]. It is a good practice to design a protocol that ensures energy and delay efficient routing, as it can improve network lifetime and performance.

1.2 Motivation

Internet of things is emerging day by day and becoming the most attractive place from every perspective of life. The use of sensors and wireless technologies in the IoT has impacted on humans' lives and improved their quality of life. Wireless sensor networks in IoT have its own importance. The large scale IoT applications based on these networks enable wireless communication with limited energy and power requirements. Smart monitoring and controlling systems are among the most common examples of wireless sensor based IoT applications. Moreover, the communication between these sensor nodes and further operations are carried out using routing protocols or algorithms. Routing in any network is a crucial part, as routing provides the way for the correct propagation of data and information. However, in such networks, where sensors collect and transmit data for further processing, the battery life for these nodes has some constraints. The energy consumed by these sensor nodes has an impact on the data delivery ratio and overall network lifetime. So, the routing protocols for such networks must consider these issues in their design. Hence, a lot of research work is required to improve network performance and reliability in these protocols.

1.2.1 Architecture

Wireless sensor networks form the basis for the development of the IoT. It is defined as the group of a large number of sensor devices and two or more sinks. The sensors are wirelessly connected and distributed in an environment to monitor and collect data [13]. These sensors are called "smart devices" and are responsible for data gathering, monitoring, and processing. Usually, sensors work cooperatively and send data to the target node or sink. The sink processes data for use in various IoT applications such as in traffic monitoring, surveillance, healthcare, and others [14].

The basic architecture for WSN-based IoT Applications is shown in Figure 1.1. A group of sensor nodes is connected to the sink. The sink is connected to the internet through gateways, which is responsible for further processing data to be used in various applications. Sensors are the essential components of WSNs and IoT. The sensors are small devices with limited battery, processing, and storage capabilities. A lot of energy is consumed by these nodes while processing data causes death of nodes which directly impacts on network performance [15]. The performance of IoT applications such as traffic control, battlefield surveillance, and healthcare monitoring may suffer due to these issues.

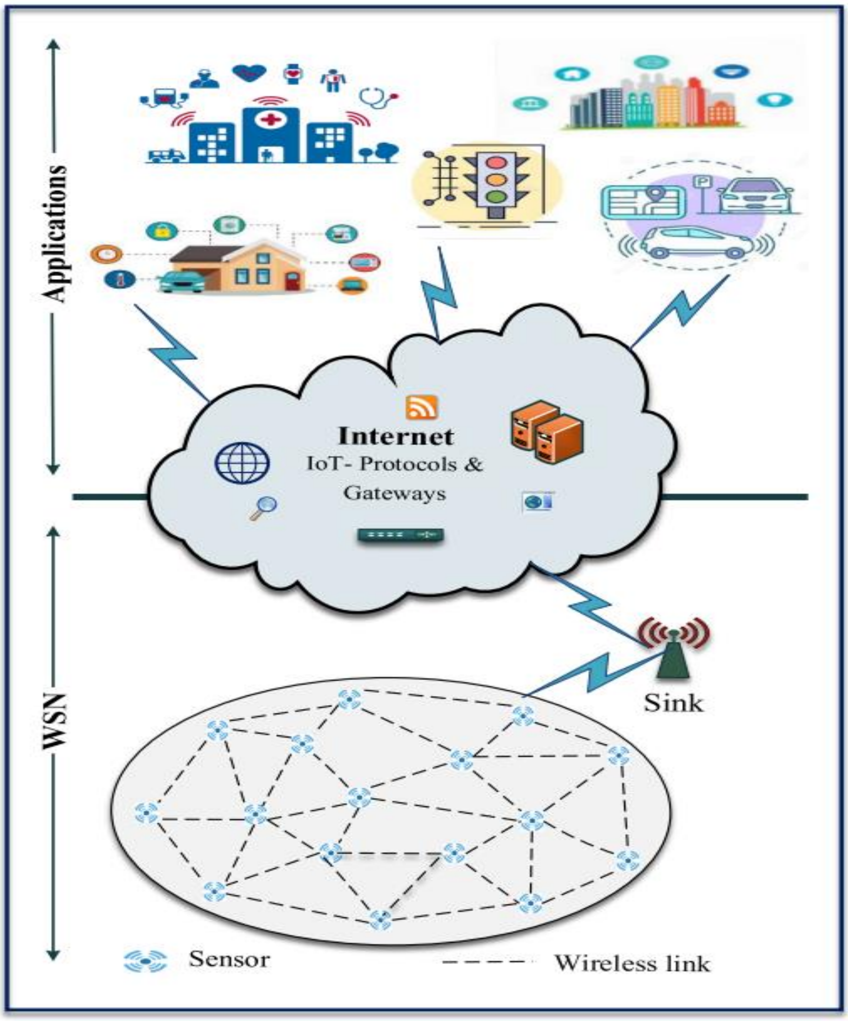


Figure 1.1: Architecture of WSN-based IoT Applications

1.2.2 Applications

IoT has gained a lot of attention due its rising applications in different sectors. IoT applications are assisting humans in every sector such as in monitoring and controlling, medical fields, industries, surveillance, tracking, transportation, and many others. Some of the applications are discussed below.

i. Smart Home Automation: Smart home automation plays a major role in the development of IoT applications. These systems have made human life even smarter, providing them with a friendly environment, and assisting in the form of intrusion detection, remote access to the appliances, surveillance, temperature control, and many other ways [16].

ii. Smart Healthcare: IoT-based healthcare applications are providing solutions to medical professionals where they can remotely monitor patients' health. IoT also assists hospitals in many ways by keeping track of their staff, patients, equipment used in hospitals, and bed occupancy detections, etc. Wearable are also used to monitor temperature, pulse rate, blood pressure, and heart rate [17, 18].

iii. Smart Environment and Agriculture: The production of agriculture is based on environmental factors (humidity and temperature). The devices equipped with sensors help the farmers get better production by measuring these factors. Moreover, automated irrigation, air pollution monitoring, and greenhouse production are better assisting in agriculture growth [19].

iv. Smart Cities: The use of smart technologies and data analysis in smart cities is providing an improved quality of service. Smart city applications provide a smarter and digitized environment, which enables monitoring and controlling devices without the involvement of human effort. There are a wide variety of applications in the smart city domain that are assisting in many ways such as smart transportation, smart parking, and street lighting [20].

1.2.3 Constraints

Since sensors are the core components in designing sensor networks and IoT. Due to the low computational power, radio, and battery power of sensors, the routing protocols need to be designed while considering the following issues or constraints.

a. *Limited Energy*

In WSNs, maintaining energy efficiency is a challenging task. Sensors play a major role in data processing and transmission. Energy of sensors drains quickly in these operations due to limited resources, which causes inefficient routing. Additionally, communication overhead occurs when the sensor nodes exchange a large amount of data with each other, which results in more energy depletion. Network sustainability is highly affected by energy utilizations, as increase in energy consumption shortens the network's lifespan [21]. Thus, an efficient mechanism is required for routing in WSNs to reduce energy consumption.

b. *Fault Tolerance*

Due to low power radio links and so, suspected to be environmental interference, some sensor nodes may break down. It is necessary to actively modify the transmission powers and signal rates on the current links in order to reduce energy consumption and to re-route packets through areas of the network where there is more energy available [22].

c. *Scalability*

Network scalability is a big challenge to be considered. In a sensing region, hundreds or thousands of sensors are deployed. Network operations are highly influenced by changes in network structure and node density. Therefore, a network should be scalable enough to cope with environmental changes [23].

d. *Node Mobility*

In most network architectures, sensors are assumed to be static. However, multiple applications require the mobility of sinks or sensors. Data routing through mobile nodes is a challenging task. Node mobility creates communication overhead and requires movement prediction models for increased efficiency. Therefore, stable route planning is a crucial issue that needs to be addressed in addition to energy and bandwidth [23].

e. *Bandwidth*

In WSNs, transmitting data consumes more power than processing it. WSN makes use of infrared, optical, and radio links for communication. Data transmission in wireless communication has a limited bandwidth of 10–100 Kbits/second. Sensor message exchanges are directly impacted by bandwidth restrictions since synchronization is impossible without message exchanges. Therefore, limited bandwidth leads to congestion and high bit error rates, which contribute to packet loss and power waste [24].

1.3 Problem Background

With the advancement of technologies, the rise in real-time monitoring and the controlling system has increased the demand for WSNs in IoT applications. In WSNs, sensed data is usually transferred to the base stations for further operations, which is then used for IoT applications [25]. To accomplish this, efficient routing mechanisms are required to deal with the issues formed in these networks. A lot of work has been done previously by many researchers to provide solutions to the routing challenges in WSNs for IoT applications. In order to provide efficient routing for these networks, different techniques were proposed to deal with the energy consumption, packet delivery ratios, end-to-end delay, and network lifetime by using geographical methods, mobile sink deployment, clustered-based approaches, and efficient data routing schemes.

Due to the sensitive nature of IoT applications and WSNs, the resource constrained sensing devices are subjected to delays and energy depletes. The low-power radio signals in wireless sensor networks during multi-hop transmission are distorted by noise and interference which creates unstable links [26]. Since based on these issues the traditional methods are not reliable and efficient. Therefore, efficient routing mechanisms are required for reliable data transmissions in WSNs. A solution that efficiently manages energy of sensors and keeps an eye on the stability of wireless links in order to avoid delays, and improves network lifetime.

The issues in wireless sensor networks arise mainly due to the sensor devices. Since these devices have limited power supplies and are deployed for large-scale data sensing environments. It is a challenging task within these networks to establish energy-efficient routes for data transmissions. A lot of energy is consumed by the sensing nodes during multi-hop data transmissions leading to the death of nodes which reduces the network lifetime. Moreover, the unnecessary updates for energy in multi-hop data communications results in more energy drains [27]. In WSNs, the unstable links are formed as a result of low-power radio signals distorted by environmental factors i.e. noise and interference. Data retransmissions occur due to unreliable and unstable links which create packet loss and lowers packet delivery ratio. Hence, there is a need to design a routing scheme for transmitting data effectively in WSNs. Additionally, the routing mechanism should be able to control energy efficiently and monitor the quality of links with an optimal route establishment for data transmissions. To fill this gap, an energy-efficient and optimal link-based routing scheme is presented to improve network performance.

1.4 Problem Statement

The radio links in sensor networks are affected by environmental factors which results in unstable links between nodes. The instability and poor quality of links cause packet loss and retransmissions which consequently lowers the packet delivery ratio [28]. Since energy of the nodes decreases on transmitting data, which requires regular energy updates into the whole network. These unnecessary updates in the network cause collisions and more delay which affects network performance [27].

1.5 Research Questions

This study addresses the following research question given below:

1. How to choose next hop nodes for data transfer among neighbors with weak links to increase packet-delivery ratio?
2. How to avoid frequent network updates to enhance energy efficiency in the network?

1.6 Aim of the Research

In WSN-based IoT networks, the energy consumption and low packet delivery ratio are the challenges that still need research. The WSNs are composed of sensor nodes that consume more energy while processing data. Energy depleted by sensing devices affects network efficiency and lifetime. Since, WSNs are deployed in a sparse environment. These networks are always affected by interference and noise which reduces the quality of link between sensors. Due to the poor links between sensors data transmission is highly affected. The transmission delays lead to low packet delivery ratios and somehow affects network performance. The aim of this research is to provide an efficient routing scheme that ensures high packet delivery ratio and reliable data transmission. Energy efficiency will be enhanced by avoiding the unnecessary network updates during routing. The packet delivery ratio will be increased by providing reliable links and minimizing delay.

1.7 Research Objectives

The following objectives are defined in the study.

1. To design and develop a scheme to calculate link quality to increase packet delivery ratio.
2. To develop and design a scheme that reduces periodic updates to improve energy efficiency in the network.

1.8 Thesis Organization

The rest of thesis is organized as follows:

Chapter 2 will provide introduction of the domain and further addresses the related problems in WSNs for IoT. It provides a comprehensive analysis of all previous research and explains how this study differs from existing frameworks. Additionally, it includes a categorical discussion, a thorough comparison of the state-of-the-art schemes, and an analysis of their research limitations that point in the direction of new research directions.

Chapter 3 presents methodology and detail of the technique that is used in problem identification. A solution to address the problem is also presented in the Chapter. The research methodology consists of operational framework, research design, and simulation framework. Detailed information of simulation framework and performance metrics is also given in the section. Chapter 3 also provides a detailed working of operational framework and verification of Link-Quality based Energy-Efficient routing protocol. It also discusses and analyzes the steps of LQEER i.e. Network Setup, Estimating Link Quality, and Packet routing with energy balancing, to provide efficient routing in WSNs for IoT applications.

Chapter 4 will provide performance evaluation of Link-Quality based Energy-Efficient routing protocol. It discusses the results of the experiments and provides the comparative analysis of these results in terms of performance metrics i.e. packet delivery ratio, energy consumption, end-to-end delay and network lifetime with other schemes. The final results are illustrated in the form graphs

Chapter 5 will give the summary of contributions of the research. It also discusses the gaps of the proposed protocol which provides the directions for the future work.

CHAPTER 2

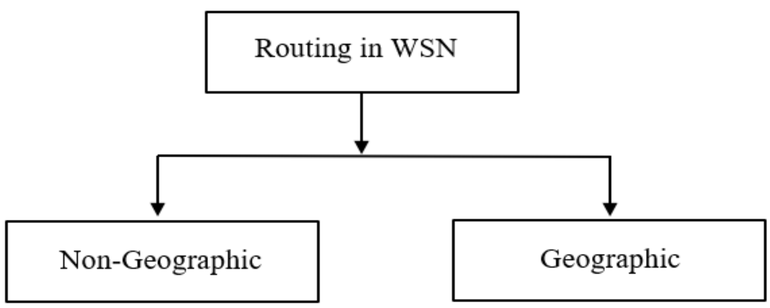
LITERATURE REVIEW

2.1 Overview

In this Chapter, a detailed study of the related literature has been done which provides the way for the research. IoT is becoming more important as a result of the rapid development of technology and connectivity to the world. The use of wireless sensor technologies in IoT has increased its importance. As the use of WSN for IoT applications like monitoring and controlling systems are high in demand. However, these networks face routing challenges due to the limited energy, fluctuated links, and delay. The various existing routing techniques and approaches are studied. The number of challenges in these networks is explored in this chapter.

2.2 Routing in WSN Networks

Based on existing work, the literature of the proposed study is mainly categorized into geographic and non-geographic routing [29] based on their mechanisms.



2.2.1 Non-Geographic Routing

In this kind of routing, sensor nodes directly send their data to the sink without utilizing multi-hop forwarding [30]. Multiple schemes that have used different mechanisms [31-34] for routing are presented in this category. Abastkeleş-Turgut, I., et al. [35] proposed fully distributed energy-aware multi-level clustering routing protocol for WSN. The protocol adopted intra-cluster two-level and inter-cluster multi-level communication where the second level group is formed by calculating the distance between nodes and the base station. In the network, clusters are distributed statically, where re-clustering is also performed, and the clustering limit is chosen by self-organized nodes. The two-level communication reduces communication cost, improves residual energy, and increases network lifespan. However, this method is limited to relying on a single dominant source as it is not suitable for the deployment of varying nodes.

A routing protocol based on cluster head with static hub (CHPSH) was proposed by Lenka, K., R., et al. [36]. In CHPSH, cluster formation and selection of CHs are formed on the basis of information collected from neighbors. CH receives data and then forwards it to the hub through direct or indirect communication. When energy of devices becomes lower than the defined limit, the hub then performs re-clustering and re-routing. Clustering techniques reduce network overload due to redundant data in a dense environment. However, the devices nearest to the hub consume energy rapidly, which results in a hotspot problem near the hub. In mobile WSNs, it is necessary to maintain and update the location information of mobile sinks.

To improve network performance in an IoT enabled WSNs, energy efficient multi-adaptive clustering (MAC) was proposed by Asad, M., et al. [37]. It is composed of a hybrid clustering structure of centralized and distributed regions. A static BS is placed at the center of the network with homogeneous and heterogeneous nodes deployed in two regions. Data is transmitted in an energy efficient manner with the selection of nodes having high energy and distance value. During routing when the packet transmission is done and no more packets are left, the process is terminated to avoid unnecessary energy depletion. Further, hotspot problem is also minimized by utilizing super nodes on the behalf of CHs for holding data for a specific time. However, work can be extended by applying this scenario to mobile networks and using more metrics for measuring network performance.

An energy-efficient region source routing (ERSR) was introduced by Xu, C., et al. [38]. Network is composed of fixed sensor nodes which are distributed in a circular region. A circular field is divided into different regions with a source node (SN) at center which is selected on the basis of high energy. The region is further divided into sub-regions in two scenarios. First, common nodes can directly locate SN when there is one SN in the range of common nodes. Secondly, if there are multiple SNs, the common nodes select the SN by estimating communication cost with distance and energy information. The SN with a better energy efficiency value gets to the common nodes. SN collects information from nodes in a DODAG manner. A ring domain distance-based structure is established for SN where an optimal ring domain is selected for data transmission. In addition, an ant-colony distance-based algorithm is used for finding a global path for the nodes in the ring domain. The use of an ant-colony algorithm and region division has improved energy consumption and increased the packet delivery ratio. However, the protocol is designed for static networks that somehow increase network overload and reduce network performance.

Jaiswal, K., et al. [27] presented an energy-efficient optimal multipath routing (EOMR) protocol for homogeneous WSNs. EOMR utilized optimization factor to make decision for the selection of routing paths. The optimization factor is composed of three parameters i.e. nodes lifetime, communication reliability, and traffic density. EOMR utilizes four phases i.e. initialization, establishing and discovering paths, transmitting data, and maintaining paths. In initialization, each sensor node computes an optimization factor based on its own neighboring table. For establishing and discovering paths, source node broadcasts a route request packet to its neighbors. This process continues until destination is identified. In data transmission, the source then selects a node with best optimization factor to transmit data. In path maintenance, parameters used in optimization factor are updated. EOMR has improved energy consumption and packet delivery ratio by utilizing optimal paths. However, it is proposed for static network. It can increase communication overhead and has poor scalability in case of mobile networks. Moreover, there is no mechanism defined to control parallel transmission which may result in packet loss and more energy consumption.

Wang, J., et al. [39] gave the concept of sink mobility for an energy efficient routing in WSNs. They have used the clustering technique along with a mobile sink scenario. CH is selected on the basis of higher energy, distance, and higher weight value. CH is responsible for collecting data from other CHs and transmitting it to the sink. Inter-cluster communication uses a greedy algorithm where chains are formed that reduces long-distance communication.

Sink moves with angular velocity and its current position is then estimated using the initial position and angular velocity. Clustering has improved the energy balancing problem and provides efficient energy consumption in the network. However, the uneven energy distribution among the clusters affects network performance.

Zhang, X., et al. [40] considered a scenario in which wireless sensors gather and send data to a micro-BS and forwards it to the macro-BS for an IoT network. A wireless power transfer (WPT) technique is used for providing power supply to sensor nodes. A restart artificial bee colony (RABC) method has also been proposed. A shortest traveling path for sensors is calculated first, then the mutual interference between sensor and BS is considered, and finally the optimal uplink route is calculated. The RABC attempts to perform asymptotic convergences to solve the problem while finding the best shortest path and optimal uplink. This method tries to solve problems incurred during transferring data while reducing energy consumption problems in an efficient manner. However, this method is so complex and WPT technique can increase the cost of the network.

Lenka.R. K, et al. [41] proposed a reliable routing infrastructure for green-IoT networks. A star-shaped network structure is deployed where rendezvous points are placed in the center. Clustering and multipath methods are used for sensing and transmitting data. The use of clustering and multipath methods is a better solution for less energy consumption and improving network reliability. The problem that comes with this type of scheme is that there is more delay while data forwarding between the destination node and the source node.

Umbreen, S., et al. [42] proposed an energy efficient mobility based cluster head selection (EEMCS) routing to prolong the lifetime of WSNs. Cengiz, K., et al. [43] proposed an energy aware multi-hop routing (EAMR) protocol to reduce transmission overhead and improve the lifespan of WSNs. The CHs are selected on the basis of probabilistic function which is calculated on energy, distance, and hop-count information. The transmission between CHs and the sink happens either directly or indirectly based on the distance.

Dwivedi, K, A., et al. [44] proposed an energy efficient two stage routing for WSN-assisted IoT. Based on clustering, cluster head (CH) and secondary cluster head (SCH) are used. The parameters such as residual energy, distance, communication cost, and density are used for the selection of CH. The SCH is used as a backup for CH and performs all the operations of CH when its energy decreases. Therefore, the more consumption of energy is minimized in this case. The two-way intra-cluster and inter-cluster communication is used in the secondary phase which reduces the re-clustering process and as result prolong network lifetime. However, this method consumes more energy during the selection of primary and secondary cluster heads.

Dogra, R., et al. [45] introduced an enhanced smart energy efficient routing protocol (ESEERP). This is designed to solve the issues created by the sensor nodes closer to the sink having a short lifetime. Large amount of energy from these nodes is consumed in processing heavy traffic. ESEERP performed a selection of CH based on distance, cost, and energy using an energy efficient algorithm. A Sail Fish Optimization (SFO) algorithm is used to select an optimal route from CH towards the sink. However, the lifetime of the network is affected due to the unequal consumption of energy by nodes.

2.2.2 Geographic based Routing

Geographic routing is a technique where each node chooses its next-hop relay node, which is closer to the destination. Moreover, each node in the network is position aware which is utilized in next hop selection [46]. There are different routing methods which are used along with this kind of routing. Yarinezhad, R., et al. [28] gave the concept of routing based on tree and geographic protocol (RTG). In this protocol, a mobile sink is used with static sensor node deployment. The network is divided into two sections, the sink movement is limited to a specific area called the inner-section, and the nodes that are away from the sink are placed in the outer-section. A geographic routing mechanism is used in the outer-section for data forwarding, and a tree-based mechanism is used in the inner-section for routing near the sink. The protocol attempts to solve the hot-spot problem using a mobile sink scenario, as well as the protocol reduces the infinite loop problem that results in an energy balanced network. However, there are more energy depletions due to frequent network updates that cause overall network performance degradation.

An energy efficient multicast geographic routing (EMGR) was presented by Huang, H., et al. [47] for WSNs, which improves PDR and reduces energy consumption. A multicast scenario is developed where a source node sends data to multiple destinations which forms a tree structure. The optimal next node selection is made by publishing a request-to-send message. A clear-to-send message is sent to ensure the availability of the next node with the shortest distance toward the destination. A bypass mechanism is introduced to reduce the possibility of void regions near the destination. However, neighbor’s location estimation increases the exchange of extra messages, which also causes extra energy consumption due to network overhead.

A method based on a virtual grid-based rendezvous points (RPs), and sojourn location selection (VGRSS) was proposed by Mehto, A., et al. [48] to select energy and delay efficient paths. RPs is responsible for collecting and forwarding data to sensor nodes. A sojourn location is an area near RPs where the sink is allowed to move. In VGRSS, the network is divided into grid cell structures where these cells are named sojourn locations. The RP is selected as the intersection of four cells. When the sink comes closer to these sojourn locations, the RPs send data to the sink. The use of the virtual grid method reduced the reselection overhead and energy-hole problem in WSNs. However, the method defined above is time consuming as the RP needs to wait for the sink, which creates a delay.

Redjimi, K., et al. [49] proposed a geographical routing protocol called improved energy-aware and delivery guarantee geographic routing (IEGGR). In this method, the data is forwarded on energy efficient paths while utilizing the positions of neighbor nodes that are closest to the base station. An improved mechanism is used for forwarding data packets efficiently around voids. In this algorithm, the WSN is treated as a connected graph, and during the data forwarding phase, it attempts to make the locally optimal decision at each intermediate node to find the global optimum path that uses the least amount of energy. Further, the data delivery is guaranteed by introducing recovery method while forwarding packets around voids. The protocol attempts to use energy efficient routing while improving network lifetime. However, packet forwarding around big voids in the recovery method, the energy consumption is not addressed. Manjunath, et al. [50] proposed a blind path geographical energy-aware routing protocol for WSNs. A network is randomly divided into multiple grids where each grid has its own grid head (GH). GHs are selected based on maximum energy and minimum distance values. A GH communicates directly with its grid members and with neighboring GHs. Each sensor node in the grid is aware of its location, which reduces the storage overhead for sensors. Moreover, the energy for each sensor node is different at the initial stage, which may change with packet transmission. During data transmission, the data from grid members is forwarded to the grid head, which selects the neighboring GH as the next hop. This process of data transmission continues until the destination is reached. The drawback of this method is that it causes more delay while forwarding data.

To reduce latency and increase the lifetime of WSNs, Leao, L., et al. [51] proposed geographic multi-cast (GeoM) routing with multi-sink. In GeoM, route planning decisions are made on the location information. The linear combination of network parameters with weight is used for the selection of the next hop. During the network lifetime, the paths continuously change based on the energy consumed to balance energy across the network. Multicast communication with geographic routing maintains the trade-off between energy and delay. However, in some scenarios, multicast communication is limited and may be a costly process.

Hajipour, Z., et al. [52] presented an energy efficient layer routing protocol (EELRP) in WSNs. The network is divided into concentric circular layers having various radii and sink at center. The layers are then divided into eight sectors at a 45-degree angle and the connection between sectors and layers is formed into sections. An agent node is then selected in each section by exchanging a hello packet and a source packet between the nodes. The agent collects sensed data from the sensors and applies error detection and correction to the data received. After this, the agent sends this data to the lower-level layers. If any error is found in the data, the first agent tries to solve it; otherwise, it requests the re-transmission of error free data. The process is repeated at each layer until the data is received by the sink. When the energy of an agent is drained, it will be re-selected among the nodes. Hence, energy consumption is reduced in this way because only one agent is involved in transmitting and receiving data. Moreover, the predetermined paths and error correction or detection improve reliability and increase the PDR. However, this scheme has limitations if it is applied to the network with a mobile sink. The performance could be enhanced by extending it in terms of mobility models and dynamic structure in the future.

An energy-aware dual-path protocol based on geographic routing (EDGR) was proposed by Huang, H., et al. [53]. Each sensor is equipped with GPS where location and energy information of neighboring nodes is obtained by exchanging a beacon message. Anchor nodes are used here, which are identified by broadcasting a burst packet. EDGR performed left and right burst packet forwarding from the source to the destination using anchor nodes. Anchor node scenario improves delay and overloading due to routing holes and provides the way for data forwarding. A random shift approach is also introduced in the data forwarding phase, where relay node failure is overcome by randomly shifting data to the subdestination node. In this way, the communication overhead is reduced to some extent. Moreover, EDGR is applied to the 3-dimensional network space where detour routing is introduced for energy efficient routing. However, the extra burst packet forwarding increases more energy consumption of nodes.

To improve network throughput and energy consumption in an IoT enabled sensor network Hameed, R., A., et al. [54] proposed an energy efficient geographic routing (EEG) protocol. A mean square error algorithm is used by the EEG to solve the issues of existing protocols in location estimation. During forwarding data, an optimal neighbor node is used to find the best route toward the destination. The process starts by broadcasting a beacon message from the source to the neighbors, the neighbor nodes acknowledge the source by publishing a control message to build a communication link between nodes. The selection for the neighbor node is made on the location of the node. The location is estimated along with optimal energy, residual energy, and 1-hop neighbor’s value. Once all the information is calculated, the source then sends data to the node. The same procedure is applied for best neighbor node selection till the destination node. The EEG protocols improved the throughput by reducing the void areas near the source and also reducing the energy consumption by utilizing the node’s location information. However, the delay in the network still increases in forwarding data due to the exchange of beacon and control messages.

In order to reduce delay and energy consumption in WSNs a routing algorithm based on virtual grid based (VGB) infrastructure and mobile sink was proposed by Yarinezhad, R., et al. [55]. VGB stores the last position of mobile sink to improve network efficiency. In network deployment, sensors are distributed properly where the sensing region is partitioned into various equal sized cells. Node closer to the intersection point of four cells is usually considered as a node where sink last position is stored. The other nodes in cells get sink position through these intersecting nodes so to reduce the updating cost for sink. The intersecting nodes get the position of sink by exchanging beacon messages. During data transmission sensors send requests to their corresponding intersecting nodes to get the position of the sink. Upon receiving sink position, the sensor sends data towards relay nodes using geographic routing algorithm and then intersecting nodes follow same geographic routing to send data to the sink. The replacement of intersecting nodes is defined in VGB, to avoid energy drainage. In this way, VGB provides the smallest data transfers and delay is minimized as the nodes are aware of the neighbor's position and sink to the last position.

However, because normal nodes are more probable than intersecting nodes, there is a possibility of hot spot problems near intersecting nodes.

Ullah, F., M., et al. [56] presented an energy efficient routing protocol named Enhanced Three Layer Hybrid Clustering mechanism (ETLHCM) for IoT. A hybrid hierarchical clustering (HHC) used for the selection of upper and lower-level heads. An upper layer is defined as the layer closest to the sink, where it chooses a grid head (GH) using HHC. A fuzzy c-means clustering (FCM) is then applied to check whether the node selected by the sink is GH. In the second step, control packets are exchanged between nodes, and a cluster head (CH) is selected using the HHC technique where a node with high residual energy gets priority. These steps are repeated until the completion of one round. An energy level is also defined for each node which usually puts a threshold on the control packets for each round. The use of HHC improves the control packet exchange in a layered approach which increases the energy efficiency. Moreover, the energy level helps in energy balancing and reduces the extra wastage of energy. However, the protocol is designed for a homogeneous network environment.

Haque, E, M., et al. [57] proposed a dynamic energy efficient routing (DEER) protocol for WSNs. DEER performs simple route selection by utilizing high residual energy of neighbor nodes. In the case of relay node failure or unavailability, the next nodes having high energy levels are dynamically elected as new data forwarder nodes. This provides reliable transmission of data due to the dynamic selection of new nodes. Moreover, the delay incurred due to the destination in opposite direction is minimized by setting a timer where after some threshold the data is transmitted in the right direction. In addition to the improved network performance, this protocol has some limitations in terms of unbalanced energy network. The use single energy parameter in route selection has energy depletes issue.

Hu, X., et al. [58] proposed a fuzzy logic based geographic routing (FLGR) protocol for dynamic WSNs. Logambigai, R., et al. [59] presented, an energy efficient grid-based scheme for routing in WSNs using fuzzy rules (EEGBR). In EEGBR, fuzzy logic is applied to select the best relay node to forward data based on energy and distance information. A hierarchical scheme with virtual structure based on multiple rings is used by Jain, S., et al. [60] in their delay aware green routing protocol (DGRP). The nodes closer to the rings geographically are referred to as virtual structure (VS) nodes. The VS nodes get a high preference over other normal nodes because these nodes maintain the location of the sink to avoid unnecessary updates for sink location. During routing, normal nodes send data to VS nodes, which is further forwarded to the sink. Delay is minimized by utilizing a single hop way towards the VS nodes. Moreover, an angle-based routing scheme is also used to control the exchange of messages. To avoid rapid energy depletion, an energy threshold is defined for VS nodes so that they can be replaced with normal nodes when their energy is drained. However, the author argued that the performance of the model can be improved for the network with multiple mobile sink nodes.

2.3 Comparison of Routing Schemes

In this section, a comparative analysis of various routing protocols according to the classification shown in Figure 2, and a tabular representation of further analytical study of the schemes used in these protocols shown in Table 2. In this table, comparison of various routing protocols based on their schemes, working, strengths, and weaknesses is shown.

Table 2.1: Comparative Analysis of Routing Schemes for WSN

Reference	Scheme	Working/Method	Strength	Weakness
Non-Geographic Routing Techniques				
Lenka, K.,R., et al. [36]. (2020)	Routing protocol based on cluster head with static hub (CHPSH).	Cluster formation and selection of CHs are used in data transmitting.	Reduces network overload.	Devices nearest to the hub consume energy rapidly.
Asad, M., et al. [37].(2019)	Energy efficient multi-adaptive clustering (MAC).	A hybrid clustering structure of centralized and distributed regions is used where the selection of next node is based on high energy and distance value.	Avoid unnecessary energy depletion. Minimizes hotspot problem.	Not applicable for mobile network scenarios.
Xu, C., et al. [38]. (2019)	Energy-efficient region source routing (ERSR).	Network is distributed in a circular region which is divided into different regions. A ring domain distance-based	Improves energy consumption. Increases packet-	Increases network overhead. Poor network

		structure is established for source where an optimal ring domain is selected for data transmission.	delivery- ratio.	performance.
Jaiswal, K., et al. [27]. (2019)	Energy-efficient optimal multipath routing (EOMR) protocol.	EOMR utilizes optimization factor to make decision for the selection of optimal path among multipath towards destination.	Minimized energy utilization per bit. Multi-path routing. Less end-to-end delay.	Low PDR for parallel transmission. Homogeneous network.
Wang, J., et al. [39]. (2019)	An energy efficient routing in WSNs with mobile sink.	Clustering method with greedy algorithm which reduces long-distance communication.	Provides energy efficiency. Improves load balancing.	Uneven energy distribution among the clusters. Poor network performance.
Lenka.R. K, et al. [41]. (2019)	Reliable routing infrastructure for green-IoT network (RR).	A star-shaped network structure is deployed where rendezvous points are placed in the center. Then using clustering method data is sensed and transmitted.	Energy consumption is minimized. Improves network reliability.	More chances of delay due to network structure.
Dwivedi, K, A., et al. [44]. (2021)	Energy efficient two stage routing.	Clustering method utilizes cluster head and secondary cluster head in data communication.	Prolongs network lifetime.	More energy consumptions in selection of primary and secondary cluster heads.
Abastkeleş-Turgut, I., et al. [35]. (2021)	Fully distributed energy-aware multi-level clustering.	Adopts intra-cluster two-level and inter-cluster multi-level communication for data transmission and forwarding.	Reduces communication cost. Increases network lifespan.	Not applicable for mobile networks.
Dogra, R., et al. [45]. (2022)	An enhanced smart energy efficient routing protocol (ESEERP).	Sail Fish Optimization (SFO) algorithm is used to select an optimal route from cluster head to sink.	Reduces energy hole problem near sink.	Poor network lifetime.
Geographic Routing Techniques				
Huang, H., et al. [47]. (2017)	Energy efficient multicast geographic routing (EMGR).	Uses an optimal node selection method and a bypass mechanism to reduce void regions**.**	Energy Efficient. Increases throughput. Reduce voids near destination.	Extra energy consumption due to the overflow of extra packets.

Mehto, A., et al. [48]. (2020)	Virtual grid-based rendezvous point and sojourn location selection (VGRSS).	Uses grid cell structures and sojourn locations for data forwarding.	Improves network lifetime.	Increases delay.
Redjimi, K., et al. [49]. (2021)	Improved Energy-aware and Delivery Guarantee Geographic Routing (IEGGR)	Forwards data along the energy efficient paths while utilizing the positions of neighbor nodes closer to base station.	Efficient route planning. Increases network lifetime.	Energy consumption is not addressed while packet forwarding around big voids in the recovery method.
Manjunath, et al. [50]. (2019)	A blind path geographical energy-aware routing.	Uses grid-based structure and grid heads for data forwarding.	Increases network lifetime.	More delay due unequal distribution of nodes.
Leao, L., et al. [51]. (2018)	Geographic multi-cast (GeoM) routing.	A multi-sink scenario is used which involve next-node selection based on weighted value.	Increases network lifetime.	Costly and limited procedure.
Hajipour, Z., et al. [52]. (2021)	An energy efficient layer routing protocol (EELRP).	A circular layer structure with agent node is used for data routing.	Increases packet-delivery-ratio. Improves network reliability.	Not designed for mobile networks.
Huang, H., et al. [53].(2017)	An energy-aware dual-path protocol based on geographic routing (EDGR).	An anchor node scenario with two-way routing is applied for transmitting data from source to destination.	Minimizes load balancing problem. Enhances network lifetime.	The extra burst packet forwarding results in more energy depletions.
Yarinezhad, R., et al. [28]. (2021)	Routing based on tree and geographic protocol (RTG).	Divides the whole network into two sections, where a sink movement is allowed up to specific areas.	Increases network lifetime. Reduce end-to-end delay.	No multiple sinks. More energy depletion during frequent energy updates.
Hameed, R., A., et al. [47]. (2020)	An energy efficient geographic routing (EEG) protocol.	A mean square error algorithm is used to estimate location. An optimal neighbor node is used to find the best route toward the destination.	Reduces voids near the sink. Increase throughput.	Delay increases due the exchange of necessary packets.
Yarinezhad, R	A routing	Virtual grid based (VGB)	Reduces delay.	There is a

et al. [55]. (2018)	algorithm based on virtual grid based (VGB) infrastructure.	infrastructure and mobile sink scenario is used. Data forwarding is performed by applying geographic routing.	Improves energy efficiency.	possibility of a hotspot problem due to the highest probability of normal nodes.
Ullah, F., M., et al. [56]. (2019)	Enhanced three-layer hybrid clustering mechanism for energy efficient routing in IoT.	A hybrid hierarchical clustering (HHC) with layering is used. It also involves a fuzzy c-means clustering (FCM) to select optimal paths.	Improves energy efficiency. Improves load balancing.	Designed for homogenous networks.

2.4 Research Gap and Directions

A detailed review of existing research work on various routing schemes and techniques for WSN has been done in the literature. Multiple routing schemes were proposed to ensure the energy efficiency in WSN and to improve network lifetime. However, there are some factors that impact the performance of the network and still need to be addressed. According to the study of state-of-the art literature, some of the short-comings of the previous work are identified in this section. The key short-comings that are identified in this study are given below;

- Static sink deployment causes energy holes due to high data traffic at sink, which also affects the network lifetime. In some research works, mobile sink scenarios are adopted to reduce energy hole problems, and for balancing energy in the network. However, propagation of sink’s location through the nodes in the network and updating next-hop nodes is challenging. In order to avoid such an issue, routing protocols need a mechanism to be aware of the sink's moving position.

- Network lifetime suffers due to energy depletion of sensor nodes and has an impact on performance, as it loses the reliability of data transmission. A protocol must be built to use low energy levels while reducing the distance between nodes and sink, in order to extend network lifespan and to improve performance. Geographic-based routing is best suited for routing in energy-efficient WSNs, as it makes use of the location of the neighbor to discover the best routes to forward data to the destination node or sink. This type of routing lowers energy costs and increases network lifespan.

- In multi-hop data transmission, data travels through intermediate nodes and then sent to the destination. However, there are chances of energy loss during these transmissions which will result in node death and further latency. Therefore, in order to complete transmission and minimize data loss for nodes that have neighbors, routing protocols must take into account the optimum route selection approach.

- In WSN routing protocols, most of the existing schemes focus mainly on energy efficient and delay efficient methods to improve network lifetime. However, little attention is paid to the efficiency of the communication links between nodes.

- Low packet delivery ratio is one issue that needs to be addressed during the data forwarding phase. Due to noise, distortion, and environmental conditions, WSN links between nodes can have varying quality. While using geographic protocols with moving nodes, these issues become severe. A high packet delivery ratio is dependent on a number of variables, including metrics used to choose the nodes at the next hop and a good link quality which helps to reduce packet loss and retransmission. Therefore, link quality estimation is required by routing protocols in order to choose a reliable link from multiple possible candidates at the next hop.

- In most routing protocols such as, the continuous energy updates for a node due energy depletions cause collision in the whole network. This creates an unbalanced energy network and more delays. To provide a balanced energy network, routing protocols must consider an energy balancing scheme in data forwarding. It is necessary to improve energy utilization and to reduce delay.

Different schemes have been proposed that aim to provide efficient and reliable routing for IoT enabled WSN. In such routing protocols, energy utilization, end-to-end delay, throughput, QoS, network lifetime, and performance are considered as significant factors in the design. A lot of research work has considered energy and delay efficiency, which accounts for reliable data transmission between sensor nodes and better network lifetime. The effectiveness of these routing schemes depends on various features such as network topology, node’s mobility, minimum distance, low energy consumption, data collection, next-hop selection, and routing mechanism. However, it has been analyzed that the unreliability of radio links between communicating nodes and collisions in the network that causes more delay are not considered as part of achieving good performance.

Based on the aforementioned findings, this research aims to propose link quality based and energy efficient routing, which should be capable of estimating link quality to improve reliability of data transmission while lowering packet loss and efficiently utilize energy of nodes to reduce frequent updates in the network. Additionally, it should contribute to maximizing network lifetime and enhancing performance.

2.5 Summary

In chapter 2, a detailed study of existing schemes used for routing in WSN has been done. The main focus of the chapter is to review existing routing techniques in the literature. The routing schemes have been critically analyzed. A comparative study of routing schemes on the basis of energy efficiency, network lifetime, delay, and packet delivery ratio has been done. Moreover, tabular representations for comparison which include working, strength, and weaknesses of the schemes have also been presented. Further, research gaps in the previous work and directions for it have been highlighted.

CHAPTER 3

METHODOLOGY

3.1 Overview

In this chapter, a research methodology for the design and development of **an improved Link-Quality based Energy-Efficient Routing (LQEER) for WSN-based IoT** is presented. The main concern of this study is to provide a mechanism for enhancing energy utilization and data transmission reliability in the network. This scheme is intended to develop an efficient routing with optimal route selection for data forwarding by utilizing the quality of links. Moreover, a strategy is followed to increase energy efficiency by reducing frequent network updates. The objective of this study is to minimize energy consumptions and delays, and to increase packet delivery ratio. Therefore, the research methodology presented in this chapter is considered as an initial step that provides a direction for the steps undertaken to achieve set targets.

3.2 Operational Framework

The goal of the proposed LQEER protocol is to provide efficient routing in WSNs. This scheme aims to reduce energy consumed by sensors during data forwarding and to improve packet delivery ratio. The overhead of unnecessary network updates is minimized to use energy efficiently. Moreover, a method for estimating quality of links is also used to tackle low packet delivery and reducing packet loss. This approach can overcome the shortcomings of the existing method used in WSN for IoT monitoring applications. The operational framework is divided into three phases as shown in Figure.3.1. The first is the analysis phase; it involves a detailed study of the existing routing protocols in WSNs for IoT applications and problem identification. Research design and development is the second phase; it introduces a solution strategy applied in the proposed approach. Lastly, third phase of the framework is; performance evaluation where the performance of the proposed protocol is evaluated against state-of-the-art routing protocols.

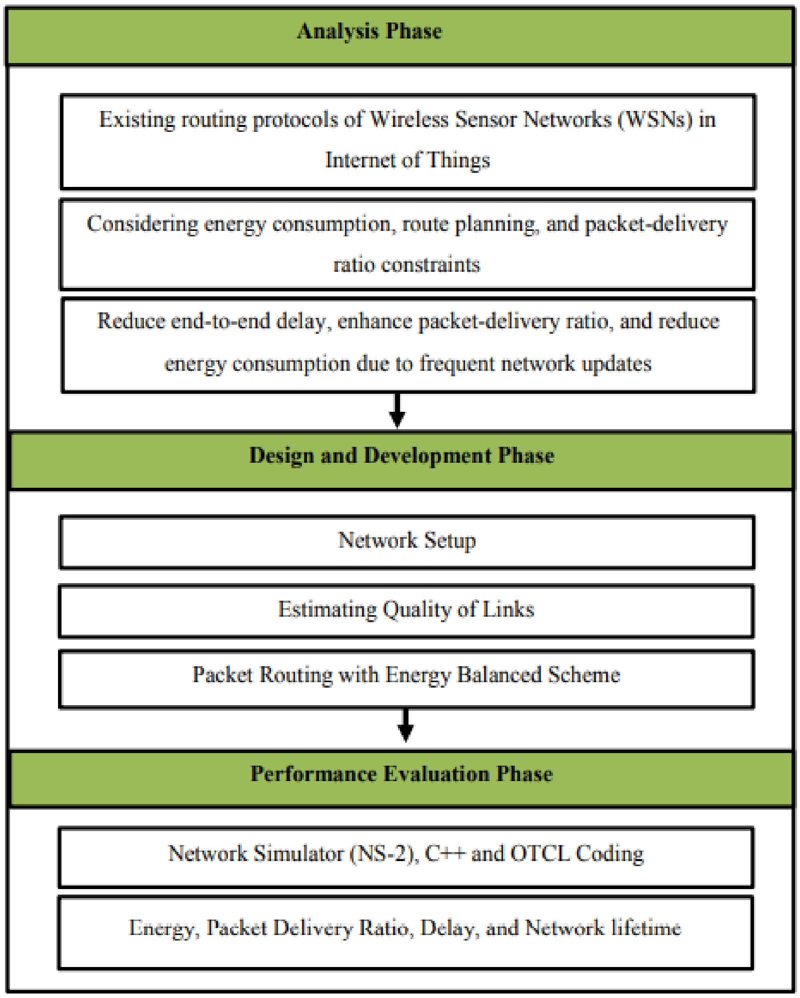


Figure 3.1: Operational Framework of the Research

3.3 Research Design and Development

The design and development of the LQEER protocol composed of following steps; network setup, estimating quality of links, and packet routing with energy balanced scheme, will be addressed here.

3.3.1 Step 1: Node Deployment and Information Distribution

The setup step consists of node deployment and information distribution in the network. A sink is placed at the center and ordinary sensor nodes are randomly placed around it. All nodes are location-aware and are stationary, except the sink node. Sink is mobile, which is allowed to move in certain areas to collect data from different nodes. In order to create routes for data transmission, beacon messages are used to distribute local information across the network. For this purpose, the sink initiates the process by broadcasting an “access” packet towards its 1-hop neighbors. An "access" packet contains node-id, current energy level, its location and timestamp information. Any node that receives the "access" packet will acknowledge its source and store the collected information (node-id, energy, and location) in the routing table. This process continues until each node gets information. Once the 1-hop neighbors receive the packet, they will forward this packet to their 1-hop neighbors after a holding time to avoid network congestion and collisions.

3.3.2 Step 2: Estimating Quality of Link

After distributing information into the network, each node in the network will compute link quality towards their 1-hop neighbors using the routing table. WSN is a network of spatially distributed sensor devices in a large geographical area. Data is transmitted through low power radio signals in these networks, which form radio links between sensors. These radio links are influenced by many factors such as interference, distortion, and multipath fading, which degrade quality of links. The poor quality of links leads to retransmissions and packet loss. Data transmission via good quality links improves packet delivery ratios and network lifetime by reducing re-transmission attempts and route re-selection. Therefore, to achieve high packet-delivery-ratio, reduce energy consumption and end-to-end delay, link measurement needs to be accurate for the selection of a reliable path. This proposed protocol takes advantage of Fuzzy logic-based link quality estimator (FLQE) [61] to estimate link quality between nodes. FLQE utilizes “link estimation (est_Link)” packet which contains node-id and timestamp information to calculate link quality among neighboring nodes. These packets are disseminated to the potential neighbors in a particular time interval to compute metrics used in estimating links.

3.3.3 Step 3: Packet Routing with Energy Balancing

Each node has its node-id, energy, link quality, and location information, stored in the routing table. The routes are then planned based on this information. In order to forward data packets, a node will be chosen from the routing table as next-forwarder node based on lower cost value. Cost is estimated on three parameters: energy level, link quality, and distance. So, a node that has high energy level, higher link quality, and shorter next-hop distance (location), will get priority. Since the position of all the nodes is fixed, link quality will remain the same. However, battery power of a sending node will be decreased each time it forwards a packet to the next-hop. Each time a packet is forwarded the energy of the node decreases. When the energy of a node decreases, it requires updating the energy status of that node in the whole network. These periodic updates for energy in the whole network cause collisions and delay. Hence, in this scheme a mechanism is introduced to avoid unnecessary updates in a network due to energy depletions and to provide energy balanced routing.

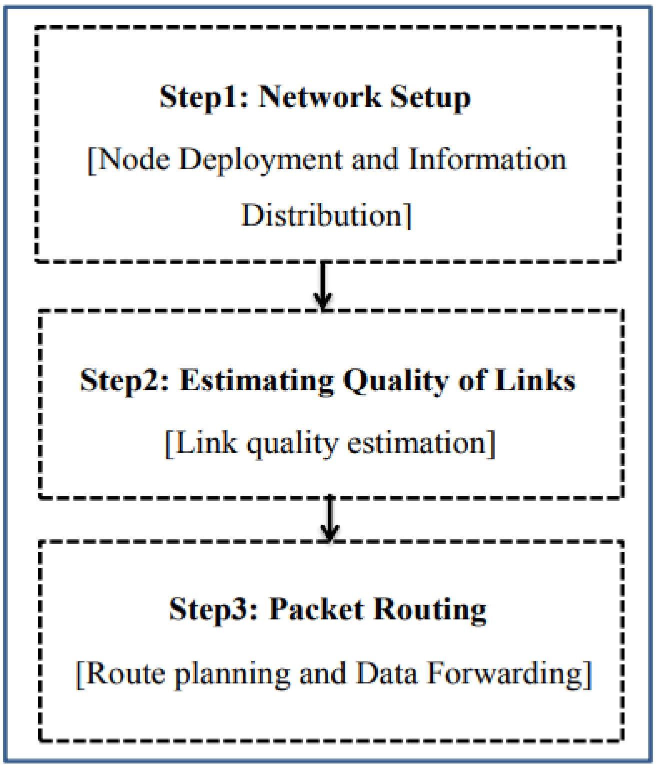


Figure 3.4: Steps in Proposed Methodology

3.4 Simulation Framework

In order to evaluate the performance of proposed protocol, we use standard network simulator (version 2) NS-2 tool. NS-2 is an event-driven tool, which provides an effective simulation of communication networks. In NS-2 simulation, C++ works at backend and object-oriented tool command language (OTcl) works at frontend. C++ and OTcl linked together through TclCL. On the basis of C++ classes, OTcl is used to create and maintain scripts, configure objects, and schedule discrete events. After simulation, the trace file generated from TCL is then fed into network animator (NAM) and XGraph to get results [62]. The simulation environment for LQEER is shown in Figure 3.3. Network scenario defined for the purpose of simulation, consists of 500mx500m network area. The maximum numbers of 400 sensor nodes are used in the network. A mobile sink is placed at the center, where its movement is predefined. Moreover, the simulation parameters are defined in Table 3.1. Simulation process starts after configuring all simulation parameters to test the proposed LQEER protocol. In order to evaluate the performance of LQEER protocol, it is compared with the related schemes such as RTG and EOMR.

Figure 3.3: Simulation Environment

Table 3.1: Simulation Parameters

Parameter Descriptions	**Values**
Network Sensor field	$500m \times 500m$
Number of Nodes	$50 - 350$
Propagation Model	Two Ray Ground
MAC protocol	IEEE 802.15.4
Speed of Mobile Sink	$10m/s$
Sink Mobility Pattern	Random
Data packet size	$512\ Bytes$
Traffic Type	CBR
Channel Type	Wireless
Initial Energy	100 J
Simulation Time	$100s$
Data Transfer Rate	250 Kb/s
Sending Energy	1.4 W
Receiving Energy	1.0 W

3.4.1 Performance Metrics

The following metrics are used in simulation to evaluate the performance of protocol:

i. **Packet Delivery Ratio** (pdr): referred to as the ratio of the number of packets successfully received at destination to the number of packets transmitted by source. It can be given by below equation 3.1 [63]:

$$pdr = \frac{no.of\ packets\ received}{no.of\ packets\ transmitted} = \frac{\sum P_r}{\sum P_{tr}} \tag{3.1}$$

ii. **Delay** is defined as the average time taken by a data packet while traveling from source to the destination. It can be given by below equation 3.2 [64]:

$$delay = \frac{total\ delay\ time}{no.of\ packets\ sent} = \frac{\sum_{i=0}^{n} (T_{ri} - T_{si})}{\sum P_n} \tag{3.2}$$

'T_{ri}' is packet reception time 'T_{si}' is packet transmission time, and 'i' is packet identifier.

iii. **Energy Consumption** is the amount of energy consumed by nodes during transmission of data. It can be calculated as the difference of initial energy 'Ei' to the final energy 'Ef' of sensor nodes. It can be determined by following equation 3.3 [65]:

$$E = \sum_{j=0}^{n} \left(Ei_j - Ef_j\right) \tag{3.3}$$

iv. **Network Lifetime** has inverse relation with the energy consumed by nodes and it refers to a time from network initialization to the point at which energy of first node completely drained.

3.4.2 Assumptions and Limitation

Following assumptions and limitations are considered for simulation:

- WSN-based IoT contains a set of fixed sensor nodes and a mobile sink.
- Sink is initially placed at the center and nodes around it, where the sink is allowed to move at a predefined region of the network.
- Initially all the sensor nodes have similar capabilities such as battery power and processing. Sink has unlimited battery power and processing capabilities.
- All the sensor nodes are assumed to be location aware, where the location coordinates are used to calculate distance between nodes.
- The nodes are declared dead when all of their energy is completely exhausted.

3.5 Proposed Scheme:

Link-Quality based Energy-Efficient Routing (LQEER)

A routing scheme LQEER is proposed for WSN-based IoT applications, to overcome the shortcomings of existing protocols. The proposed model aims to improve network performance by providing energy efficient and reliable routing. The goal is to reduce energy consumption during transmission/retransmission of data and in network updates. Moreover, the reliability of the network is gained by estimating the quality of links which accounts for an improved packet delivery ratio and end-to-end delay. This scheme consists of the following steps which are discussed below in detail.

3.5.1 Node Deployment and Information Distribution

In the deployment step, sensor nodes are randomly deployed in a network field to form a WSN. A sink node is placed in center, where the ordinary sensor nodes are positioned around it. Figure 3.4 depicts an example of the network architecture. A square represents mobile sink and dotted circle represents the inner section where sink is allowed to move. Sink movement is limited to certain area where it collects data from different nodes. The hollow circles represent the 1-hop neighbor nodes of the sink in Figure 3.4 (a). When the sink changes it position, the 1-hop neighbors also changed in Figure 3.4 (b).

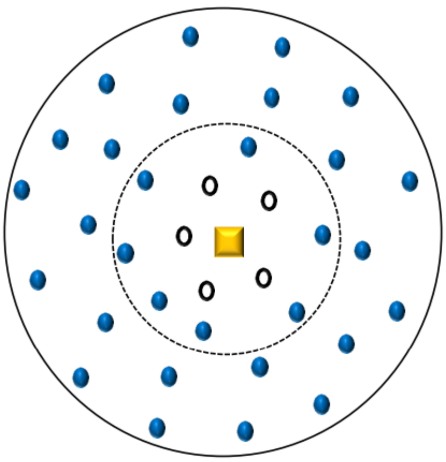


Figure 3.4 (a): Network Architecture for LQEER

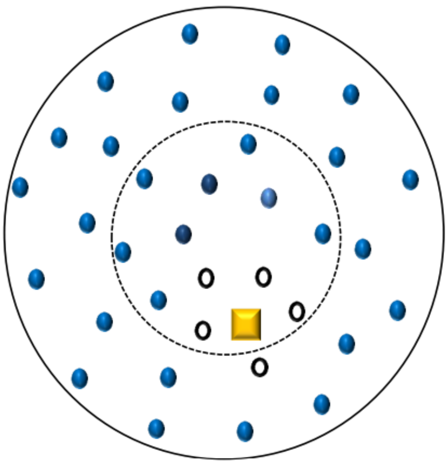


Figure 3.4 (b): Sink changed position

After network deployment, the next step is to initialize the network. This process starts by distributing the locally calculated information across each node. It is necessary to create a reverse hop-by-hop path, from each node to the sink. An "access packet" is used to initiate the process. The structure of "access packet" is shown in Figure 3.5 below.

Packet Type	Node ID	Energy Level	Location	Timestamp
1 byte	2 bytes	2 bytes	4 bytes	2 bytes

Figure 3.5: Structure of Access Packet

"Node ID" is the unique identity of each node while "energy level" represents the energy of the node. The time at which a packet is sent is represented by "timestamp". Location information of nodes is stored in the "location" field. The location coordinates of nodes give "distance" between nodes which is calculated by given formula Equation 3.4.

$$d = \sqrt{(x2 - x1)^2 + (y2 - y1)^2} \tag{3.4}$$

The sink starts the information distribution process by broadcasting an "access packet" containing Node ID, current battery power, its distance, and timestamp information to its 1-hop neighbors in its range, as shown in Figure 3.6 (diagram). Upon receiving "access packets", the nodes acknowledge the source, and store the collected information in the routing table. In this way, when the 1-hop neighbors receive the packet, they will forward this packet to their 1-hop neighbors after holding for some time to avoid network congestion. This process continues until each node gets information.

3.5.2 Estimating Quality of Links

The next step is to compute link quality of each node towards their 1-hop neighbors using the routing table. In LQEER, Fuzzy Link Quality Estimator [61] is used to estimate the quality of links. FLQE comprises four metrics as smoothed packet receive ratio (SPRR), stability factor (SF), asymmetric link (ASL), and signal to noise ratio (SNR) [61] given in Table 3.2.

Table 3.2: FLQE Metrics [61]

Metric	Description
Smooth-Packet-Receive-Ratio (SPRR)	It considers packet receive ratio (PRR), and smooth it by filtering to handle temporary changes in quality of link.
Stability Factor (SF)	Computed as change in PRR over numerous rounds.
Asymmetric Link (ASL)	Calculated as the difference between packets received from source to destination and vice versa.
Signal-to-Noise-Ratio (SNR)	Evaluate channel quality as average Signal-to-Noise-Ratio (ASNR) over the number of received packets.

Each metric calculation provides an actual state of the link. Stability factor is one metric that plays a crucial role in providing reliability with node mobility as in the case of sink in proposed scenario. FLQE is defined in Equation 3.5 [61].

$$FLQE(\alpha, w) = \alpha \times FLQE + (1-\alpha) \times LQ \tag{3.5}$$

where ‘α’ is a constant and its value ranges between [0-1], w denotes number of packets received and LQ is the link quality metric that combines SPRR, ASL, SF and ASNR into a member function ‘$\mu(i)$’ given in Equation 3.6 [61].

$$LQ(w) = 100 \times \mu(i) \tag{3.6}$$

$$\mu(i) = \beta \times \left(\mu SPRR(i) + \mu ASL(i) + \mu SF(i) + \mu ASNR(i)\right) + (1-\beta) \times mean(\mu SPRR(i) + \mu ASL(i) + \mu SF(i) + \mu ASNR(i)) \tag{3.7}$$

Where value of 100 obtained from Equation 3.7, represents a good link quality and 0 as poor link quality. ‘$\mu(i)$’ is a membership function and ‘β’ is a constant whose value ranges from [0-1] [61]. FLQE utilizes est_Link packets that contain Node ID and timestamp information by sending a selected number of packets to calculate link quality among neighboring nodes as shown in Figure 3.7.

Node ID	**Timestamp**
2 bytes	4 bytes

Figure 3.7: est_Link Packet

These packets are disseminated to the potential neighbors in a particular time interval. To compute aforementioned metrics, the source and receiver exchange a certain number of dummy packets are required by FLQE, which are set to five [61]. In the case, when there is no information available for a metric, that metric will be ignored. In LQEER, the sink is allowed to move at certain regions, hence, the distance will change. Therefore, for that particular region the distance will be re-calculated with dummy packets. Algorithm 1 presents the process for link quality estimation.

Algorithm 1: To Estimate Quality of Links

D_p arrived at node
if node.ID exists in RT **then**
    Cancel previous waiting_timer and Start new waiting_timer
    Update $pc \leftarrow pc + 1$
    Update $tc \leftarrow tc + 1$
    Calculate $SNR = SNR + (SL - TL - NL + DI)$
        if $(tc \neq pc)$ **then**
            Increment $SPRR = +\alpha.SPRR/(tc - pc)$
        end if
        if $(tc \geq 5)$ **then**
        $Count_{PRR} = Count_{PRR}\ MOD\ 5$
        $PRR[Count_{PRR} ++] = pc/tc$
        Calculate $SF = \sum(PRR\ [0:4])/5$
        Call *Calc_FLQE ( )* ►See Algorithm 2
        end if
else
    Drop Packet
end if

```
19. if waiting_timer expired then
20.     tc ← tc + 1
21.     if (tc ≠ pc) then
22.         Decrement SPRR = + α.SPRR/(tc − pc)
23.     end if
24.     if (tc ≥ 5) then
25.         Count_PRR = Count_PRR MOD 5
26.         PRR[Count_PRR ++] = pc/tc
27.         Calculate SF = ∑( PRR [0 : 4])/5
28.         CALL Calc_FLQE( )                              ►See Algorithm 2
29.     end if
30. end if
31. if (tc < 5) then
32.     Reset and Start New waiting_timer
33. end if
```

Figure 3.8: Scheme for Estimating Link-Quality

Once a node receives est_Link packet, it verifies the entry of that node in its routing table. If node entry exists, the receiver saves the information and cancels the previous timer. It starts a new timer for the next packet else it discards the packet. Since the packet is received before time expires, it will update the value for both packet counter 'p_c' and time counter 't_c'. In the next step, to determine channel quality, it computes SNR value. In step 6, SNR value for each packet received is calculated to measure channel quality. Next, the receiver checks a condition to measure SPRR value. If 't_c' is equal to 'p_c', it means that a packet is received, and it increases SPRR (step 7 & 8). Otherwise, SPRR decreases with unsuccessful packet reception of packet. After this, a receiver checks another condition in step 10, if the time counter 't_c' for receiving all five packets is completed then it computes SF. The SF is calculated over these five packets' receive ratio history. Each packet receive ratio value is stored in an array. After computing all these values, a FLQE calculation function shown in Algorithm 2, is called to find the final value.

Algorithm 2: FLQE Calculation Function (Calc_FLQE ( ))

1. Initialize: $i \leftarrow 0$, $\alpha \leftarrow 0.9$, $\beta \leftarrow 0.7$, $w = 5$, $FLQE = 100$
2. Calculate: $\mu(i) = \beta \times min(\mu SPRR(i) + \mu ASL(i) + \mu SF(i) + \mu ASNR(i)) +$ $(1-\beta) \times (\mu SPRR(i) + \mu ASL(i) + \mu SF(i) + \mu ASNR(i))/4$
3. Calculate: $LQ = 100 \times \mu(i)$
4. Calculate: $FLQE\ (\alpha, w) = \alpha \times 100 + (1-\alpha) \times LQ$
5. **Return** FLQE value

Figure 3.9: FLQE Function Calculation

In other cases, if the packet is not received within specified time and 't_c' expires. Then the value of 'p_c' remains the same while 't_c' increments by 1. The receiver checks conditions to estimate SPRR value. If 't_c' is not equal to 'p_c' (computes the new SPRR in step 21), then SPRR value decreases because the packet is not received. The receiver then checks whether the time for receiving five packets have expired or not. If time is expired and 't_c' is equal to five (step 24), then it will repeat steps 25-28 to compute SF. After this, the value for FLQE is calculated using a function defined in Algorithm 2. If the receiving time is not expired then the waiting timer will be reset and start waiting for the next packet.

Table 3.3: Notations used in Algorithm 1 & 2

Notations	Meaning
D_p	Dummy Packet
RT	Routing table
Pc	Packet counter
Tc	Time counter (time at which packet should be received)
SNR	Signal to Noise Ratio
SL	Source Level of Signal at given frequency.
TL	Transmission loss (total reduction in signal intensity over a distance at frequency)
NL	Noise level at the receiver over a given frequency.
DI	Directivity Index
SPRR	Smoothed Packet Receive Ratio (Number of consecutive packet received successfully)

$Count_{PRR}$	Counts for the history of PRR.
PRR	Packet Receive Ratio (Initially set to 0)
SF	Stability Factor (Calculated over history of packets and initially set to 1)
$\mu(i)$	Member Function
W	Number of Packets
LQ	Link Quality
$FLQE\ (\alpha, w)$	FLQE metric function

3.5.3 Packet Routing with Energy Balancing

Third phase is planning routes and forwarding packets. The structure of a packet which will be forwarded from source to destination is shown in Figure 3.11. It contains 'packet type' used to differentiate between access, est_Link, and data packets. 'Node ID' is the unique identity of a node, 'energy level' represents the remaining energy level of a node, 'next-hop' is a successive node receiving data, and 'sequence no' keeps the track of packets received.

Packet Type	Node ID	Energy Level	Next-Hop ID	Sequence No
1 byte	2 bytes	2 bytes	2 bytes	2 bytes

Figure 3.10: Structure of Data Packet

A. Packet Routing

Each node has its local information (ID, energy, link quality, and distance) stored in the routing table. The route planning is now performed using the information stored in routing table. During forwarding data, it will be checked if the destination is at 1-hop distance from source then packets are sent directly to the destination. However, in the second case, a node will be selected as the next node forwarder in the direction of destination to forward packets. Algorithm 3 shows a detailed working scenario of packet forwarding.

Algorithm 3: Packet Forwarding

1. A node has a packet 'P' to send, $C_N \leftarrow P$
2. **if** *packet drops for node less than 2*, RT[C_N].drop < 2 **then**
3.   **if** C_N is at 1-hop neighbor of D_N **then**
4.   Send packet to D_N
5. D_N sends ack to C_N, ack = 1
6.   **else if** C_N is not at 1-hop neighbor of D_N **then**
7.   **for** each node in its range from routing table **do**
8.   Select $N_{xt}N_{gh}$= *Cost_Func ( )* ►Algorithm 4
9.   Send packet to $N_{xt}N_{gh}$
10.   *Update current node*, $N_{xt}N_{gh} \leftarrow C_N$
11.   *Start time counter*, t_c
12.   **if** *acknowledgement is received within sending time*, ack = 1 **then**
13.   *packet received successfully*, RT[C_N].drop = 0
14.   *cancel time counter*, $t_c = 0$
15.   **Else**
16.   Drop Packet
17.   RT[C_N].drop ++
18.   **end if**
19.   **end for**
20.   **end if**
21. **else if** *packet drops 2 times and time counter expired*,
RT [C_N].drop = 2 && t_c = *Expires* **then**
22.   *remove entry of node*, RT[C_N.ID] = 0
23. **Else**
24.   go to step 2
25. **end if**

Figure 3.11: Scheme for Packet Routing

Algorithm3 explains that, a source or a node 'C_N' has a packet to send. A variable RT[C_N].drop stores the number of time packet drops and initially its value is 0. First, it checks if RT[C_N].drop is less than 2. Then, using information stored in the routing table it checks if 'C_N' is at 1-hop distance from destination. Then, send the packet to the destination and an acknowledgement for this packet is received by 'C_N'. Otherwise, if 'C_N' is not at 1-hop distance from the destination then, it will check all the neighbor nodes in its range and select a node with minimum cost as next-hop neighbor '$N_{xt}N_{gh}$' from the routing table by calling cost calculation function (Algorithm 4). A packet is then sent to '$N_{xt}N_{gh}$' and updates 'C_N'. Then it starts the time counter 't_c' at which acknowledgement is received. If acknowledgement is received within 't_c' i.e. ack=1. Then, the value for packet drop remains the same and 't_c' is cancelled. Else, it drops the packet and increments drop count. In other cases, if the packet is dropped two times and 't_c' is expired. Then, the entry of that node is removed from the routing table. Otherwise, it goes back to step 2 for packet further forwarding.

Table 3.4: Notations used in Algorithm 3

Notation	Meaning
C_N	Current node
D_N	Destination node
RT[C_N].drop	Stores number of packets drops for node
RT[C_N.ID]	Identity of node in routing table
$N_{xt}N_{gh}$	Next Neighbor

B. Cost Function

The decision for the selection of the next node forwarder is made on cost value. This cost is calculated using a cost function based on three parameters; energy level, link quality, and distance shown in Equation 3.8. The purpose of using cost function is to select the best node forwarder from its neighbors.

$$Cost = \left(x \times \left(\frac{N_j.e}{e_{max}}\right) + \ y \times \left(1 - \frac{N_{(i,j)}.l}{l_{max}}\right) + \ \ z \times \left(1 - \frac{N_{(i,j)}.d}{d_{max}}\right)\right) \tag{3.8}$$

Where '$N_j.e$' represents remaining energy of node, '$N_{(i,\,j)}.l$' is link quality between node i and j. '$N_{(i,\,j)}.d$' represents distance between sink and node j. 'e_{max}', 'l_{max}' and 'd_{max}' are the maximum values of energy, link quality, and distance specified for network respectively. Weights '*x*', '*y*', *and* '*z*' are used here, to define priority of each parameter as $x > y > z$. Thus, according to priority a value is assigned to each weighted factor such that $x + y + z = 1$. After performing tests with weight values, 0.5, 0.3, and 0.2 are set for *x, y, and z* respectively. Algorithm 4 explains the cost calculation function below.

Algorithm 4: Next Neighbor Selection (Cost_Func ( ))

1. $N_{xt}N_{gh} \leftarrow \emptyset$, c_Value ← *0*
2. **for** all neighbor nodes of C_N **do**
3. Calculate: $$Cost = \sum \left(\begin{array}{c} x \times \left(\frac{N_j.e}{e_{max}}\right) + \\ y \times \left(1 - \frac{N_{(i,j)}.l}{l_{max}}\right) + \\ z \times \left(1 - \frac{N_{(i,j)}.d}{d_{max}}\right) \end{array} \right)$$
4. *c_Value* ← Cost value for each neighbor node in RT
5. $N_{xt}N_{gh} \leftarrow$ *min(*c_Value*)*
6. **end for**
7. **return** $N_{xt}N_{gh}$

Figure 3.12: Scheme for Next Neighbor Selection

The current node or source searches for all of its available neighbors from the routing table. Then it will calculate the cost value for each neighbor. A node with minimum cost value among the others, is selected. So, a node in the neighbor list of sender, having lower cost value gets priority and elected as next node forwarder. This node is then used to forward data packets.

3.5.4 Reducing Energy Updates

Unnecessary energy updates for a node consume more energy and cause an unbalanced network. Every time a packet is transmitted, a node's energy drops and requires regular network updates. LQEER protocol set a threshold for energy draining levels ($E_{th} =$ 10%), so when a particular node's energy drops by 20% of original energy value, it broadcasts a message to its nearby nodes. Upon receiving this information, the nearby nodes update the energy of that node in the routing table (Algorithm 5). Therefore, rather than updating the energy status for the entire network, only the node whose energy is draining is updated. This technique ensures energy balancing in the network, which also contributes in extending network lifetime.

Algorithm 5: Reducing Energy Updates

1. **for** any node N_i in RT **do**
2. **if** $N_i.e$ is drops by E_{th} **then** *//node's energy ($N_i.e$)*
3. broadcast *EnergyDraining_msg*
4. $N_i.e \leftarrow E_c$ *//assign current energy (E_c)*
5. update $N_i.e_n$ in RT *//update new energy value e_n of N_i*
6. **end if**
7. **end for**

Figure 3.13: Scheme for Energy Updates

For example; two nodes 'A' and 'B' use node 'Y' from the neighbor list in data forwarding. The energy level of node 'Y' drains quickly as it is used by both nodes 'A' and 'B'. It is noted that when the energy level of node 'Y' drops by 20% of the initial energy level then it will send an energy-draining message to the nodes 'A' and 'B'. Upon receiving the message, both nodes 'A' and 'B' then update the energy status of node 'Y' in their routing table and select another node from neighbors whose energy level is greater than node 'Y'. This technique helps to reduce the energy updates in the whole network and also helps to keep the energy-balanced network by avoiding unnecessary energy updates for node.

3.6 Summary

In this chapter the problems in existing routing protocol are discussed and a methodology for the proposed protocol is given to solve these problems. An operational framework to give basic flow of proposed methodology is also presented. Moreover, different phases of the methodology are also explained with the help of figures. Multiple methods that are used to solve specific issue are presented. Moreover, the steps in proposed protocol such as network setup, estimating link quality, and packet routing in data forwarding phase are briefly explained here.

CHAPTER 4

PERFORMANCE EVALUATION OF LQEER

4.1 Overview

In Chapter 4, a detailed discussion of the results and findings of simulation to evaluate proposed protocol (LQEER) is presented. Additionally, a comparative analysis with other contemporary protocols while considering various performance metrics is given here.

4.2 Results and Analysis

To evaluate the performance and effectiveness of LQEER, the following evaluation metrics are considered: Packet Delivery Ratio, Energy Consumption, End-to-End Delay, and Network Lifetime. These metrics are adopted from related protocols i.e., RTG and EOMR. Moreover, a comparative analysis is performed with these schemes in this section. The outcomes of the metrics are also shown in graphical form.

Additionally, the varying numbers of nodes are used in examining the metrics. The similar values of the nodes used in this work are obtained from EOMR and RTG protocols. This is necessary to observe the effect of nodes on the performance of the protocol. As the increased number of nodes in EOMR has increases energy consumption due to uncontrolled flooding of route request packets and parallel transmissions. These energy depletes consequently lessen the network lifetime. As a result, to study the behavioral impact of these nodes on the performance of the protocol, it is crucial to evaluate the LQEER protocol with varying numbers of nodes.

4.3 Performance Comparison with related Schemes

In this section, the proposed LQEER protocol is compared with benchmark protocols i.e. EOMR [27] and (RTG) [28] routing based on tree and geographic protocol, to evaluate its performance. RTG is based on geographic routing where it forwards data by utilizing energy and location of nodes. EOMR is energy-efficient optimal multi-path routing protocol. It performs the selection of optimal path towards destination based on an optimality factor. Among multiple paths towards destination, a path with highest optimality factor is chosen for forwarding data. First, it has been observed that, RTG use dynamic tree structure for connecting sink and nodes in inner section. The tree structure updates with movement of sink, and hence creates inefficient routes. Secondly, in EOMR parallel data transmissions cause packet drops and retransmissions. Moreover, in data transmissions there are unnecessary energy updates in whole network which increases the probability of collisions in network and delay. On contrary to this, LQEER introduces link-quality estimation in proposed solution for reliable routes. It employs a standard FLQE estimator for estimating quality of links, which is composed four metrics. To avoid packet drops it is necessary to establish reliable data paths for data forwarding. LQEER uses a cost function followed by energy, link-quality, and distance of nodes for route selection decision. Along with this, an energy balanced technique is also employed in proposed solution to avoid collisions in network respectively. Therefore, simulation results of LQEER are compared with above mentioned schemes in this section. The performance metrics and network topology used are same as used in RTG. While simulation parameters and node values are adopted from EOMR.

4.3.1 Packet Delivery Ratio

Figure 4.1 depicts the results for packet delivery ratio under the influence of number of nodes for LQEER, RTG, and EOMR. As observed from the graph, with small number of nodes at 50, EOMR exhibits high PDR of 88%. EOMR is based on multipath routing where it utilizes an optimality factor for route selection and hence more nodes are available for forwarding data. However, RTG gains PDR of 89% because it utilizes shortest path for forwarding data. It can be observed from figure, PDR for EOMR drops to 77% which is gradually decreasing with increasing number of nodes. The reason for this decrease is due to the parallel data transmissions in EMOR. The parallel data transmission is not properly addressed in EOMR which creates packet loss and frequent data retransmissions. However, in RTG, updating position of sink changes the structure for routing and lowers the route efficiency. The absence of link-quality estimation and unreliability of routes between nodes causes packet drops and hence lowers the PDR up to 79%. On contrary to this, LQEER achieves better PDR around 92% and 98% in case of small number of nodes and with large number of nodes respectively. This is because LQEER provides reliable routes for data forwarding by employing a cost function for route selection. LQEER utilizes link-quality estimation which ensures reliability of links between nodes. FLQE provides good quality of link by utilizing its four metrics. The composite value of energy, link-quality, and distance for routing decisions helps to achieve efficient transmission and hence reduces the overhead of packet loss and retransmissions at large extent. Therefore, the proposed LQEER protocol outperforms both protocols as it has improved packet delivery ratio by 25% and 21% more in comparison with EOMR and RTG respectively.

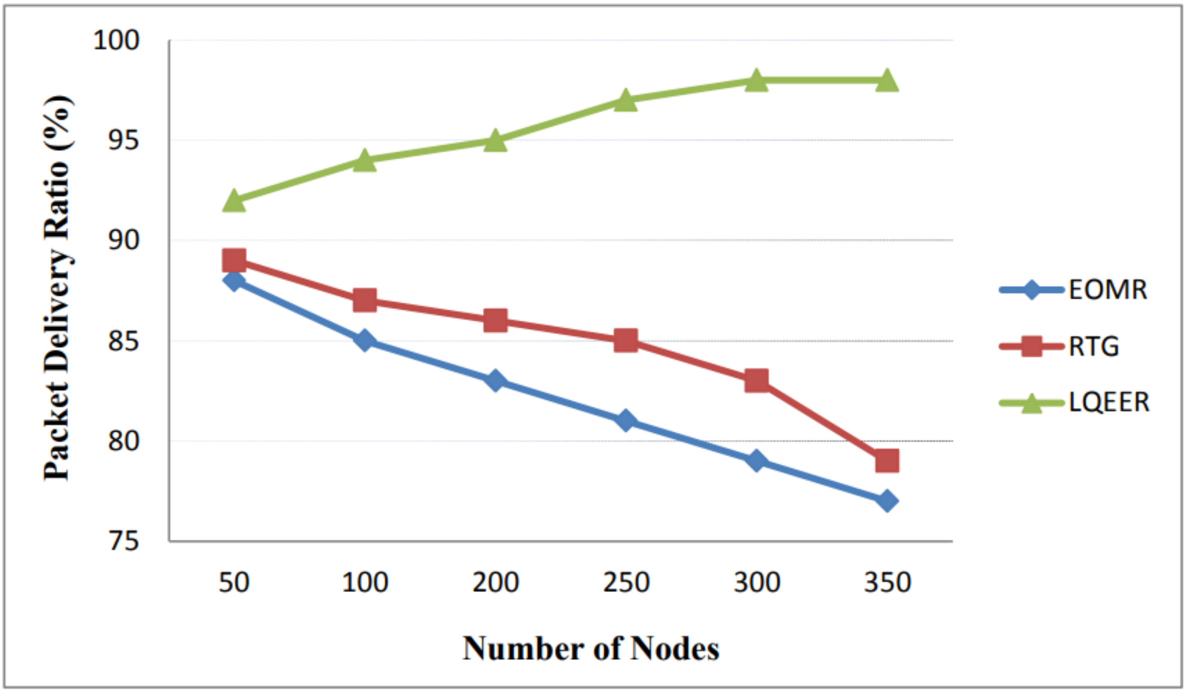


Figure 4.1: Comparison of Packet Delivery Ratio

4.3.2 End-to-End Delay

The performance comparison of proposed LQEER and existing schemes RTG and EOMR in terms of end-to-end delay is illustrated in Figure 4.2. It is clear from figure; EOMR has high end-to-end delay particularly with large nodes. In EOMR, it takes more time in path exploration as when there is no path available towards destination, the packet has to wait until the path towards destination is discovered. However, RTG has slow processing time as it utilizes simple next-hop selection method based on energy and location of nodes. The updating tree structure due to sink movement creates poor links between nodes which is responsible for unreliable routes, and hence data transmission through these routes suffers delay. In comparison with above schemes, LQEER achieves low end-to-end delay during processing time. It employs the use of link-quality and distance information for discovering routes where packet does not need to be held by node for longer time. Furthermore, LQEER uses threshold on node's energy to limit unnecessary updates. LQEER improved performance by gaining 20% and 25% less end-to-end delay in comparison with RTG and EOMR respectively. The results of simulation can be analyzed from the figure below.

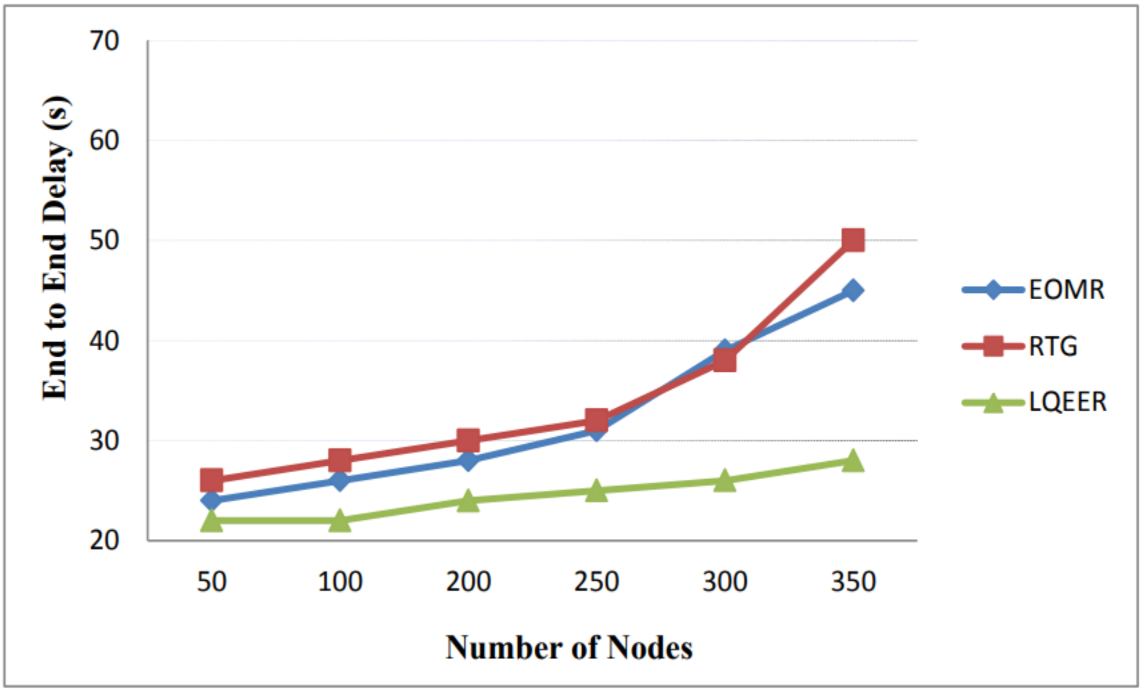


Figure 4.2: Comparison of End to End Delay

4.3.3 Energy Consumption

The results of energy consumption under the influence of nodes for three schemes i.e., LQEER, RTG, and EOMR are depicted in Figure 4.3. In EOMR, during route discovery process the flooding of route request packets incurs additional energy overheads as the source keep transmitting packets until response from destination is received. Due to the multipath path nature of EOMR, the simultaneous parallel data transmission increases the overhead of retransmissions, which consequently increases more energy depletes. From figure, there is exponential increase in energy consumption of nodes with growing number of nodes in EOMR. As with growing number of nodes energy updates in whole network increase which create collisions and reduce the energy efficiency in network. However, there is slightly less energy depletes in RTG as compared to the EOMR protocol. Because it involves shortest path selection for transmitting data, however, the updating paths with mobile sink has overhead of energy consumption. The absence of link quality between nodes has unreliable paths in this scheme. The data forwarded through these links cause packet loss and retransmissions as nodes are not aware of underlying quality of links. A lot of energy is consumed during packet transmissions forming energy inefficient network. On the contrary, LQEER outperforms both EOMR and RTG protocol as it has less energy consumption. This is mainly due to the following reasons. First, it does not involve unnecessary flooding of route request packets instead it broadcasts hello packets to allow each node to be aware of previous node’s information. Second, it employs a cost function for finding optimal next-hop for forwarding data. It reduces energy depletes due to updating paths by applying threshold on unnecessary updates. Additionally, the route selection decision involves link quality value which ensures the reliability of paths between nodes. Figure 4.3 depicts that the result of energy consumption between EOMR and RTG has little difference of 8%. However, LQEER has reduced energy consumption to large extent i.e. by 30% and 25% less to the EOMR and RTG respectively. Hence, it is proved that LQEER has more energy efficiency than other two routing protocols.

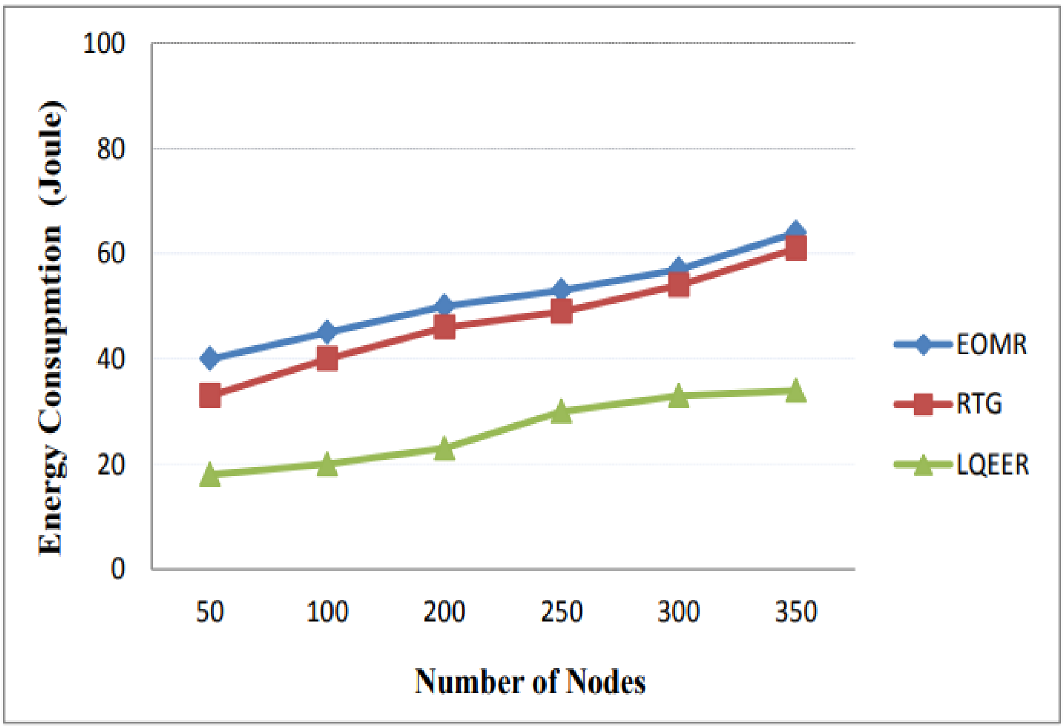


Figure 4.3: Effect of Energy Consumption on Different Schemes

4.3.4 Network Lifetime

Network lifetime is the key parameter in analyzing network performance as longer the network lifetime better a network performs. Figure 4.4 shows performance of three protocols i.e., EOMR, RTG, and LQEER in the context of network lifetime. EOMR has poor network lifetime because due to the static nature of nodes same node is used repeatedly which results into rapid energy drains. The parallel data transmissions increase the probability of retransmissions which consequently drains the energy of node faster. Hence, absence of energy balancing mechanism to combat with this results in poor network lifetime. On the contrary, RTG and LQEER has better network lifetime than EOMR. Both RTG and LQEER uses mobile sink with shortest path routing technique to balance energy of nodes. However, RTG selects next-hop node based on energy and location information of nodes, it means it could perform node selection with smaller location with low energy. Hence, there is possibility of using same node again with smallest location which results into short network lifetime. In contrast, LQEER uses three parameters i.e., energy, link-quality, and distance, where it uses single cost function that takes weighted values of these three parameters and makes a decision for next-hop node. The use of multiple parameters and weighted cost function helps to select reliable and efficient routes. Along with this, to balance energy of nodes a threshold based mechanism is also defined to avoid unnecessary energy drains. Hence, results shows that LQEER has gained 18% and 19.5% better network lifetime over EOMR and RTG respectively.

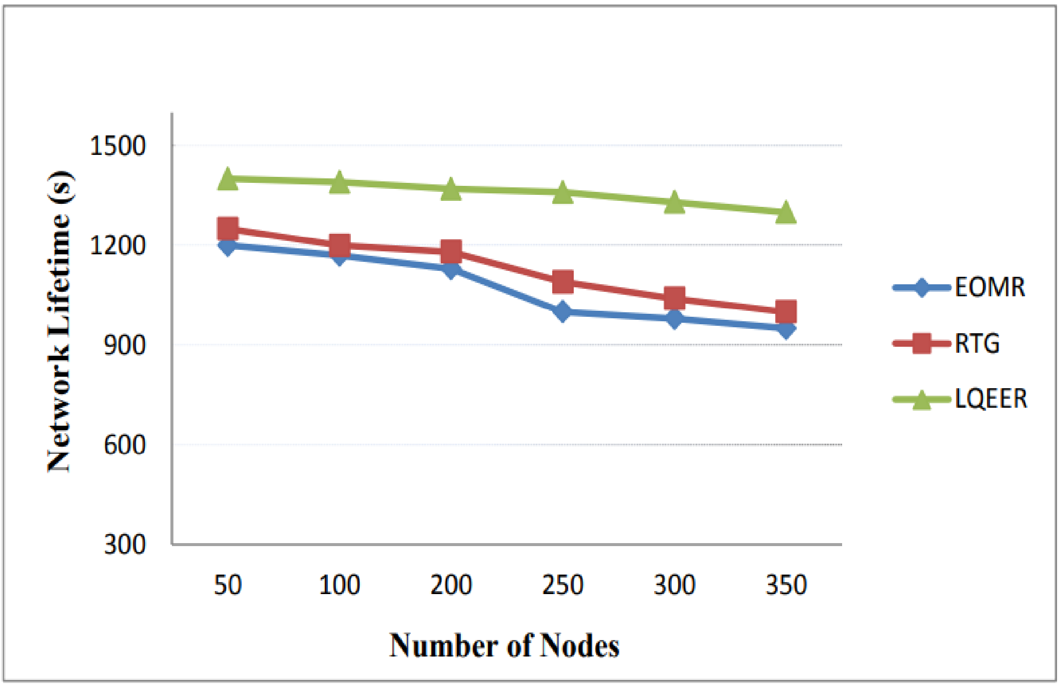


Figure 4.4: Effect of Network Lifetime on Different Schemes

4.4 Summary

In this chapter, the simulation results and performance evaluation of proposed protocol are discussed. A link quality based and energy efficient routing protocol has been proposed for WSN based IoT applications. The main objective of the proposed scheme is to overcome the shortcomings of related schemes in terms of energy consumption, packet delivery ratio, and end-to-end delay. The experiments and simulation are conducted using a standard network simulator NS-2 to analyze the performance of protocol. The comparative analysis of proposed scheme with related schemes has also been performed while considering the performance metrics. From the results it has been proved that the proposed LQEER has achieved better performance in terms of all performance metrics.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Overview

In this chapter, conclusion and future work of the research is discussed. The main objective of this research work was to highlight the issues of energy consumption, packet delivery ratio, and delay in existing routing schemes and to provide solution of these issues. The performance of proposed link quality based energy efficient routing protocols is evaluated by NS-2 simulator. The results are compared with related schemes in terms of performance metrics.

5.2 Conclusion

Wireless sensor network involves deployment of smart sensor nodes in an environment to sense and collect data for further processing. However, routing in such network is a challenging task due many reasons. One of the main reasons for this is sensor nodes are the low battery power devices that mean, their energy exhaust quickly in transmitting data which has huge impact on network lifetime. The poor energy utilization results into inefficient routes and poor data transmissions. Besides packet delivery ratio and end-to-end delay are also affected due the unreliable routes and poor data forwarding. Many researchers presented several solutions for efficient routing in WSNs to improve the performance of IoT applications. However, there are various issues with existing research in terms of energy efficiency, link quality, unreliable routes, packet delivery ratio, and end-to-end delay. Therefore, a link-quality based energy-efficient routing (LQEER) protocol is proposed to address these issues. In the proposed protocol, the network is composed of a mobile sink with static nodes around it where sink movement is defined to some specific area. Unlike RTG and EOMR, the proposed scheme utilizes link quality estimation along with energy and distance to make route decisions for data forwarding. During network initialization, a hello packet is broadcasted to learn about the neighbor's information. A link quality estimation is then performed which uses various metrics to provide high links between nodes. The link quality estimation ensures reliable links which reduces the probability of packet loss and retransmissions, result into high packet delivery ratio. A routing decision is then made on the cost value followed by a composite weight function consist of node's energy level, link quality, and distance. In this way, reliable and efficient routes are selected to perform data transmission. Moreover, to use energy more efficiently, an energy balanced scheme is also used in the proposed work. It also reduces collisions in the network which results in minimum delay. Moreover, the performance of proposed protocol is evaluated using NS2 simulator. The performance of LQEER is compared with contemporary protocols RTG and EOMR in the context of energy consumption, packet delivery ratio, end-to-end delay, and network lifetime. The proposed protocol has achieved better performance in comparison to these contemporary protocols. The results obtained from simulation show that LQEER reduces energy consumption by 30% and 25% compared to EOMR and RTG. LQEER improves packet delivery ratio by 25% and 21% over EOMR and RTG respectively. Moreover, LQEER also minimizes end-to-end delay and gains improved network lifetime as compared to EOMR and RTG protocols.

5.3 Future Work

As the future direction, we are intended to further enhance the packet delivery ratio and performance of protocol by modifying it with the addition of multiple mobile sinks. However, adopting multiple sinks would require for maintaining and keep updated with changing sink position which could also result in communication overhead. Therefore, the proposed can be further enhanced by adding multiple mobile sinks while introducing a scheme to combat with these issues.

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REFERENCES

1. Sethi, P. and S.R. Sarangi, *Internet of things: architectures, protocols, and applications.* Journal of Electrical and Computer Engineering, 2017. **2017**.
2. Rani, S., et al., *A novel scheme for an energy efficient Internet of Things based on wireless sensor networks.* Sensors, 2015. **15**(11): p. 28603-28626.
3. Hassan, W.H., *Current research on Internet of Things (IoT) security: A survey.* Computer networks, 2019. **148**: p. 283-294.
4. Kalla, A., P. Prombage, and M. Liyanage, *Introduction to IoT.* IoT Security: Advances in Authentication, 2020: p. 1-25.
5. Kocakulak, M. and I. Butun. *An overview of Wireless Sensor Networks towards internet of things*. in *2017 IEEE 7th annual computing and communication workshop and conference (CCWC)*. 2017. Ieee.
6. Gulati, K., et al., *A review paper on wireless sensor network techniques in Internet of Things (IoT).* Materials Today: Proceedings, 2022. **51**: p. 161-165.
7. Kingsy Grace, R. and S. Manju, *A comprehensive review of wireless sensor networks based air pollution monitoring systems.* Wireless Personal Communications, 2019. **108**(4): p. 2499-2515.
8. Lee, I. and K. Lee, *The Internet of Things (IoT): Applications, investments, and challenges for enterprises.* Business horizons, 2015. **58**(4): p. 431-440.
9. Nakas, C., D. Kandris, and G. Visvardis, *Energy efficient routing in wireless sensor networks: a comprehensive survey.* Algorithms, 2020. **13**(3): p. 72.
10. Shukla, A. and S. Tripathi, *An effective relay node selection technique for energy efficient WSN-assisted IoT.* Wireless Personal Communications, 2020. **112**(4): p. 2611-2641.
11. Mishra, M., G.S. Gupta, and X. Gui, *Network lifetime improvement through energy-efficient hybrid routing protocol for IoT applications.* Sensors, 2021. **21**(22): p. 7439.
12. Warrier, M.M. and A. Kumar, *An energy efficient approach for routing in wireless sensor networks.* Procedia Technology, 2016. **25**: p. 520-527.
13. Jindal, V., *History and architecture of Wireless sensor networks for ubiquitous computing.* International Journal of Advanced Research in Computer Engineering & Technology (IJARCET), 2018. **7**(2): p. 214-217.
14. Lalwani, P., H. Banka, and C. Kumar, *BERA: a biogeography-based energy saving routing architecture for wireless sensor networks.* Soft Computing, 2018. **22**(5): p. 1651-1667.
15. Naghibi, M. and H. Barati, *EGRPM: Energy efficient geographic routing protocol based on mobile sink in wireless sensor networks.* Sustainable Computing: Informatics and Systems, 2020. **25**: p. 100377.
16. Al-Kuwari, M., et al. *Smart-home automation using IoT-based sensing and monitoring platform*. in *2018 IEEE 12th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG 2018)*. 2018. IEEE.
17. Mathew, P.S., A.S. Pillai, and V. Palade, *Applications of IoT in healthcare*, in *Cognitive Computing for Big Data Systems Over IoT*. 2018, Springer. p. 263-288.
18. Evangeline, C.S. and A. Lenin, *Human health monitoring using wearable sensor.* Sensor Review, 2018.

19. Ping, H., et al., *Mini-review of application of IoT technology in monitoring agricultural products quality and safety.* International Journal of Agricultural and Biological Engineering, 2018. **11**(5): p. 35-45.
20. Adamu, A.A., et al., *An integrated IoT system pathway for smart cities.* International Journal on Emerging Technologies, 2020. **11**(1): p. 1-9.
21. Amgoth, T. and P.K. Jana, *Energy-aware routing algorithm for wireless sensor networks.* Computers & Electrical Engineering, 2015. **41**: p. 357-367.
22. Abdullah, M. and A. Ehsan, *Routing protocols for wireless sensor networks: classifications and challenges.* Journal of Electronics and Communication Engineering Research, 2014. **2**(2): p. 05-15.
23. Agarkar, P.T., et al., *A comprehensive survey on routing schemes and challenges in wireless sensor networks (WSN).* Int J Comput Netw Appl (IJCNA), 2020. **7**(6): p. 193-207.
24. Bala, T., et al., *A survey: issues and challenges in wireless sensor network.* Int. J. Eng. Technol, 2018. **7**(2): p. 53-55.
25. Khalil, N., et al. *Wireless sensors networks for Internet of Things*. in *2014 IEEE ninth international conference on Intelligent sensors, sensor networks and information processing (ISSNIP)*. 2014. IEEE.
26. Gorce, J.-M., R. Zhang, and H. Parvery, *Impact of radio link unreliability on the connectivity of wireless sensor networks.* EURASIP Journal on Wireless Communications and Networking, 2007. **2007**: p. 1-16.
27. Jaiswal, K. and V. Anand, *EOMR: An energy-efficient optimal multi-path routing protocol to improve QoS in wireless sensor network for IoT applications.* Wireless Personal Communications, 2020. **111**: p. 2493-2515.
28. Yarinezhad, R. and S. Azizi, *An energy-efficient routing protocol for the Internet of Things networks based on geographical location and link quality.* Computer Networks, 2021. **193**: p. 108116.
29. Cadger, F., et al., *A survey of geographical routing in wireless ad-hoc networks.* IEEE Communications Surveys & Tutorials, 2012. **15**(2): p. 621-653.
30. Qu, H. and S.B. Wicker, *Co-designed anchor-free localization and location-based routing algorithm for rapidly-deployed wireless sensor networks.* Information fusion, 2008. **9**(3): p. 425-439.
31. Wang, Z., et al., *An energy efficient routing protocol based on improved artificial bee colony algorithm for wireless sensor networks.* IEEE Access, 2020. **8**: p. 133577-133596.
32. Elsmany, E.F.A., et al., *EESRA: Energy efficient scalable routing algorithm for wireless sensor networks.* IEEE Access, 2019. **7**: p. 96974-96983.
33. Tabatabaei, S. and A.M. Rigi, *Reliable routing algorithm based on clustering and mobile sink in wireless sensor networks.* Wireless Personal Communications, 2019. **108**(4): p. 2541-2558.
34. Ilyas, M., et al., *Trust-based energy-efficient routing protocol for Internet of things–based sensor networks.* International Journal of Distributed Sensor Networks, 2020. **16**(10): p. 1550147720964358.
35. Abasıkeleş-Turgut, İ. and G. Altan, *A fully distributed energy-aware multi-level clustering and routing for WSN-based IoT.* Transactions on Emerging Telecommunications Technologies, 2021. **32**(12): p. e4355.
36. Lenka, R.K., et al., *Cluster-based routing protocol with static hub (CRPSH) for WSN-assisted IoT networks.* Sustainability, 2022. **14**(12): p. 7304.

37. Asad, M., et al., *IoT enabled adaptive clustering based energy efficient routing protocol for wireless sensor networks.* International Journal of Ad Hoc and Ubiquitous Computing, 2019. **32**(2): p. 133-145.
38. Xu, C., et al., *An energy-efficient region source routing protocol for lifetime maximization in WSN.* IEEE Access, 2019. **7**: p. 135277-135289.
39. Wang, J., et al., *Energy efficient routing algorithm with mobile sink support for wireless sensor networks.* Sensors, 2019. **19**(7): p. 1494.
40. Zhang, X., X. Zhang, and L. Han, *An energy efficient Internet of Things network using restart artificial bee colony and wireless power transfer.* IEEE Access, 2019. **7**: p. 12686-12695.
41. Lenka, R.K., A.K. Rath, and S. Sharma, *Building reliable routing infrastructure for green IoT network.* IEEE Access, 2019. **7**: p. 129892-129909.
42. Umbreen, S., et al., *An energy-efficient mobility-based cluster head selection for lifetime enhancement of wireless sensor networks.* Ieee Access, 2020. **8**: p. 207779-207793.
43. Cengiz, K. and T. Dag, *Energy aware multi-hop routing protocol for WSNs.* IEEE access, 2017. **6**: p. 2622-2633.
44. Dwivedi, A.K., et al., *EETSP: Energy‐efficient two‐stage routing protocol for wireless sensor network‐assisted Internet of Things.* International Journal of Communication Systems, 2021. **34**(17): p. e4965.
45. Dogra, R., et al., *ESEERP: Enhanced Smart Energy Efficient Routing Protocol for Internet of Things in Wireless Sensor Nodes.* Sensors, 2022. **22**(16): p. 6109.
46. Subhash, A. and C. Kumuthini, *A Survey on Geographical Routing Protocols in Wireless Sensor Networks.*
47. Huang, H., et al., *EMGR: Energy-efficient multicast geographic routing in wireless sensor networks.* Computer Networks, 2017. **129**: p. 51-63.
48. Mehto, A., S. Tapaswi, and K. Pattanaik, *Virtual grid-based rendezvous point and sojourn location selection for energy and delay efficient data acquisition in wireless sensor networks with mobile sink.* Wireless Networks, 2020. **26**(5): p. 3763-3779.
49. Redjimi, K., M. Boulaiche, and M. Redjimi, *IEGGR: Improved Energy-aware and Delivery Guarantee Geographic Routing.* Journal of Communications Software and Systems, 2021. **17**(2): p. 143-153.
50. Manjunath, D. and S. Thimmaraju. *A blind path geographical energy aware routing protocol for wireless sensor networks*. in *2019 1st International Conference on Advanced Technologies in Intelligent Control, Environment, Computing & Communication Engineering (ICATIECE)*. 2019. IEEE.
51. Leão, L. and V. Felea. *Latency and network lifetime trade-off in geographic multicast routing for multi-sink wireless sensor networks*. in *Mobile, Secure, and Programmable Networking: 4th International Conference, MSPN 2018, Paris, France, June 18-20, 2018, Revised Selected Papers 4*. 2019. Springer.
52. Hajipour, Z. and H. Barati, *EELRP: energy efficient layered routing protocol in wireless sensor networks.* Computing, 2021. **103**(12): p. 2789-2809.
53. Huang, H., et al., *Energy-aware dual-path geographic routing to bypass routing holes in wireless sensor networks.* IEEE Transactions on Mobile Computing, 2017. **17**(6): p. 1339-1352.
54. Hameed, A.R., et al., *Towards energy and performance-aware geographic routing for IoT-enabled sensor networks.* Computers & Electrical Engineering, 2020. **85**: p. 106643.

55. Yarinezhad, R. and A. Sarabi, *Reducing delay and energy consumption in wireless sensor networks by making virtual grid infrastructure and using mobile sink.* AEU-International Journal of Electronics and Communications, 2018. **84**: p. 144-152.
56. Faizan Ullah, M., J. Imtiaz, and K.Q. Maqbool, *Enhanced three layer hybrid clustering mechanism for energy efficient routing in IoT.* Sensors, 2019. **19**(4): p. 829.
57. Haque, M.E. and U. Baroudi, *Dynamic energy efficient routing protocol in wireless sensor networks.* Wireless Networks, 2020. **26**: p. 3715-3733.
58. Hu, X., et al., *Fuzzy logic-based geographic routing protocol for dynamic wireless sensor networks.* Sensors, 2019. **19**(1): p. 196.
59. Logambigai, R., S. Ganapathy, and A. Kannan, *Energy–efficient grid–based routing algorithm using intelligent fuzzy rules for wireless sensor networks.* Computers & Electrical Engineering, 2018. **68**: p. 62-75.
60. Jain, S., et al., *Edvwdd: Event-driven virtual wheel-based data dissemination for mobile sink-enabled wireless sensor networks.* The Journal of Supercomputing, 2021. **77**: p. 11432-11457.
61. Baccour, N., et al. *F-lqe: A fuzzy link quality estimator for wireless sensor networks*. in *Wireless Sensor Networks: 7th European Conference, EWSN 2010, Coimbra, Portugal, February 17-19, 2010. Proceedings 7*. 2010. Springer.
62. Issariyakul, T., et al., *Introduction to network simulator 2 (NS2)*. 2009: Springer.
63. Karthikeyan, T., V. Brindha, and P. Manimegalai, *Investigation on maximizing packet delivery rate in WSN using cluster approach.* Wireless Personal Communications, 2018. **103**(4): p. 3025-3039.
64. Chen, H., *End-to-end delay analysis and measurements in wireless sensor networks*. 2012.
65. Khan, W.Z., N. Saad, and M.Y. Aalsalem. *An overview of evaluation metrics for routing protocols in wireless sensor networks*. in *2012 4th international conference on intelligent and advanced systems (ICIAS2012)*. 2012. IEEE.