Energy Efficient Routing Approach based on Volunteer Participation and Adaptive Ranking of Forwarder nodes in WSNs

A thesis submitted to the

University of Petroleum and Energy Studies

for the award of

Doctor of Philosophy

in

Computer Science and Engineering

By

Premkumar Chithaluru

AUGUST 2020

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Declaration

I declare that the thesis entitled **"Energy Efficient Routing Approach based on Volunteer Participation and Adaptive Ranking of Forwarder nodes in WSNs"** has been prepared by me under the guidance of Dr. Rajeev Tiwari, Sr.Associate Professor at School of Computer Science, University of Petroleum & Energy Studies and Dr. kamal kumar, Assistant Professor at Computer Science and Engineering, NIT Uttrakhand, Srinagar. No part of this thesis has formed the basis for the award of any degree or fellowship previously.

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ABSTRACT

Wireless Sensor Networks (WSNs) are popular and used in remote applications to share the data packets among Sensor Nodes (SNs). The clustered wireless networks **are** very famous for increasing digitization. The world merged with small-sized sensors for sending and receiving data packets through their wireless network. Based on remote applications, sensors fetched the data from any time, any place for searching data packets and processing queries. SN deployment is not that easy to the node that may range from underwater to mountain from desert to dense forests, and the sensor is complex to set up the infrastructure for communication. With wireless sensors that can receive, send, and process data packets, commands, and queries. Primarily, sensors useful for surveillance and monitoring activities. Sensor network challenges like best usage of energy in sensors, optimal Forwarder Node (FN) selection during packet sending/receiving, and enhancements in network lifetime. In wireless networks, FN needs to explore for a better solution. In this thesis, we tried to **extend** lifetime using adaptive ranking technique and optimal FN selection.

Due to issues related to energy and controlling of sensors (listening nodes), dense networks, cluster-based routing, and energy-efficient techniques are gaining popularity. In this thesis, an Adaptive Ranking based Energy-efficient Opportunistic Routing (AREOR) protocol is proposed. The AREOR protocol **uses** the adaptive ranking technique to select an optimistic and effective Cluster Head (CH). The adaptive ranking technique proposes an enhanced selection of forwarders based on the least distance from Source Node (N_s) and threshold energy. The remaining energy and their distance are used for computing ranks for SNs. Simulation analysis is performed on the proposed scheme and is compared with competing for traditional protocols like Low Energy Adaptive Clustering Hierarchy

(LEACH), Ad Hoc On-Demand Distance Vector (AODV), Ant Colony Optimization (ACO), Improvised Ant Colony Routing (IACR), and Efficient Minimum Cost Bandwidth Constrained Routing (EMCBR). The proposed technique has offered improvements in parameters like Energy Consumption (EC), jitter, Message Success Rate (MSR), Packet Loss Ratio (PLR), Packet Delivery Ratio (PDR), and End-to-End delay (E^2 delay) to determine the efficiency of the network. The proposed protocol results prove that less EC, more packets have been transferred to the Base Station (BS) during the simulation. The proposed scheme has offered an improvement of 0.078 in MSR, 0.115 in PDR, 0.163 in EC, and 0.631 in E^2 delay.

Keywords- opportunistic routing (OR), adaptive ranking, cluster head, wireless sensor network (WSN), lifetime, forwarder node, energy efficiency, energy optimization, energy-efficient protocol, node ranking.

Acknowledgements

Thanks to my internal supervisor Dr. Rajeev Tiwari for guiding me well sincerely throughout my journey in the research work, right from the selection of the titles to analyze, integrate my works, and find the results. His enormous knowledge, motivation, and patience were there every time in this journey. His words gave me more power and the zeal to excel in my research writing. Contributing most of my time in such a difficult domain could not be as simple as he made this for me. He is my well-wisher and a healthy mentor for my doctorate study beyond my expectation.

Apart from my internal supervisor, I won't forget to express my external co-supervisor's gratitude, Dr.Kamal Kumar, for the generous encouragement and sharing of his intuitive suggestions. He played a major role in achieving my research writing skills. His endless guidance is hard to forget in my journey and throughout my life. I am pleased to thank him, who made my research simple and allowed inspiration from his experiences. It would not be possible to complete this research without his pleasurable support.

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Premkumar Chithaluru

Table of Contents

List of Abbreviations

WSN - Wireless Sensor Network.

QoS - Quality of Service.

SN - Sensor Node.

N_s - Source Node.

BS - Base Station.

CH - Cluster Head.

PDR - Packet Delivery Ratio.

TCP/IP - Transmission Control Protocol/Internet Protocol.

CPS - Cyber-Physical Systems.

EC - Energy Consumption.

IoT - Internet of things.

MEMS - Micro-Electro-Mechanical System.

SPIN - Sensor Protocols for Information via Negotiation.

DD - Directed Diffusion.

GPSR - Greedy Perimeter Stateless Routing.

TBF - Trajectory Based Forwarding.

EAR - Energy-Aware Routing.

GBR - Gradient-Based Routing.

SAR - Sequential Assignment Routing.

MN - Member Node.

ON - Ordinary Node.

E^2 delay - End-to-End delay.

GPS - Global Positioning System.

EMCBR - Efficient Minimum Cost Bandwidth Constrained Routing in WSN.

AODV - Ad Hoc On-Demand Distance Vector.

DSDV - Destination Sequenced Distance Vector.

DSR - Dynamic Source Routing.

LEACH - Low Energy Adaptive Clustering Hierarchy.

TEEN - Threshold sensitive Energy Efficient Sensor Network.

PEGASIS - Power Efficient Gathering in Sensor Information Systems.

ACO - Ant Colony Optimization.

IACR - Improvised Ant Colony Routing.

GEAR - Geographical Energy Aware Routing.

GPSR- Greedy Perimeter Stateless Routing.

OLSR - Optimized Link State Routing.

MSR - Message Success Rate.

RREP - Route Reply.

RTS - Request To Send.

RREQ - Route Request.

FN - Forwarder Node.

PLR - Packet Loss Ratio.

AREOR - Adaptive Ranking based Energy efficient Opportunistic Routing scheme in WSN.

NN - Neighboring Node.

FND - First Node Dies.

LND - Last Node Dies.

TND - Tenth Node Dies.

RERR - Routing ERror Request.

ERR - Energy Residual Ratio.

WCOT - Weighted Cumulative Operational Time.

NS - Network Simulator.

IEEE - Institute of Electrical and Electronics Engineers.

MAC - Medium Access Control.

GIS - Geo-Informatics System.

ITS - Intelligent Transport System.

CM - Cluster Member.

CLT - Central Limit Theorem.

DF - Distribution Factor.

CI - Confidence Interval.

EAR - Energy Aware Routing.

WWW - World Wide Web.

TCL - Tool Command Language.

UDP - User Datagram Protocol.

ORP - Opportunistic Routing Protocol.

RR - Rumor Routing.

ACQUIRE - ACtive QUery forwarding In sensoR nEtworks.

HEED - Hybrid Energy-Efficient Distributed.

APTEEN - Adaptive Threshold-sensitive Energy Efficient Network.

TTDD - Two-Tier Data Dissemination.

DUC - Distributed Uniform Clustering.

GAF - Geographic Adaptive Fidelity.

MECN - Minimum Energy Communication Network.

SMECN - Small Minimum Energy Communication Network.

CTS - Clear To Send.

GeRaF - Geographic Random Forwarding .

TBF - Trajectory-Based Forwarding.

BVGF - Bounded Voronoi Greedy Forwarding.

SPEED/SGNF - Stateless Geographic Non-deterministic Forwarding.

SAR - Sequential Assignment Routing.

ABC - Artificial Bee Colony.

MST - Minimum Spanning Tree.

RFPT - Routing by using an FPT-approximation.

LBCP - Load-Balanced Clustering Problem.

FPT - Fixed-Parameter Tractable.

FBECS - Fuzzy Based Enhanced Cluster Head selection.

FL - Fuzzy Logic.

TDMA - Time Divison Multiple Access.

VANETs - Vehicular Ad-hoc Networks.

COUGAR - Cornell University Gadget Archive.

GPS - Global Positioning System.

OFNS - Opportunistic FN Selection.

RoI - Region of Interest.

TC - Topology Control.

CI - Confidance Intervel.

ISM - Industrial, Scientific, and Medical.

BCSA - Balanced Cost CH Selection Algorithm.

List of Figures

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Journals

[1]. Chithaluru, Premkumar, Rajeev Tiwari, and Kamal Kumar. "AREOR-Adaptive ranking based energy efficient opportunistic routing scheme in Wireless Sensor Network." Computer Networks 162 (2019): 106863. (SCI), (Published).

[2]. Chithaluru Premkumar, Rajeev Tiwari, and Kamal Kumar. "Performance Analysis of Energy Efficient Opportunistic Routing Protocols in Wireless Sensor Network." International Journal of Sensors, Wireless Communications and Control, 9(4) (2019) 1-20. (SCOPUS), (Published).

[3]. Chithaluru, Premkumar, Rajeev Tiwari, and Kamal Kumar. "AR-IOR Adaptive Ranking based Improved Opportunistic Routing in Wireless Sensor Networks." Wireless Personal Communications. 116, (2021), 153-176. (SCI), (Published)

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[1]. Chithaluru Premkumar, Rajeev Tiwari, and Kamal Kumar, "Performance analysis of jitter and packet loss ratio for routing protocols in wireless sensor networks." ICACCA- 2019, IEEE. (SCOPUS).

Chapter 1

Introduction

Massive growth in wireless communication in the last few decades has developed various transmission and routing techniques. It observed that a **major** shift in wired communication to wireless communication. This drastic change results in the evolution of wireless networks, which brought an impressive research scope in the domain of controlled communication sensors. These sensors form a wireless network in which the interaction among the sensors depends on the remote application with different types of sensing like pressure and temperature. A combination of all these SNs forms a WSN. In every wireless network, SNs are used for acquiring accurate data packets from their remote locations [3]. Early generations of sensors imposed various limitations on communication and processing capabilities. Wireless communication networks have caused more demand for high connectivity and Quality of Service (QoS) than implemented for remote applications [1].

Increasing of integrated applications, which are related to multi- dimensional routing requires a change in sensor operations in the existing communication networks. Many traditional protocols used in transmission are very low adaptive for the dynamic environments, which restricts the practicality compared to wired protocols in the network [4]. Dynamic environments like temperature, sound, pollution levels, humidity, and wind cause conflicts and disorders, leading to data losses associated with selected relay nodes of wireless sensor networks. Every node acts as a relay node, which implies that nodes stay active and continuously lose energy. It directly affects the reliability of the sensors. Therefore, that impacts on network lifetime [5].

In WSN, energy-efficient and cluster-based schemes are trending opportunistic routing schemes [6]. Opportunistic routing can better the network lifetime, control & network overheads, packet loss in non-autonomous and autonomous routing schemes.

1.1 WSNs: An Overview

The network area is deployed with SNs and to form large clusters in each remote application. The heart of the wireless network is SNs, and it shares the information with its CH. In the wireless routing, the CH is used for collecting the packets from SNs and sending it to the BS [7] shown in Figure 1.1. The BS acts as an efficient data processor, and the storage center of the network [8]. The sensor routing is different from the Internet Protocol (IP) based network. Moreover, the data packets received from SNs, outcomes in the transferring and accepting the redundant packets from the neighbors in the wireless network.

Researchers have developed a new routing technique for wireless networks that differ from the internet protocol suite endorsed in the Transmission Control Protocol/Internet Protocol (TCP/IP) architecture. This technique is suited for neither storage, nor EC [9]. In terms of data processing, communication should be unallied with application concerned with an effective clustered routing technique with some metrics of WSN [10].

By considering the wireless applications, various aspects of routing are

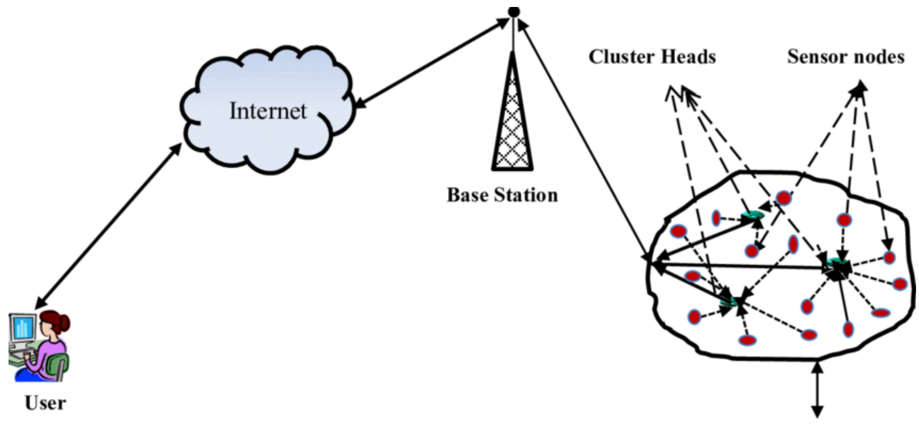


Figure 1.1: Standard topology of WSN [1]

the major problems and need motivation. First, the routing setup covers a large area, and the SNs are distributed randomly over the network area. It impacts minor challenges, such as data transmission gets faded over a large area and a chance of channel variability in the network [11]. Second, the batteries inside the SNs have a fixed lifetime, and batteries cannot replace them manually. Due to multi-hop communication, SNs lose more energy for forwarding other data packets. These two aspects of sensor networks increase EC. During communication, the data between SNs and BS, neighbor nodes awake to participate in transmission. Thus, it results in high-EC [12]. Additionally, it loses data of a N_s that shows in EC. There is no efficient infrastructure, routing, and a proper monitoring mechanism for analyzing the energy usage level at each SN and handling the issues of WSN [13].

In recent times, wireless networks become the strength for many latest trending technologies like Internet of Things (IoT), machine learning, cloud [14], and Cyber-Physical System (CPS) [15]. While considering the performance evaluation parameters such as bit rates, PLR, and jitter, all these parameters are challenges to wireless communications [16]. Sensor networks used in many applications lead to challenges such as security, heterogeneity of the network architecture, availability of bandwidth, processing, and communication of packets [13, 17].

1.2 Characteristics of WSN

Wireless networks are used to automate physical, mechanical, and electromechanical components of the industry and smart homes. The important characteristics of a wireless network are listed below.

1. Dense deployment and communication of sensors: Wireless networks are communication networks and required to deploy in either sparse or dense. Few sensors act as forwarders and others as relay nodes. It brings the effective communication of wireless networks. In a wireless network, sensors act as neighbors (next hop), and the highest energy node is considered a CH. In each cluster round, CH receives the packets from their neighbors and makes an effective routing for the data communication.

2. Routing topology changes every time due to fading and SN failures: SNs use the battery for data transmission or sensing the data packets. If the node battery completes, the topology gets changed, resulting in a new activity inside the WSN.

3. Self-organizing capabilities: The SNs must organize themselves in the network infrastructure due to the lack of a central authentication, and that makes the SNs perform routing for the receiving and transmission of the data packets.

4. The challenges in energy resources: SNs face many limitations in the data transmissions such as EC, control, and network overheads. Most of the researchers are focused on energy reduction of SNs and trying to prolong the lifetime of WSN.

1.3 Applications of WSNs

Most of the wireless networks are used for remote applications, in which sensors are a major priority in sensing and tracking; the well-known remote applications of sensor networks listed in Figure 1.2.

Wireless networks maximize social safety by connecting the complex urban areas with high-reliability networks. It uses to control infrastructures such as bridges and tunnels, and network cables. Even some remote places require long term observation that can replace with attaching a sensor. This maintenance-free sensor collects the data packets across a network area. Some of the remote applications discussed as follows,

1. Military applications: The security and safety of troops is an important aspect in military occupied zones. There are instances like surveillance and monitoring of border areas, important defense installations, ammunition depots, and even troops' movement during relocation where wireless networks play an important role without compromising the quality.

2. Environment applications: It includes monitoring of surroundings like flood detection, volcanic monitoring, and landslide detection.

3. Industrial based application: Includes inventory monitoring for decision makings, factory monitoring, structural monitoring, and human tracking in buildings.

4. Health applications: This includes patient monitoring, vital parameters monitoring, and remote monitoring of physiological data.

5. Home applications: Monitoring of smart homes, instrumentation monitoring, automated meter readings.

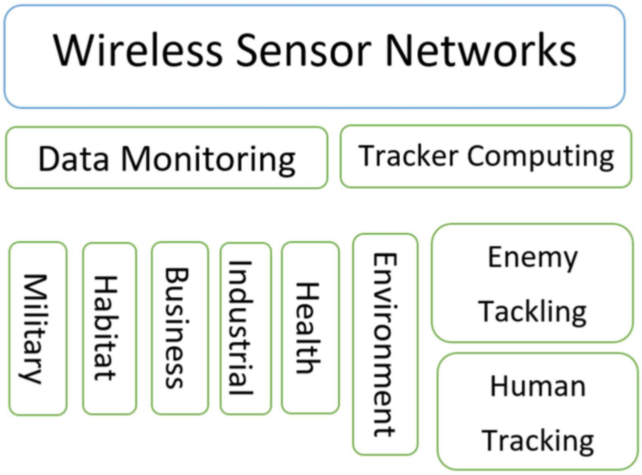


Figure 1.2: Applications of WSN

1.4 Challenges of WSNs

WSNs have some challenges and limitations as opposed to sharing many similarities with other distributed networks. These constraints affect the sensor network design, and it reflects on the working of protocols and algorithms differing from other distributed networks. The most important challenges of a wireless network discussed below.

1. Node deployment: If the nodes are deployed manually, SNs have to follow the pre-programmed routing protocol. Suppose any of the nodes get fall due to random deployment or less energy. In that case, the nodes dynamically arrange themselves and change their topology, resulting in packet loss or inefficiency during communication.

2. EC: The major challenge of sensor networks is reducing energy usage at each SN, and remote sensors designed for limited energy, and sensors cannot change batteries manually every time.

3. Nature of sensor: Sensors are either homogeneous or heterogeneous based on requirements. Heterogeneity specified in terms of the difference in transmission range, processing power, energy storage, Global Positioning System (GPS) enabled mobility and other aspects.

4. Data Aggregation: Sensor networks programmed for the collection of different physical data through sensors. Every wireless network operates with a routing protocol to minimize packet loss during transmission and controls energy usage. Therefore, integrated sensors need to fetch the data packets using an optimistic protocol.

5. Multi-hop routing technique: This technique is used in data packet sending over a large area, in which the intermediate nodes are used as relays. SN consumes power on trans-receiver operations.

6. Network Lifetime: For transmission of data, sensors should use effectively and efficiently with limited energy resources, which impacts on increasing the network lifetime, and wireless networks considered energy efficiency is a major challenge to increase the lifetime.

1.5 Motivation of research

The above-discussed issues motivate this research to provide a solution to have a scale of network communication with maximum efficiency and minimum EC. Some of the major points to be considered mainly for this research highlighted below:

1. Overheard messages can be imbibed (absorb) into the mainstream transmission and can save a sufficient number of re-transmissions.

2. Adaptive ranking of forwarding nodes can dynamically prioritize the forwarders for reliable communication.

3. Combining these findings can help in providing an enhanced routing protocol for WSNs.

1.6 Objectives of thesis

After the review of traditional protocols in sensor networks, we came across a few challenges in WSNs. In non-autonomous protocols, all the nodes use hop-by-hop communication and frequently use flooding. Since the deployment of sensors is random, we must deploy a network that uses fewer sensors distributed over a large area with BS to collect the data packets. All sensors must effectively work and collaborate among themselves for the assigned task. By considering the power supply of the sensors and capacities of data storage, sensor networks required that solutions designed for these sensors can cope with the limited resources and still provide efficient solutions. In WSN, the routing protocols must have the capacity to route data efficiently and ensure a minimum EC on the selected path. In other words, our research identifies the most important goals that achieve the routing solution of WSNs. In brief, the objective of the thesis as follows:

- Energy-efficient routing approach based on volunteer participation and adaptive ranking of forwarder nodes in WSNs.

  Sub-objectives are specified below,

  1. To propose an adaptive ranking mechanism to rank forwarder nodes.
  2. To propose an opportunistic forwarding scheme to be used by overhearing forwarder nodes participation in WSNs combining the proposed ranking scheme.
  3. To verify and validate the proposals using a simulation-based study.

1.7 Contributions of thesis

The present research work is focused on the "Adaptive Ranking based Energy-efficient Opportunistic Routing Scheme in WSN," and its major contributions are summarised below.

I Proposed an empirical formula for a ranking algorithm that considers past (or history of) relay behavior of nodes.

II Proposed an adaptive ranking approach that quantifies the length of history to be considered, based on clusters, SNs, distance, residual energy, etc.

III Proposed an opportunistic forwarding scheme that ensures participation of hearing neighboring nodes as volunteer FNs.

IV Combined the proposals I, II, and III to devise an energy-efficient routing mechanism for WSNs.

1.8 Organization of thesis

The thesis is discussed in six chapters; it includes the introduction chapter.

Chapter 2 presented the review of traditional routing protocols of WSN and primarily identifies the gaps in the node selection scheme and routing schemes of WSNs. Identified gaps have been taken as opportunities for doing this research work.

In Chapter 3 presented the opportunistic routing schemes based upon adaptive ranking and forwarder node selection. We presented two algorithm schemes for a wireless network, the first algorithm ensures ranks for sensors, and the second algorithm is forwarder node selection for optimal energy strategy. Both algorithms are effective & efficient to extend the lifetime.

Chapter 4 presents to enhance the network lifetime based on MSR, PDR, EC, E^2 delay, jitter, PLR, and stability period.

In Chapter 5 presents the statistical validation of proposed and traditional routing protocols in WSN.

Finally, chapter 6 summarizes the thesis contributions and identifies the future scope of work, and at last research contribution of this work is also provided.

1.9 Summary

This research addresses the major concerns involved in wireless networks like energy usage and network lifetime. There is a need to address the energy concerns in WSNs. The proposed protocol is much effective in terms of reducing energy usage during transmission. In the next chapter, we discussed the latest traditional routing protocols in WSN.

Chapter 2

Literature Review

A WSN is a communication medium for uniformly or randomly distributed SNs equipped in a small network area. The FNs collect the sensed packets from N_s and forward them to BS. These small SNs operate proactively or reactively. The design of wireless networks conceived from surveillance requirements in battlefields, volcanic zones, traffic congestion prone areas, unattended self-organization, and flexibility driven applications. In each remote application, wireless networks involved in the day-to-day monitoring of smart homes, hospitals, precision agriculture, deep-sea explorations, seismic activity monitoring, unattended baby care [18].

WSNs are different from mesh networks, and mobile ad-hoc networks in terms of scalability and density [19], as the number of SNs that setup is huge and highly dense. In wireless networks, SNs are connected to one or more neighbors randomly and flexibility in connections. The topology of the sensor networks may follow a star or multi-hop communication during the transmission of packets. The available communication bands ZigBee - Industrial, Scientific, and Medical (ISM) and bandwidth are between 900 MHz to 60 GHz. In wireless networks, SN uses the communication medium, which is Wi-Fi radiofrequency. The wireless network routing allows either broadcasting or flooding in nature [20, 21].

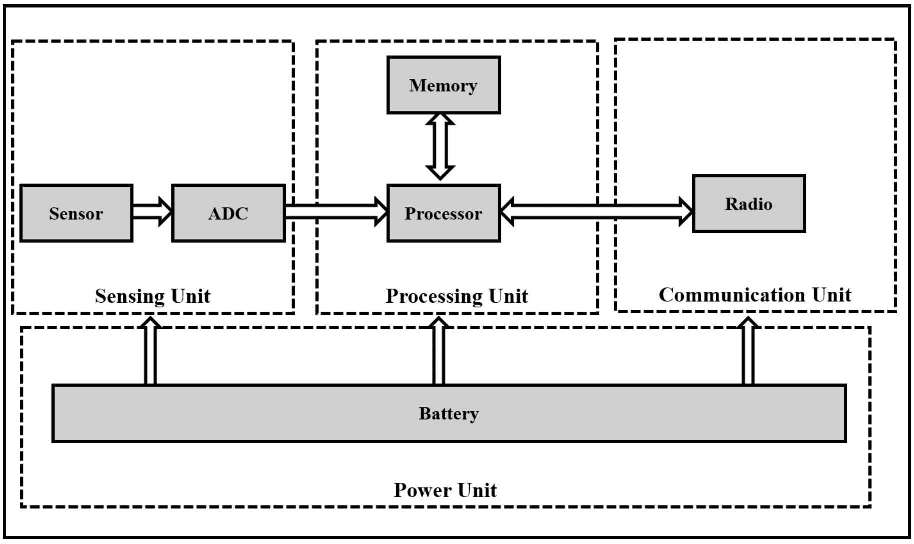


Figure 2.1: Typical SNs components [2]

Wireless networks can perform communication, sensing, and computing [22–24] and use for remote applications like infrastructure, army surveillance monitoring [25]. A multi-hop sensor network comprises a huge numbered battery-powered SN responsible for sensing the packets and sending them to the BS at regular intervals. Because of the constraints of energy resources and battery-powered SNs increase, the network lifetime becomes crucial [26]. As there is an exponential increase in energy utilization for communication distance between nodes based on the EC model [27].

Apart, as the closer SNs to the BS is liable for transferring the data packets from other SNs, their energy gets exhausted soon, which shows the effects on energy loss in the network. Thus, the entire network may result in premature death due to its separation from the network area. Various existing works motivated to reduce the energy usage of SN and extend the lifetime. The focus of researchers [28,29] improve network performance and optimize the First Node Dies (FND). Chen et al. [27] considered an energy model for balancing the SNs load during communication and improvements of FND in dense networks. The design of routing models and how to increase network lifetime described in [30]. As unbalanced energy utilization limits the network lifetime, the AREOR algorithm is used to balance the data traffic of sensor networks and prolong the FND. AREOR has proved that the clustering method improves the lifetime of the network [31], especially in the case of scalability and energy consumption. Most of the researchers are using cluster-based routing protocols. Lee et al. [31] introduced a spatial correlation method to examine the results of FND in multi-hop and mesh networks. Liu et al. [32] considered a routing protocol for improving FND depends on different cluster ranges.

Although many of the existing-works can effectively estimate FND, the period between FND and the instance when SNs are dead or the network dying is a time taking process [33]. A few dead nodes may not lead to failure of a network in most of the remote applications, but a dead node can harm the network performances [32–34]. Hence, this period cannot neglect the entire lifetime. Analyzing the enhancement of the network is unstable after the death of a few SNs. After the node's death, the remaining SNs should carry the packets not in an effective manner. Thus, analyzing the performance of network lifetime after FND is crucial.

This chapter presents an architectural view of an SN in Section 2.1. Section 2.2 briefly introduces applications and recognizes the significance of routing in WSN. Section 2.3 provides a review of traditional protocols in WSN [1]. Section 2.4 presents a review of non-autonomous (energy-inefficient) routing protocols in wireless networks. Section 2.5 presents a review of autonomous (energy-efficient) routing protocols in WSNs. A review of autonomous (energy-aware) routing protocols presented in Section 2.6. Section 2.7 presents an analysis review of traditional protocols. Fi-

[1] The major findings of this chapter have been published

- "Performance Analysis of Energy Efficient Opportunistic Routing Protocols in Wireless Sensor Network," International Journal of Sensors, Wireless Communications and Control, Vol. 9, No. 4, PP. 1-20, 2019. (SCOPUS) nally, the chapter summary is discussed in Section 2.8.

2.1 Architectural view of SN

Every SN supports the infrastructure for local sensing, reception, and small distance transmission. The generic SN is embedded with a radio transceiver circuit attached to an internal antenna and provision to connect to an external antenna. A microcontroller chip is an integrated electronic circuit to interconnect SNs shown in Figure 2.1. In WSN, SNs are the capability of small scale energy harvesting from surroundings. The SNs sizes may vary from tablet to the size of wheat grain. The cost of sensors depends upon the infrastructures available for communication. In a wireless network, SNs are sensing as per the resources and type of the application. Every SN has limitations of energy, storage, processing speed, and available bandwidth for communication.

2.2 Importance of routing in WSN

Because of the advances and demand in Micro-Electro-Mechanical System (MEMS) technology, remote applications used for industrial, home automation, habitat monitoring, IoT, agriculture, and soil [2,18]. Hence, a connection has been established between human society, the physical world, and the computing world. Generally, a wireless network includes many tiny SNs scattered over a vast region, and finally, data packets are transferred to BS. Every SNs has a limited power supply and can wireless communication, sensing, packets transferring, and receiving. In a wireless network, clusters are divided as per the need for a remote application. In each cluster, aggregating data from the source required a leader known as CH and next-hop neighbors and forwarders. The wireless network organizes the

CHs into different hierarchical levels as well. Generally, the SN with the highest remaining energy opted as CH is responsible for performing the data packets processing, aggregating, and transmission to BS.

The routing is the most important role in WSNs. Compared to traditional multi-hop networks and mesh network routing, it is more difficult because of their inherent characteristics [20,35]. At first, there are constraints on resources like transmission bandwidth, power supply, and processing capability. Furthermore, designing a scheme of IP becomes challenging. Secondly, IP cannot apply to wireless networks, as updating the address in a large-scale or dynamic sensor network may cause heavy overhead. Thirdly, constrained resources make it difficult for routing to deal with uncertain and frequent routing changes due to dead nodes in the case of a dynamic environment. Fourthly, increasing the probability of data packet processing from various SNs depends on their routing protocol. Apart from these challenges, sensor network applications mostly depend on many-to-one communication like many SNs and one BS, instead of peer-to-peer or multi-cast. At last, time-constrained applications of wireless sensors require data transmissions within a transmission time. Hence, bounded latency needs to consider to transmit data in such applications. However, energy conservation is more crucial than QoS in most of the applications in which all N_s's have energy limitations that extend the network lifetime.

2.3 Classification of traditional routing schemes

Wireless networks are data-centric networks and require queries that must target an area in the deployment or data with specific attribute values.

Table 2.1: Classification of routing schemes in sensor networks

Sr. No.	SUPER-CLASS	SUB-CLASS	MEMBERS
1	Non-Autonomous	Energy in-efficient	A. Perrig et al. [59] (SPINs) Y. Yao and J. Gehrke [62] (COUGAR) Nayyar et al. [36] (EMCBR)
			C. Intanagonwiwat et al. [60] (DD) D. Braginsky and D. Estrin [61] (RR) Saleem et al. [37] (AODV)
			Chandra et al. [38] Perkins et al. [39] Tripathi et al. [40] (DSDV)
			Varshey et al. [41] Sarao et al. [42] (DSR)
2	Autonomous	Energy efficient	Ossama Younis and Sonia Fahmy [67] (HEED) A. Manjeshwar and D. P. Agarwal [31] (APTEEN) Gill et al. [43] (LEACH)
			W.R. Heinzelman et al. [73] J. N. Al-Karaki et al. [74] J. N. Al-Karaki et al. [75] Manjeshwar et al. [44] (TEEN)
			F. Ye et al. [70] (TTDD) R. N. Enam et al. [71] H. L. Chen et al. [72] H. Lee et al. [111] Guo wenjing et al. [45] (PEGASIS)
		Energy Aware	Y. Xu et al. [79] (GAF) L. Li and J. Y. Halpern [80] (MECN) Rajeshwar et al. [46] (ACO)
			V. Rodoplu and T. H. Meng [81] (SMECN) Adam murtak et al. [47] (IACR)
			Zorzi and Rao [82] (GeRaF) B. Nath and D. Niculescu [83] (TBF) Alanwafa et al. [48] (GEAR)
			G. Xing et al. [84] (BVGF) Dehghani et al. [49] Al-Mahdi et al. [50] (GPSR)
			Guo Zhao et al. [51] (OLSR)
3	Routing Strategy Driven Routing Schemes	Multi-path Routing Protocols	C. Intanagonwiwat et al. [85] (DD) X. Mao et al. [86] (ORP)
		Query Driven Routing	C. Intanagonwiwat et al. [85] (DD) D. Braginsky and D. Estrin [62] (RR)
		Negotiation BasedRouting Protocols	A. Perrig et al. [59] (SPINs)
		QoS Based Routing	T. He et al. [87] (SPEED) I. F. Akyildiz et al. [88] (SAR) K. Akkaya and M. Younis [89]
4	Opportunistic Routing Schemes	Recent Opportunistic Routing Schemes	Devi V Seedha et al. [90] Baradaran Amir Abbas et al. [91] Yarinezhad R et al. [92] Mehra PS et al. [93]

Most of the routing schemes proposed in wireless networks; either consider large databases or digital monitoring and surveillance. Considering limited transmission capabilities and the identification of the FN is challenging in WSN. In a wireless network, most of the traditional routing protocols follow the simple flooding technique to transmit the packets to BS. Based on SN roles and deployment models' different views, the wireless network routing is classified into flat, hierarchical, and location-based. Each of these routings based on the structure of network-driven. Few routing schemes may be categorized based on the QoS parameters. These protocols consider different routing techniques based on the network type. The discussion on traditional routing protocols under a new taxonomy allows us to discuss the routing protocols into the following categories, as displayed in Table 2.1.

Classification of traditional routing scheme

1. Non-autonomous routing schemes
    - Energy in-efficient schemes
2. Autonomous routing schemes
    - Energy-efficient schemes
    - Energy-aware schemes
3. Routing strategy-driven routing schemes
    - Multi-path oriented routing schemes
    - Query-driven routing schemes
    - Negotiation and metadata-driven routing schemes
    - QoS driven routing schemes
4. Recent opportunistic routing schemes

In a non-autonomous routing, every SN is responsible for performing the same tasks and the same network functionalities. The process of transmission data is sending hop-by-hop with the help of flooding. Examples of non-autonomous routing protocols are Sequential Assignment Routing (SAR) [52], Flooding and Gossiping [21], Energy-Aware Routing (EAR) [53], Sensor Protocols for Information via Negotiation (SPIN) [54], Rumor Routing (RR) [55], Directed Diffusion (DD) [56], Greedy Perimeter Stateless Routing (GPSR) [57], Trajectory Based Forwarding (TBF) [58], Gradient-Based Routing (GBR) [59], etc. In sparse networks, non-autonomous routing protocols are somewhat useful. But, because of the resource limitations, it is comparatively not desirable in large-scale (dense) networks. However, every SN leads to more data processing and bandwidth usage. In an autonomous routing, SNs are responsible for performing various tasks in wireless networks described in the coming sub-sections.

The most popular non-autonomous (energy in-efficient) routings protocols in WSNs are EMCBR [36, 38, 60], AODV [37, 50, 61], Destination Sequenced Distance Vector (DSDV) [40], and Dynamic Source Routing (DSR) [41, 42], autonomous (energy efficient) routings protocols like LEACH [43, 62], Threshold sensitive Energy Efficient sensor Network (TEEN) [44, 63, 64], and Power Efficient Gathering in Sensor Information Systems (PEGASIS) [45,65,66], and autonomous (energy-aware) protocols are ACO [46,67], IACR [47, 68], Geographical Energy-Aware Routing (GEAR) [48, 69, 70], GPSR [49, 71, 72], and Optimized Link State Routing (OLSR) [39, 51] explained clearly in the literature review. In autonomous routing, some advantages like more robustness, less load, packets aggregation, reduce the energy usage to emerge in effective clustered based routing technique in wireless networks.

The past few years, we have seen the working and development of traditional routing protocols in WSNs. The following sections described the most important clustering routing algorithms in WSNs.

A taxonomy is structured and described for traditional routing protocols in sensor networks. In this thesis, traditional routing protocols are classified as non-autonomous and autonomous in the context of SNs participation, and nature is either proactive or reactive [73]. Essentially, proactive protocols enable continuously acquiring the routing information present in the Routing Table (R_t). Such R_t's are distinct from one another depends on the packets information send across SNs in the network. The non-autonomous routing protocols are generally helpful in detecting and updating the routes. In sensor networks, routing uses two types of updates, namely regular updates and triggered updates. More traffic is produced because of the continuous updating of the R_t. Along with it, autonomous routing protocols also use the R_t as per the need of topology. A route search need for each forwarder in the network. Thus, control overhead decreased the delay in transmitting the packets to BS. An SN identifies the next forwarder with the help of distinct network parameters. It makes use of flooding for determining the destination route. The transmission path discovery for SNs is Route Request (RREQ) and a Route Reply (RREP) from the BS.

Network type determines the functionality of different SNs within the cluster, sending packets to BS. A 1-dimensional and 2-dimensional scheme used in energy in-efficient protocols. The angle-based scheme used in energy-aware protocols and energy-efficient routing [74]. However, communication paths and data packet transmission based on various routing protocols described in Figure 2.2.

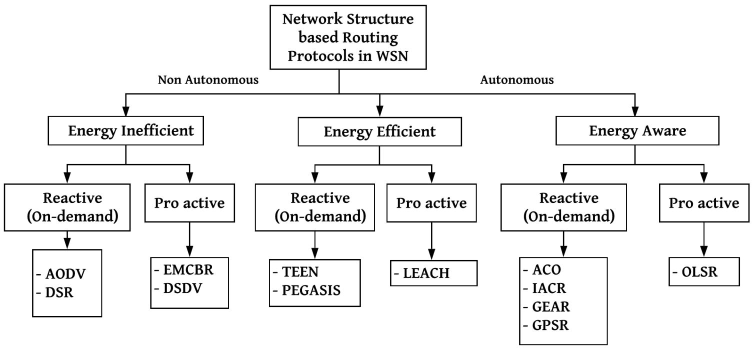


Figure 2.2: The enhanced taxonomy for traditional routing protocols in sensor network

2.4 Non-autonomous routing: Energy in-efficient routing protocols

The network overheads and control overhead are high in energy in-efficient routing protocols. This classification of routing protocols does not consider energy loss. The SN's routine function is to retrieve the packets every time but, wireless routing neither focusing on extending the lifetime nor minimizing the energy usage at each SN. In large and dense networks, identifying nodes may become unmanageable, so researchers are interested in data-centric routing [75]. Data-centric routing supports event-specific of all queries. The structure of queries depends upon the requirement, and design of networks [76]. Queries must spread from the N_s to the BS [77]. Here, we discussed the few energy in-efficient routing protocols.

Hendis et al. [60] proposed a protocol for determining an optimal route to transmitting data packets from source to BS while guarantee channel load not to surpass overall capacity. This protocol is useful in terms of scalability and efficiency for optimal routing in WSN [36]. In EMCBR, every visited node met with a backward ant for searching its memory for determining the next node where ant would send the packets [78, 79].

However, a few of the disadvantages of EMCBR are:

1. In EMCBR, by using the pheromone updating rule, few relay nodes are used for an ant to finishing its complete trip. As a result, the average transmission time and energy depletion are more.
2. The process of selecting a transmission path depends on the remaining energy and distance between hops, but it does not consider the energy dissipation during data transmission and data reception.
3. Energy holes near the BS may be resulted easily because of the traditional many-to-one transmission pattern effects on extending the network lifetime.

Mahmood et al. [50] proposed a reactive protocol to send a packets hop-by-hop, it allows a multi-hop routing, self-initiating, and dynamic node selection for transferring data from one SN to another [61]. AODV enables securing routes for the N_s and BS. The SN does not keep the path information while transmitting data packets to BS. AODV adapts the message flooding approach and recursive techniques to identify an optimal route that is efficient for communication. However, nodes need to be within the range of broadcast else packet transmission fails. Also, the protocol enables every node to transfer the packets to every next-hop SN [37].

In AODV, the route formation is based on on-demand and requirements. An SN does not have to store information about a route if they are not a part of it, and SNs are not responsible for transmitting or receiving topology-update, and thus nodes carry data through their live routes. An SN considers a live path to accepting transmission or advanced packets send to the BS. In AODV routing, a source with no valid route towards a BS wants to communicate and broadcast of finding packets called RREQ. It requires sending any change in network topology through RREP, only to the SNs that need the information. It causes the intense creation of entries in the R_t. A RERR is responsible for link failure notification in case of a link failure and link detection sent using HELLO message [80].

Chandra et al. [38] introduced an on-demand proactive route table-driven protocol. In DSDV, every SN is used for storing the next-hop SN address for sending the data packets without any loss. In DSDV, the R_t consists of the information of the neighbors [39, 40]. Additionally, the DSDV routing mechanism attains a large volume of control traffic in highly dynamic networks, like Vehicular Ad-hoc Networks (VANETs), that outcome is high depletion of energy. However, the DSDV mechanism wastage's bandwidth because of needless acknowledgments and needs memory for storing information of each SN in the R_t. Moreover, this protocol not supporting multi-hop routing.

Varshney et al. [41] considered a reactive protocol, enabling the paths for SNs to transfer data packets in ad-hoc networks. This protocol uses a request acknowledgment parameter for effective communication among the SNs. However, it leads to more consumption of energy due to inconsistency in organizing multi-hops. With the consideration of source routing, every data packet's header may reserve duplication of data for some duration [42].

A. Perrig et al. [81] used a reactive protocol for data collection using negotiations. This protocol allows us to send packets from any SN to BS due to meta-data negotiations. This protocol overcomes the redundancy of the data packet at each SN.

C. Intanagonwiwat et al. [82] described a clustering scheme known as DD. It is similar to SPIN. Queries are processed in the form of interest, the interest is flooded into the network, and gradients are set up towards the interest source. In this protocol, data may travel through multiple paths and requires in-network processing to remove redundancy; DD reports improvements in energy characteristics and network lifetime.

D. Braginsky and D. Estrin [83] suggested a RR is an extension of DD. To advertise events of interest, RR employs long-lived specialized packets. The performance of RR is better than the data-centric protocol. RR achieves a long network lifetime.

Y. Yao and J. Gehrke [84] proposed a routing scheme called Cornell University Gadget Archive (COUGAR) is to address the issue of identifying the CH. COUGAR imbibed in-network processing to overcome redundancy.

Sadagopan et al. [85] proposed a protocol ACtive QUery forwarding In sensoR nEtworks (ACQUIRE) extends the database query into sub-queries, and the query path tries to reply partially from its cached data and then sends the signal to a next-hop SN.

In Table 2.2 has shown the various characteristics of the non-autonomous (energy in-efficient) routing protocols and compiled the different parameters on energy in-efficient routing protocols shown in Table 2.3. Based on the literature, the energy-efficient routing protocols are EMCBR and AODV.

2.5 Autonomous routing

Autonomous routing protocols are self-organized for creating a temporary network in a free and dynamic manner without using any centralized operations or existing network infrastructure [86]. Based on a raised query [87], the data-driven protocols are responsible for working packets that is needed, and packets forwarded to the next forwarder for every hop, and a replica for future communications [88]. Thus, many redundant communications eradicated, and the number of transmissions reduced [89]. Here, autonomous routing classified as two types, energy-efficient and energy-aware, are discussed in the coming sub-sections.

Table 2.2: Different non-autonomous (energy in-efficient) routing protocols & their characteristics in WSNs

Energy In-efficient Routing Protocols		AODV	DSR	EMCBR	DSDV
characteristics of Cluster	Variation of cluster count	variable	variable	variable	fixed
	Size of Cluster	even	even	even	even
	Intra-cluster routing	multiple-hop	multiple-hop	multiple-hop	multiple-hop
	Inter-cluster routing	single-hop/ multiple-hop	single-hop/ multiple-hop	single-hop/ multiple-hop	single-hop/ multiple-hop
Characteristics of CH	Existence	yes	yes	yes	yes
	Device types	homogeneous	homogeneous	homogeneous	homogeneous
	Mobility	stationary	stationary	stationary	stationary
	Role	relay aggregation	relay aggregation	relay aggregation	relay aggregation
Process of Clustering	Control manners	distributed	distributed	distributed	distributed
	Nature of Execution	iterative	probabilistic	probabilistic	iterative
	Convergence of time	constant	constant	constant	constant
	Selection of CH	adaptive	adaptive	adaptive	adaptive
	Nature	reactive	reactive	proactive	proactive
	Why to do clustering?	load balancing	load balancing	load balancing	load balancing

Table 2.3: Comparison table of non-autonomous (energy in-efficient) protocols

Protocol	Type of routing	Routing overheads	Control overheads	E^2 delay	Route maintaining	Protocol type
EMCBR [36, 60]	Proactive	High	Controlled by the flooding of control Traffic (Lowest)	Wider delay distribution	R_t	Link State
AODV [37, 50, 61]	On-demand	Highest	Low	Performance decreases	R_t	Distance vector
DSDV [38–40]	Proactive	Higher	Lower than AODV	Better than AODV	R_t	Link State
DSR [41, 42]	On-demand	High	Lower	Better than DSDV	Routing Cache	Link State

2.5.1 Energy efficient routing protocols

Gill et al. [62] introduced a reactive protocol for dispensing load to a few SNs in the network. LEACH casually replaces the highest-energy node (CH) randomly; data packets are transmitting to the various SNs at a time due to that loss of their energy rapidly. This protocol uses information fusion to improving lifetime. The selection of CH is a critical and power-consuming process [43]. LEACH is an essential hierarchical clustering routing protocol that makes use of data fusion distributed clustering algorithm for CH rotation mechanism, and data aggregation effectively leads to improvement of network lifetime. The principle of proximity used for joining the corresponding CH node from the normal nodes, which are known as Cluster Members (CMs), and the packets sensed by N_s and transferred to the CH, then CH node aggregate the packets and sent to the BS [90].

LEACH protocol does not include each SN residual energy criteria while deciding CH node; because every SN has an equal probability of selecting CH. For suppose, a least-energy SN as CH leads to the early failure of the network because of high EC, which further improves energy balancing among the SNs in the WSN. Thus, data loss resulted and decreased network lifetime.

Imbalance of energy load caused due to the dynamic selection of CH. During cluster formation, distance is not considered due to network failure.

If the CH node is far from BS, it impacts more energy loss.

Yu duwei et al. and Ge yahong et al. [63] introduced a new clustering technique for time-critical applications, are using hard-threshold to define the highest energy SN sensed the packets every time and soft-threshold are using for data processing. TEEN [63] and Adaptive Threshold-sensitive Energy Efficient Network (APTEEN) [64] reduced the number of transmissions to BS [44]. The threshold-based approach prolongs network lifetime and adaptive periodicity. In APTEEN, energy dissipation reduced using threshold limits.

Guo wenjing et al. [65] introduced a position-based energy effective protocol based on LEACH. In this protocol, every relay node has data packets of N_s. Also, individually each SN can transfer packets to the BS directly [66]. PEGASIS accepts every node transmitting packets to BS and consumes a similar amount of energy [45]. As every node is stable and has global awareness, the chain can assemble effectively using a greedy procedure. In every round, an SN is chosen from each cluster to communicate accumulated information to the BS. In the first round, node 1 (mod N) is considered as CH. The sequence contains N_s, followed by a neighboring node on every hop, and finally formed a BS route. The CH directs the accumulated packets to the BS.

Ossama Younis et al. [91] proposed a protocol, was another extension to LEACH, for incorporating SNs energy and distance as decision metrics, as primary and secondary parameters for CH election and achieved equal energy usage. Hybrid Energy-Efficient Distributed (HEED) proposed an adjustable, adaptive transmission level and the long-distance inter-clustering communication. HEED overcomes the control overheads, uniform clusters in geography aspect, and short lifetime of LEACH. HEED improved the energy characteristics, and other evaluation parameters of WSNs [92].

F. Ye et al. [93] introduced a protocol in that stationary SNs are location-aware, and mobile BSs collect data from grids located in the deployment region. In each cluster grid, the SNs delivered data on behalf of grid members. Wireless applications required location awareness equipment on SNs, which is impractical for inexpensive SNs.

R. N. Enam et al. [94] proposed a Distributed Uniform Clustering (DUC) algorithm for WSNs. Instead of the location-dependent clustering approach, the virtual grid and SN transmission range considered. Another motivation suggested by the variability of size and number of packets in different clusters. In each cluster, CH decides as per proximity and distance. The overall distribution of the scheme is twice better, and EC improved by 50%.

H. L. Chen et al. [95] introduced an enhanced routing approach, in every round, comprises packets and reduces data delivery time. The setup phase identifies CHs for the current round. The first sub-phase identifies CHs in far regions using their residual energy. In the second sub-phase, the CH transfers the packets to BS. To reduce collision among contenders in the nearest cluster, the controller used an estimation setup and need to collect each SN's information. In the case of routing collision, the controller resolves the problem with broadcasting. Energy characteristics of the proposal show improvements over LEACH by 7% and network lifetime by 49%.

H. Lee et al. [96] considered a clustering algorithm to prolong the network lifetime and better allocation of CHs in each cluster round. Based on the MSR, identifies CHs and representative paths of BS in a centralized manner. A reliable multi-hop routing scheme is proposed and that supports inter and intra-cluster communication paradigms. Finally, this protocol performs 2% better than LEACH.

W.R. Heinzelman et al. [97] considered the remote application in which SNs required to monitor and track activities, a collection of methods proposed in [97].

J. N. Al-Karaki et al. [98] proposed a hierarchical routing technique, in that CH selection is optimal, utilizes for aggregation, and in-network processing for removing redundancy, both locally and globally. J. N. Al-Karaki et al. [99] introduced an efficient aggregation technique for CH. Both proposals improved the network lifetime and energy efficiency.

Table 2.4 shows the characteristics of autonomous (energy efficient) protocols used in WSN.

Table 2.5 shown the network metrics are used to characterize the protocols considered. The LEACH protocol seems to be having more routing overheads from the aspect of energy, which proposes a problem to energy efficiency.

2.5.2 Energy aware routing protocols

In energy-aware routing protocols, the management of SNs placed as per their geological positions. With the qualities of the incoming signal, the network can determine the position between neighboring SNs efficiently. The data is traded among neighbors to find the relative directions of neighboring SNs [100]. Determining the location of SNs is easily processed with GPS [101].

Dhiman et al. [67] proposed a strategy for optimum route discovery in multi-hop WSN, achieved through allotting a group of agents. The agents will work decentralized to collect the packets from the source and transfer them to an essential destination over a multi-hop manner. Though SNs have an energy supply, communication, storage space, and limitation in bandwidth optimize resources. The resultant may increase SN congestion in the network [46].

ACO [102] is a reactive routing protocol that operates with limited en-

Table 2.4: Different autonomous (energy efficient) routing protocols & their characteristics in WSNs

Energy Aware Routing Protocols		**LEACH**	**TEEN**	**PEGASIS**
Characteristics of Cluster	**Variability of cluster count**	variable	variable	variable
	Size of Cluster	even	even	even
	Intra-cluster routing	single-hop	multiple-hop	multiple-hop
	Inter-cluster routing	single-hop	multiple-hop	single-hop
Characteristics of CH	**Existence**	yes	yes	no
	Device types	homogeneous	homogeneous	NA
	Mobility	stationary	stationary	NA
	Role	relay aggregation	relay aggregation	NA
Process of Clustering	**Control manners**	distributed	distributed	distributed
	Execution nature	probabilistic	probabilistic	probabilistic
	Convergence time	constant	constant	constant
	Selection of CH	adaptive	adaptive	adaptive
	Nature	proactive	reactive	reactive
	Why to do clustering?	load balancing	reactive scenes lifetime extension	load balancing

ergy, delay, and the limitation of resources at the SNs. The problem is identifying communication paths from a source to the BS along with two metrics: The first metric is the value of delay is lesser compared to an

Table 2.5: Comparison table of autonomous (energy efficient) routing protocols

Protocol	Type of routing	Routing overheads	Control overheads	E^2 delay	Route maintaining	Protocol type
LEACH [43, 62]	Proactive	High	Relatively Low	Wider delay distribution	R_t	Link state
TEEN [44, 63, 64]	Reactive	Higher	Low	Performance decreases	R_t	Distance vector
PEGASIS [45, 65, 66]	Reactive	Highest	Low	Performance increases	R_t	Link state
AREOR [20]	Proactive	High	Low	Performance increases	R_t	Distance vector & remaining energy

abounding value D. The second metric is that value of the Energy Residual Ratio (ERR) = $E_{residual}/E_{initial}$, is greater than a particular threshold value [103]. A R_t checked for a suitable path for delivering data packets through a N_s or SN. If no suitable path is found in the R_t, ants find their communication path based on past transmission history; due to this, FND will early, and network life is no longer.

The drawbacks of ACO related to FND is as follows:

1. ACO protocol is not efficient in searching for a delay-constrained path in terms of energy, as the forward ants have to store the routing information, which leads to huge depletion of energy.
2. The energy loss is not considered during packet transmission and reception.
3. In dense networks, the ants' whole trip causes a huge delay due to uni-casting.

Adam murtak et al. [68] proposed a reactive protocol, which is an enhancement of the ACO protocol. The primary benefit of IACR has considered the usage of energy at each SN includes a quality parameter of WSN. This protocol overcomes various challenges like congestion, energy efficiency, computation of SNs, and packet dropping due to mobility [47]. IACR lays a strong foundation for optimal network routing in the context of consuming less energy, less memory storage, and low processing power. IACR [104] is an ACO-based routing protocol whose objective is reducing the path distance and achieving load balance to some extent. The pheromone trail is updated during the process of creating the path by considering both the path distances and the remaining energy of SNs. The communication path for both forwarding ants and backward ants based on the pheromone trail, including of remaining energy of each ant and the number of SNs in the network [78].

IACR has the following disadvantages:

1. The relay node selection is equivalent to random search, as every SN loses the same residual energy in all transmissions.
2. The selection of routing paths is based on remaining energy and the total number of hops, but there is no consideration of the energy loss at each SN.
3. In this protocol, the load balancing technique is not considered. IACR uses the many-to-one transmission scheme where SN near to BS has a higher communication load than SNs that are far from the BS.

Haider et al. [69] proposed a routing protocol that performs the task of routing queries to some particular areas of a sensor network. In this protocol, every SN has a GPS module to identify the location. Energy-aware heuristics that depend on geographic information are responsible for selecting nodes for transferring data to the BS. Compared to DD [70], restriction of the nodes focusing on a region and not forwarding the packets to the BS. There is a higher energy utilization in this protocol compared to DD [48].

An estimated cost and learning cost are applied to every SN and next-hop neighboring nodes. The algorithm performs in two phases:

1. Transmitting packets using Region of Interest (RoI);
2. Receiving of packets within the region.

Xiao et al. [71] proposed an effective routing protocol for VANET. The nature of GPSR is symmetric. GPSR is highly efficient for symmetric connections (bidirectional accessible). However, the nature of real-time WSNs is asymmetric. In a WSN, SNs are not certain through their IP address locations that may use for identifying paths [49]. However, when it comes to SN identification, GPSR is not highly efficient in terms of power. Besides, consistency is a major challenge in deployment [72].

Guo Zhao et al. [51] introduced an optimized clustering scheme for mesh networks. This protocol is used for mesh networks as well. The OLSR protocol uses "HELLO" and Topology Control (TC) messages to discover forward paths and then disseminate link-state information within the mesh network. The source identifies the next-hop forwarder using routing knowledge.

Y. Xu et al. [105] introduced a Geographic Adaptive Fidelity (GAF) protocol, and it is a location augmented approach and resulted in improving energy efficiency. The deployment area is divided into multiple virtual grids. SNs used GPS to associate themselves with the closest path in the virtual network grid. GAF adopted sleep-wake cycles for improving performance. GPS is a requirement used for identifying the shortest path in GAF.

L. Li and J. Y. Halpern [106] proposed a Minimum Energy Communication Network (MECN) is a location-augmented protocol for mobile networks, overcome the mobility of SNs, and maintains a low energy network. The

MECN functions are based on constructed spanning tree with minimum energy requirement paths to obtains a sub-graph. The sub-optimal edges have been removed from the network graph. Data transmission through sub-graph (spanning tree) results in less EC. MECN is applied to mobile SNs and losses to static networks. MECN suffers from an energy depletion problem when the cluster will always use the same SNs for sending data packets to BS.

V. Rodoplu and T. H. Meng [107] proposed a Small Minimum Energy Communication Network (SMECN), which was an improvement to MECN by incorporating a neighbor discovery approach. SNs will broadcast neighbor discovery packets using different energy limits. If N_s next-hop neighbor were the same threshold energy limit, then that neighbor received the data packets and sent them to a next-hop neighbor in the same manner. This approach helps to overcome the limitation of partitioned networks in MECN.

Zorzi and Rao [108] suggested a dynamic and opportunistic selection of FNs for sending packets to BS. The N_s's near to BS are in a high priority delivery zone than N_s's that are farther. The SNs are not aware of the locations and sleep awake patterns of neighbors. In this context, the N_s knows only the position of self and BS. if the source has packet information, it finds the neighbor using Request To Send (RTS) and waits for Clear To Send (CTS) from an awake neighbor. If CTS is received, the packet is forwarded towards the SN. Otherwise, RTS is requesting a possible reply from a comparatively higher priority neighbor. This process continues until the data packet is not timed out.

B. Nath and D. Niculescus proposed a Trajectory-Based Forwarding (TBF) [109] that is applicable for dense and location-aware networks. SNs are aware of their locations using their coordinates. The sender packets specify the trajectory path towards the destination. The trajectory specification is coordinate by coordinate. The sender node makes greedy decisions to transfer the data to a next-hop SN nearest to the next hop in the trajectory. The movement of sensors in the region is supported using the function of TBF, but not with the SNs IDs.

G. Xing et al. considered Bounded Voronoi Greedy Forwarding (BVGF) [110], which exploited the Voronoi network, SNs are location-aware. In BVGF, the sender node always forwarded a packet to a neighbor, which resulted in the farthest movement of packet move towards BS. The SNs in the regions which were intersected by the segment line combines the sender and BS. The selection of the same neighborhood as forwarder each time results in unbalanced EC among SNs in the region.

Table 2.6 shows the characteristics of autonomous (energy-aware) protocols used in WSN. The ACO and IACR protocols influence the energy-aware protocols represented in Table 2.7. Because of the availability of energy-aware based protocols, routing and control overheads are crucial for achieving energy efficiency.

2.6 Routing strategy-driven schemes

This section reviews strategy-driven routing protocols in WSN. For example, multi-path routing schemes use a multi-path strategy to improve fault tolerance.

2.6.1 Multi-path routing protocols

In the dynamic topology of wireless networks and sharing the relay overhead among multiple one-hop neighbors towards a destination, many proposals suggested using a multi-path routing strategy.

C. Intanagonwiwat et al. [111] proposed DD, which was the most suitable

Table 2.6: Different autonomous (energy aware) routing protocols & their characteristics in WSNs

Energy aware routing protocols		ACO	IACR	GEAR	GPSR	OLSR
Characteristics of Cluster	**Variability of cluster count**	variable	variable	variable	fixed	variable
	Size of Cluster	even	even	even	even	uneven
	Intra-cluster routing	single-hop	multiple-hop	multiple-hop	multiple-hop	single-hop
	Inter-cluster routing	single-hop	single-hop/ multiple-hop	single-hop/ multiple-hop	single-hop/ multiple-hop	multiple-hop
Characteristics of CH	**Existence**	yes	yes	yes	yes	yes
	Device types	homogeneous	homogeneous	homogeneous	homogeneous	homogeneous
	Mobility	stationary	stationary	stationary	stationary	stationary
	Role	relay aggre-gation	relay aggre-gation	relay aggre-gation	relay aggre-gation	relay aggre-gation
Process of Clustering	**Control manners**	distributed	distributed	distributed	distributed	distributed
	Execution nature	iterative	probabilistic	probabilistic	iterative	iterative
	Convergence time	constant	constant	constant	constant	constant
	Selection of CH	adaptive	adaptive	adaptive	adaptive	adaptive
	Nature	Reactive	Reactive	Reactive	Reactive	Proactive
	Why to do clustering?	load balancing	load balancing	load balancing	load balancing	load balancing

example in this type of routing schemes. A traveling query established multiple gradients towards the source query. These gradients are used for transmission paths with node acknowledge.

Table 2.7: Comparison table of autonomous (energy-aware) based structure protocols

Protocol	Type of routing	Routing overheads	Control overheads	E^2 delay	Route maintaining	Protocol type
ACO [46, 67]	Reactive (On-demand)	Higher	Low	Performance decreases	R_t	Distance vector
IACR [47, 68]	Reactive (On-demand)	High	Relatively Low	Decreases and increases simultaneously	R_t	Distance vector, Link state
GEAR [48, 69, 70]	Reactive (On-demand)	Higher	Low	Performance increases	Route messages	Distance vector
GPSR [49, 71, 72]	Reactive (On-demand)	Higher	Lowest	Gradually increases	Route messages	Distance vector
OLSR [51]	Proactive	High	Low	Gradually increases	Route messages	Link state

X. Mao et al. considered a list of forwarding nodes identified in [112] for selecting nodes out of one-hop neighbors towards a particular destination. SNs were homogeneous in nature and had a fixed transmission range. Each cost energy to the sender and receiver with an error-prone environment to each link suffers some error. The cluster has selected SNs with a possible set of FNs. It is treated as a priority list and node considered to the most preferred. Opportunistic nodes forward the message towards BS. There is a possibility of multiple messages transmitted from the FNs due to hidden node problems. Opportunistic network routing may suffer from duplicate packets as there is no solution for schedule nodes to send packets to the BS.

2.6.2 Query-driven routing

In this routing, transmission packets are obtained from querying the network with an event of interest. The N_s initiates the query, and nodes reply to a route query either fully or partially, based on the cached information. DD and RR discussed above are query-driven routing schemes.

2.6.3 Negotiation based routing protocols

In negotiation based routing protocols reduce the number of data packets transmission to BS. SPINs [81] discussed in previous sections and are suitable for negotiation routing.

2.6.4 QoS based routing

A routing protocol may consider one or more parameters for qualifying requirements to increase the lifetime. The network parameters are routing efficiency, re-keying messages, message updates, delivery ratio, and the throughput consider for QoS [113].

T. He et al. [114] considered a QoS driven routing protocol named as SPEED [114]. SPEED guarantees E^2 delay by ensuring that each packet must travel with the network's specified speed. In this protocol, SNs used geography-based decisions to find the paths. The protocol overcome congestion in the network. SPEED protocol also works like a Stateless Geographic Non-deterministic Forwarding (SGNF). In the SGNF module, the sender selects the node based on the delay and miss ratio. The control overhead of SPEED is less compared to AODV [37,50,61] and DSR [41,42]. Moreover, AODV and DSR have less gain on delay and throughput while compared to SPEED protocol.

I. F. Akyildiz et al. [115] proposed a SAR, which was the first QoS based routing protocol in WSNs. This protocol is table-driven, and each node maintained table information of all other SNs in a network. The routing decision is based on three factors: energy resource, packet priority, and QoS. The periodic updates require reconstruction of the tree due to SNs failure. The storage requirement may be a limitation in large-sized networks.

K. Akkaya and M. Younis [116] proposed an EAR protocol for real-time image traffic. This protocol is considered energy-efficient least-cost paths. The selected communication path meets the transmission delay criteria. The cost was measured using complex parameters. A queuing model is exploited to support both real-time and non-real-time traffic. The protocol used a greedy approach to find the least cost path and that meets QoS criteria. This protocol has limited bandwidth for communication.

2.7 Recent opportunistic routing schemes

Devi V Seedha et al. [117], considered a cluster-based aggregation scheduling scheme for reducing the packet loss ratio and increasing the delivery ratio in WSN. In this protocol, the election of CHs based on the Artificial Bee Colony (ABC) algorithm as depicted in two phases:

In phase-1, Once the cluster is formed, its ACK is broadcasted from the CH, which also includes the CH ID, residual energy, cluster-ID, location, and cluster size. A Minimum Spanning Tree (MST) provides the required CHs and the tree information broadcasted for all CHs at a time.

Phase-2 comprises estimating the expected PLR at the BS. For the estimation of delay, the maximum delay (d_m) is calculated for every SN. The packet loss ratio and d_m are used to allocate the time slots. This protocol avoids packet losses and meets deadlines using the packet scheduling [118]. Yarinezhad R et al. [119] proposed an efficient routing technique, where an fpt-approximation algorithm is taken into consideration for solving the Load-Balanced Clustering Problem (LBCP). The technique Routing by using an FPT-approximation algorithm (RFPT) dividing the network operations into two phases, setup and steady-state. In the setup phase, the network is configured with clustering and routing. In the bootstrapping routing phase, the N_s sends the local information to the BS. In the steady-state phase, each SN sends the packets to its respective CH, and after that, CHs use their next-hop FNs for transferring the packets to the BS. This phase includes total rounds that are pre-specified as the specifications of the network.

Mehra PS et al. [120] proposed an enhanced version of a Balanced Cost CH Selection Algorithm (BCSA). The improvement has been shown in three methodologies. Firstly, the selection of CH using fuzzy logic so that the best candidate is chosen from the nodes that are available in the network. Secondly, consider the SNs remaining energy level. At last, all the SNs density was used for selecting the CH. Mehra PS et al. [121] proposed another protocol named as Fuzzy Based Enhanced Cluster head Selection (FBECS), and it is a distributive protocol similar to LEACH. The building phase and forwarding phase are used for identifying the best-suited CH for sending packets to BS.

In the topology building phase, the distribution of N_s's deployed in the target area. In every round, CH is identified based on the maximum energy node from the deployed alive SNs. The data packet includes coordinates of the regions, location of BS, and time slot for SN for evading collision.

Forwarding phase, once the cluster is formed successfully in the topology setup phase, CH performs the role of collecting data from its members following the Time Division Multiple Access (TDMA) slot assigned to every member to allow communication without any collisions. A TDMA slot is provided to the CH; then, it collects information from every SN and aggregates it to limit the repeated information to minimize the communication cost. The BS collects aggregated information from each CH as per schedule time [28, 34].

Furthermore, to discuss of traditional routing protocols has shown some efficiency to-words FND. Ozgovde et al. [33] proposed that FND is a critical stage for the network's complete lifetime and is a crucial criterion for evaluating network performance. A utility-based lifetime measurement framework known as Weighted Cumulative Operational Time (WCOT) determines the network's lifetime based on the entire history of the wireless network. Lee et al. [122–124] proposed a new routing technique for evaluating the energy utilization and SN's lifetime.

Many researchers usually evaluate the network lifetime using probabilistic approaches [34, 125, 126]. To increase the lifetime and ensure that SNs are alive for a longer duration are demanding for WSNs, it can cause the premature network death [127]. Olariu et al. [128] proposed a centralized clustering routing technique for balancing the usage of energy at each SNs with the help of adjustments in the transmission power. Perillo et al. [129] evaluated the condition in which the energy loss could occur. Kacimi et al. [130] proposed a load balancing technique for minimizing the energy loss problem in the case of large-scale WSNs [131, 132].

Most of the works are [132–136] focused on energy-efficient node near BS, designing the enhanced clustering protocol to reduce energy loss. But, recent studies [32,124,137,138] reflect that the energy-efficient node may not be close to the BS every time and is greatly dependent on some network parameters like the communication range of SNs and the EC model. However, there is no provision of theoretic analysis in current works to estimate the location and emerging time of the highest energy SN and its evolution process.

2.8 Issues in traditional routing protocols

The wireless network needs the best routing protocol that is energy-efficient and effectively chooses the forwarder node to enhance network routing. Thus, the chapter presents the opportunistic routing techniques for selecting the next FN, which is important for maintaining the packets from the source and forwarding the same packets to CH. The selection of the FN is based on remaining energy and distance. In case of no response from the selected FN in a predetermined period, the next highest residual energy FN can receive and aggregate the packets from a source and forward it to the CH.

Some issues are found in the above traditional protocols gives the concept of lesser FND and Last Node Dies (LND). So the SNs in a network can die very rapidly. Thus, a better approach is needed to rank the FNs to increase FND time and improve the network lifetime.

2.9 Research gaps identified

A thorough investigation of the routing protocols concerning various aspects discussed in this chapter. These are the research challenges **identified here as**.:

1. If the BS might be far from the CH, higher power is used to transmit the packets.

2. After each transmission cycle, every SN energy will update in the R_t, and this a memory consumption approach as well as a time delay process. It may lead to increased delay and communication overhead of transmission in the case of large networks. Along with it, addressing network congestion becomes difficult as network size increases. Thus, efficient network routing is required in autonomous routing protocols having confining parameters such as time delays for forwarding packets and different energy limits for sending packets.

3. In an autonomous routing, every SN calculates the elapsed time since an acknowledgment received for the last data packet sent. It leads to a higher transmission delay.

This research addresses the difficulties such as efficient clustering techniques to determine the selection of best FNs, reduce the energy usage of each SN, and shows the impact on lifetime. By using an adaptive ranking approach and opportunistic routing technique may increase the performance of the network.

2.10 Analysis

This section summarises the challenges behind the development of the thesis. Most of the routing protocols reviewed in this chapter; has problems with FN selection, packet loss, cluster stability, CH selection, reduction of EC, uniform load balancing, efficient network maintenance, and QoS issues.

In brief, this chapter survey identifies the issues in traditional routing protocols, namely computation round, communication complexity, cluster maintenance, and CH election, control overheads, and network overheads. The mentioned performance metrics have a significant impact on the sensor's energy loss. These all are open challenges in the wireless network.

2.11 Summary

This chapter presented the comparative analysis of non-autonomous (energy in-efficient) protocols, autonomous (energy efficient) protocols, autonomous (energy-aware) protocols, strategy-driven routing schemes like multi-path oriented routing schemes, query-driven routing schemes, negotiation & metadata-driven routing schemes, and QoS driven routing schemes, and the most recent opportunistic routing schemes based on performance evaluation done by authors in their respective thesis. Our analysis is based on characteristics of a cluster, CH, and algorithm structure. Similarly, sub-parameters are also discussed in Table 2.2, Table 2.4, and Table 2.6. After all the reviews, it would be better to research in the area of energy-efficient WSNs. In the next chapter, we consider the adaptive ranking scheme and FN selection scheme for the wireless network.

Chapter 3

AREOR

This chapter presents two schemes, which rely upon the ranking of nodes and FN selection. By considering an adaptive ranking & FN algorithms computationally efficient procedure for optimal energy strategy. Both algorithms are energy-efficient and extended the lifetime [1].

Many research works implemented and deployed on different protocols are discussed in the literature review. Most important parameters, like scalability and route metrics, are critical when it comes to evaluation. Furthermore, the energy usage is high while sending and receiving packets in wireless routing. According to the literature, non-autonomous (energy in-efficient), autonomous (energy-aware) schemes have high overheads and more delays. Likewise, non-autonomous (energy in-efficient), autonomous (energy-aware) have bottlenecks for congestion and data loss when it comes to the network's scalability. Altogether, the transmission performance of

[1] The major findings of this chapter have been published

- "AREOR-Adaptive ranking based energy-efficient opportunistic routing scheme in Wireless Sensor Network," Computer Networks, Vol.162, 2019. (SCI)
- "ARIOR Adaptive Ranking based Improved Opportunistic Routing in Wireless Sensor Networks," Wireless Personal Communications, Vol.116, PP.153-176, 2021. (SCI)
- "Performance analysis of jitter and packet loss ratio for routing protocols in wireless sensor networks," Proceedings of ICACCA, 2019. (SCOPUS).

these schemes is not as effective in non-autonomous (energy in-efficient), autonomous (energy-aware), but a bit effective in autonomous (energy efficient) because of the clustering approach. The discussed protocols are not bounded to energy constraints. Working on energy efficiency would also be beneficial.

3.1 Problem formulation

The requirements of a routing algorithm, which is effective in selecting the FNs optimally for enhancing the routing algorithm. Thus, this section presents the new routing technique to choose the next FN that receives the source's data and transfer to the CH. In the present scheme, a routing queue is used for storing the FNs. The given criteria used for selecting FN include remaining energy and relative position. In case there is no response from the chosen FN in the given broadcast time, the SN having the next highest priority is to take the responsibility of receiving and aggregating the packets from a source and forwarding it to the CH.

3.2 AREOR: Definition

This section describes an opportunistic routing technique AREOR protocol, and its design. It improves the PDR, MSR, PDR, EC, E^2 delay, jitter, PLR, stability period, and throughput. The mechanism focused on the adaptive ranking of SNs, and these ranks are used for the selection of CH and FN. The deciding criteria for rankings are the SNs position and the remaining energy of the SN. The AREOR using a routing queue is for identifying the FNs and CH during transmission of packets to BS.

3.2.1 System model

Going through the literature and describing the issues identified in the traditional routing protocols, a probable transmission approach is energy-efficient. In WSNs, opportunistic routing and cluster-based routing are considerable for effective transmission and extend the lifetime. The coming sub-sections focused on the research problem as well as a network model for the proposed protocol.

3.2.2 Network model

For proposing a solution to the research problem [20,139] while considering a wireless network that covers a geographical area using limited SNs. The network is categorized into clusters for the process of communication. The distance is used as a metric for forming the clusters. Every SN that broadcasts within a distance (radius) considered for each cluster. Thus, ensuring that every SN comes under one cluster or the other. CHs are selected based on the highest residual energy, as shown in Figure 3.1. SNs are also relieved from computational overhead for the process of cluster formation. In every transmission, each node consists of the information of source and CH.

3.2.3 Mobility

In the network area, the SNs, CH, and FNs positions are static. Thus, there is no concern about mobility in AREOR.

3.2.4 Energy model

In general, SNs lost their energy due to packet sensing, sending and receiving, and idle listening when SNs are in sleep state [140, 141]. In the simulation, SNs not considered EC in sleep mode because it is small enough

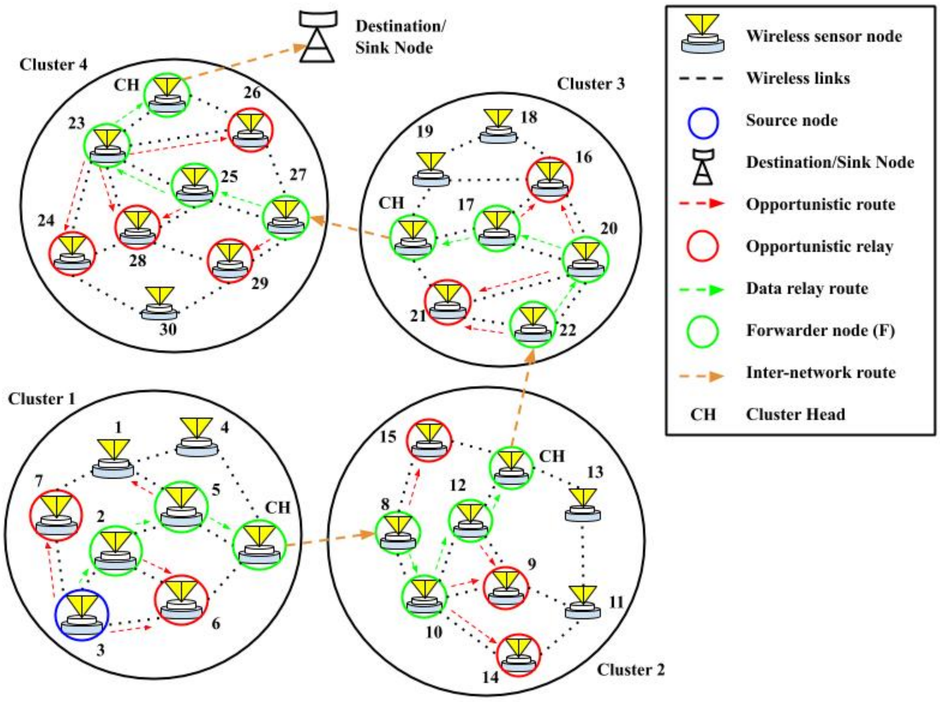


Figure 3.1: Opportunistic volunteer routing protocol based on adaptive ranking

to be neglected [27,141,142]. According to the radio model [31], the calculation of EC's for transmitting (E_{xt}) and receiving (E_{xr}) for l bits of data are computed as per Eq. (3.1), Eq. (3.2), and Eq. (3.3), respectively.

$$E_{xt} = lE_{el} + lE_{fs}d^2, d \leq d_t \tag{3.1}$$

$$E_{xt} = lE_{el} + lE_{mp}d^4, d > d_t \tag{3.2}$$

$$E_{xr} = lE_{el} \tag{3.3}$$

E_{el} denotes transmitting packet loss, and d_t is the threshold distance. The free space energy model and the multi-path fading energy model are used and estimated using Eq. (3.1), Eq. (3.2) & Eq. 3.3). If the transmission distance d is larger than the threshold distance d_t, the multi-path fading channel is adopted; otherwise, it would use the free space channel. The E_{fs} and E_{mp} denote the energy for power amplification in the two models. L is the data transmission rate of each SN. For idle listening, the EC rate of the SNs denoted as E_{ip}.

Calculation of d_t is shown in Eq. (3.4),

$$d_t = \sqrt{\frac{E_{fs}}{E_{mp}}} \tag{3.4}$$

Total initial energy E_t is proposed in the network; after each round, SN energy is computed using Eq. (3.5).

$$E_t = E_{CH_i} + E_{N_i} | E_N \in C_h \cup F_h, i \in 0, 1, ..., k \tag{3.5}$$

The number of rounds supported for the complete network is estimated using Eq. (3.6).

$$R = \frac{E_t}{E_r} \tag{3.6}$$

Where R is denoted as a total number of rounds before the death of all SNs in a network, E_r is the energy dissipation for completing one round and is estimated using Eq. (3.7).

$$E_r = C(2NE_{el} + NE_{da} + lE_{mp}d_{toBS}^4 + NE_{fs}d_{toCH}^2) \tag{3.7}$$

Where C is the clusters generated in the network, E_{da} is the energy function of CH for data aggregation, d_{toBS} is the distance between CH to BS and d_{toCH} is the distance between CMs to CH. d_{toCH} and d_{toBS} are estimated using Eq. (3.8) & Eq. (3.9),

$$d_{toCH} = \frac{M}{\sqrt{2\pi C}} \tag{3.8}$$

$$d_{toBS} = 0.85 * \frac{M}{2} \tag{3.9}$$

C_{opt} is optimal number of CHs for each cluster is estimated using Eq. (3.10)

& Eq. (3.11).

$$C_{opt} = \sqrt{\frac{N}{2\pi} * \frac{E_{fs}}{E_{mp}} * \frac{M}{d_{toBS}^2}} \tag{3.10}$$

$$CH_{prob} = \frac{C_{opt}}{N} \tag{3.11}$$

Where $CH_{prob} = 0.1$ is the probability of CH in each cluster.

3.2.5 Design and structure of AREOR protocol

In AREOR protocol, for identifying the next-hop FN for N_s, is based on remaining energy (FN should have the threshold limit of CH) and least distance from N_s, after that, as for the information of SNs, the ranks will assign and updates in the R_t. The SN having high remaining energy and the least distance from the N_s is chosen to be the forwarder as shown in Figure 3.2. Similarly, to choose the FNs from N_s to destinations in a recursive manner.

Figure 3.2 shows the selection of the next FN using the R_t information.

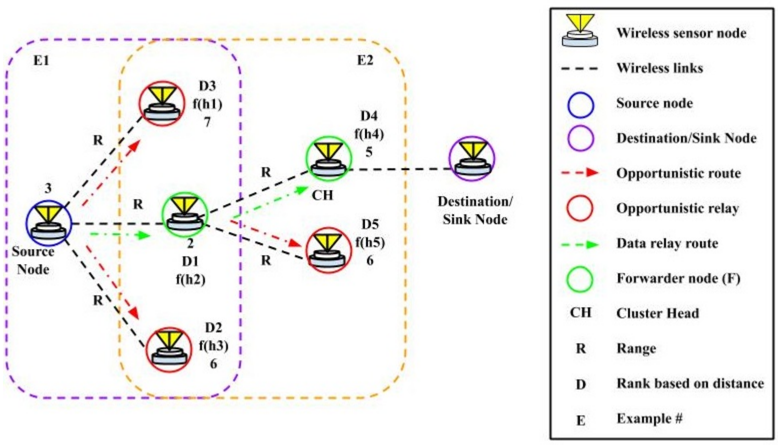


Figure 3.2: Cluster based FN selection in AREOR

The given examples are the idea of selecting opportunistic FNs in detail.

Scenario 1: The selection of FN for next-hop in cluster 1: FN selection for SN ID-3. Table 3.2 indicates that the SN has the least rank is ID-2 (Based on its position from the N_s and residual energy). Thus, it is selected as the

Table 3.1: Acronyms

Symbols	**Meaning**
N	Total number of SN.
N_r	Number of data packets received by SN
β_i	i^{th} SN in the network where 1 $\leq$ i $\leq$ N
N_t	Number of data packets sent by SN
P_{rp}	Data packet receiving power
P_{tp}	Data packet sending power
N_i	Initial power of β_i
N_s	Set of N_s's
β_j	FN
(x_i, y_i)	Position of N_s
(x_j, y_j)	Position of FN
CH	Set of CHs
$E_{res(max)}$	Remaining energy of SN
E_{max}	Highest energy of SN
E_{β_i}	Energy of SN (β_i)
d	Distance between β_i to CH
τ_{β_i}	CH energy threshold
F_h	FN set
$(MSR)_{F_h}$	Threshold energy of FN
$E_{\beta_k(max)}$	Highest energy of FN set
C_h	Candidate node set
P_{rs}	Receiving size of each packet
N_{st}	The time when the nodes start to transmit
N_{sp}	The time when the nodes stop to transmit
$n(H)$	Number of hops
R_t	Routing table
t_b	Transmission timer
$\chi : R_t \rightarrow CH$	Retrieving data packets from $R_t \rightarrow C_h$
$\mu : C_h \rightarrow CH$	Retrieving data packets from $C_h \rightarrow$ CH
N_{sp}	Number of sending data packets
N_{rp}	Number of receiving data packets
D_{pd}	Data packet delay difference
P_{id}	Data packet id
D_{ee}	Present E^2 delay
D_{pee}	Previous E^2 delay
P_{pid}	Present packet id
L_{pid}	Previous packet id

Table 3.2: Ranking of FNs from N_s

SN ID	SN rank	Remaining energy of SN	Distance
2	2	79%	0.57 m
7	4	75%	0.78 m
6	3	74%	0.64 m

next FN for the N_s.

Scenario 2: Selection of the next-hop FN for SN ID-2 in cluster 1. Table

Table 3.3: Ranking of FNs from previous-hop FN

SN ID	SN rank	Remaining energy of SN	Distance
CH	1	90%	0.71 m

3.3 depicts that node ID-5 is the CH, and it takes the aggregated packets from the previous least rank forwarder is ID-2.

3.2.6 Routing operation of AREOR

The classification of the new routing table is designed for AREOR. This modification has been mandated for node selection based on rank for the next forwarder in AREOR. Thus, Table 3.4 incorporates the hop information, which is very important for selecting the FN. The R_t parameters and their metrics are mentioned in Table 3.5.

Table 3.4: Parameters of R_t *w.r.t* example 1

SN ID	trans mission time	route queue	route next FN	route cycle	route expire	route flag
3	7.432156	2,6,7	2	1	8.67543	1

Table 3.5: Description of R_t metrics

Parameter	Description
SN ID	Sensor node ID
transmission time	N_s is able to send its data packets within a transmission time slot
route queue	Queue containing all ranked SNs for the next hop FN
route next FN	Highest ranked SN in the queue
route cycle	Sequence of time cycle
route expire	When route expires
route flag	The successful of data packets sent from N_s represents with 1

3.3 Implementation

This section discusses the algorithms, flowcharts, simulation parameters, and evaluation parameters for showing effective results.

3.3.1 Algorithms

This section is discussed about the proposed AREOR algorithm. The technical description of algorithms and flowcharts are discussed in the following subsections 3.3.1.

3.3.1.1 AREOR- Adaptive ranking for FNs

In the AREOR- adaptive ranking for FNs, the FN rank is computed based on distance and residual energy. The computed ranks are used for FN selection and CHs. Computing the ranks of every SN requires two parameters; one is the calculated distance between SNs. The other is the remaining net energy of SNs. After that, the SN having the highest net residual energy

Algorithm 1 AREOR: Adaptive ranking for FNs

Input: $E_{res[\beta_i]}$, $d(\beta_i, \beta_j)$, $(x_i,\, y_i)$, $(x_j,\, y_j)$, R_t
Output: Highest Energy of the Node $E_{\beta_i(max)}$, the net distance between β_i and β_k is d
calculating remaining energy
for `i` $\leftarrow$ `1 to N` **do**
    $E_{res[\beta_i]} = N - ((N_r * P_{rp}) + (N_t * P_{tp}))$;
    $E_{\beta_i(max)} = \max(E_{res[\beta_i]},\, E_{res[\beta_i - 1]})$
end for
if $E_{\beta_k(max)}$ occurs; $k \in \{1, 2, ...N\}$ **then**
    $\beta_k \in CH$
end if
Compute the distance between source and forwarder.
$\forall\ \beta_i \in N_s$ & $\beta_j \in F_h$,
$d(\beta_i,\, \beta_j) = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$
Update in R_t.
return

compared to other candidate SNs is ranked on the top and so on. The SN having the least rank is chosen as the CH. Using the identification of CH and subsequent ranking, determine the position of SNs as per the N_s. So, the ranking mechanism establishes a communication path over N_s, FNs, and CH. Along with that, updating the rank of each node is based on distance and remaining energy.

3.3.1.2 OFNS: Opportunistic FN Selection for optimal energy strategy

In OFNS, forwarder selection for optimal energy strategy focuses on identifying FN. Table 3.1 for acronyms as well as variables used in the simulation. After that, initiate the transferring of packets from N_s to the CH. Once the transmission timer set, anyone N_s identified from C_h. For the successful transmission of packets, SN residual energy and distance are computed for every round. After successful validation, the N_s transfers the packets to the CH. Suppose any failure occurred in the network, the next FN with the highest energy within the time cycle is used to aggregate the data pack-

Algorithm 2 OFNS: Opportunistic FN selection for optimal energy strategy

1: **Input:** τ_{β_i}, $(MSR)_{F_h}$, β_k, $n(H)$, C_h, CH, F_h, N_s, E_{β_k}, $CH \subset C_h$, $F_h \subset C_h$, $H \subset C_h$, t_b, $N_s \subset C_h$ s.t. $CH \cap F_h \cap H \cap N_s = \emptyset$.
2: **Output:** To identify β_k.
3: **Event:** μ: $N_s \rightarrow CH$.
4: Set t_b.
5: $\forall\ \beta_i \in C_h$,
6: **if** $(\tau_{N_{s\beta_i}} \& \ (MSR)_{\beta_i(max)})$ occurs; **then**
7: $\quad \mu \circ \chi: \quad R_t \rightarrow CH$
8: **else**
9: $\quad$ Choose $\beta_k \in F_h$ s.t. $E_{\beta_k(max)}$ occurs; $k \in \{1, 2, ...N\}$ where β_k possess $t_{min} \leq t_b$ & d_{min}.
10: $\quad \forall\ \beta_k,\ \mu(\beta_k) \rightarrow CH$ extinguishes all β_k including $n(H)$
11: $\quad$ **if** $\mu(\beta_k)$ is not defined (error) **then**
12: $\qquad$ `choose` β_k`' possessing` $t_{min} \leq t_b$ `&` d_{min}
13: $\qquad$ return to step 9
14: $\quad$ **end if**
15: **end if**
16: **return**

ets and send them to CH. In case of any current FN failure within the transmission time, the FN selection process repeats.

3.3.2 Flowcharts

Figure 3.3 shows that the SN residual energy calculation assigns its ranks. In the beginning, the candidate SN residual energy estimates, in which SN consists of the highest remaining energy, that SN will become a CH, after that, the CH assigned to each cluster. The computing distance from the N_s to the next-hop neighbor's information is updated in the routing table R_t.

Figure 3.4 shows the process of selecting an FN during transmission. It is a process that aims the identifying optimal energy-efficient FN in less time and a small distance. The selection criteria validated the process repeatedly using the FN set for obtaining the best FN. Thus, the obtained FN helps to complete the transmission from N_s to the CH.

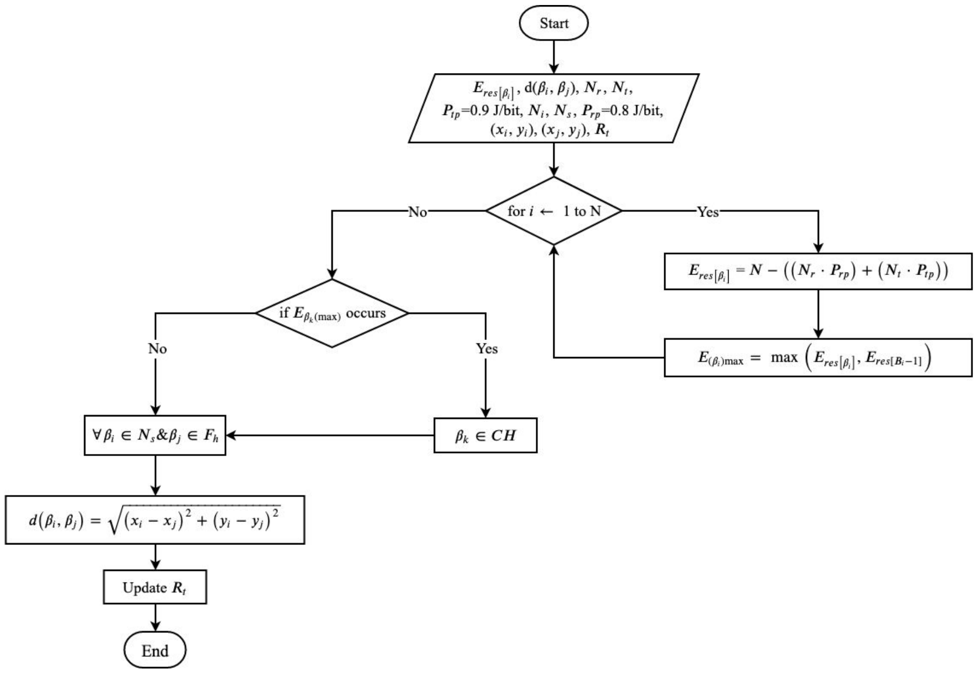


Figure 3.3: Adaptive ranking for FNs

3.3.3 Simulation setup & Settings

The simulation environment is capable of replicating the real-time conditions of the wireless network. There are various simulators like Qualnet, NS3, MATLAB, Contiki, and OMNET++, but NS2 was chosen for the experiment. Since NS2 is open-source, it allows programmable changes with Tool Command Language (TCL). TCL provides customization in evaluation parameters and simulation settings of the network. Hence, the simulator NS2 [121,143] is used as a platform to simulate and evaluate the results of proposed and traditional routing protocols considered in the thesis.

A wireless network established with 100 nodes and arranged in an omnidirectional antenna for 1000×1000 m^2 range. The Medium Access Control (MAC) protocol, IEEE 802.11 standard used to address the SNs. To start the simulation, radio electronics energy, free space energy, application energy, data aggregation energy, threshold energy, idle power, data transmission rate, and sink node position are 50 nj/bit, q0pJ/bit/m^2, 0.0013 pJ/bit/m^4, 5nJ/bit/signal, 0.85%, 0.80 mJ/s, 512 kb/s, and (500, 500) re-

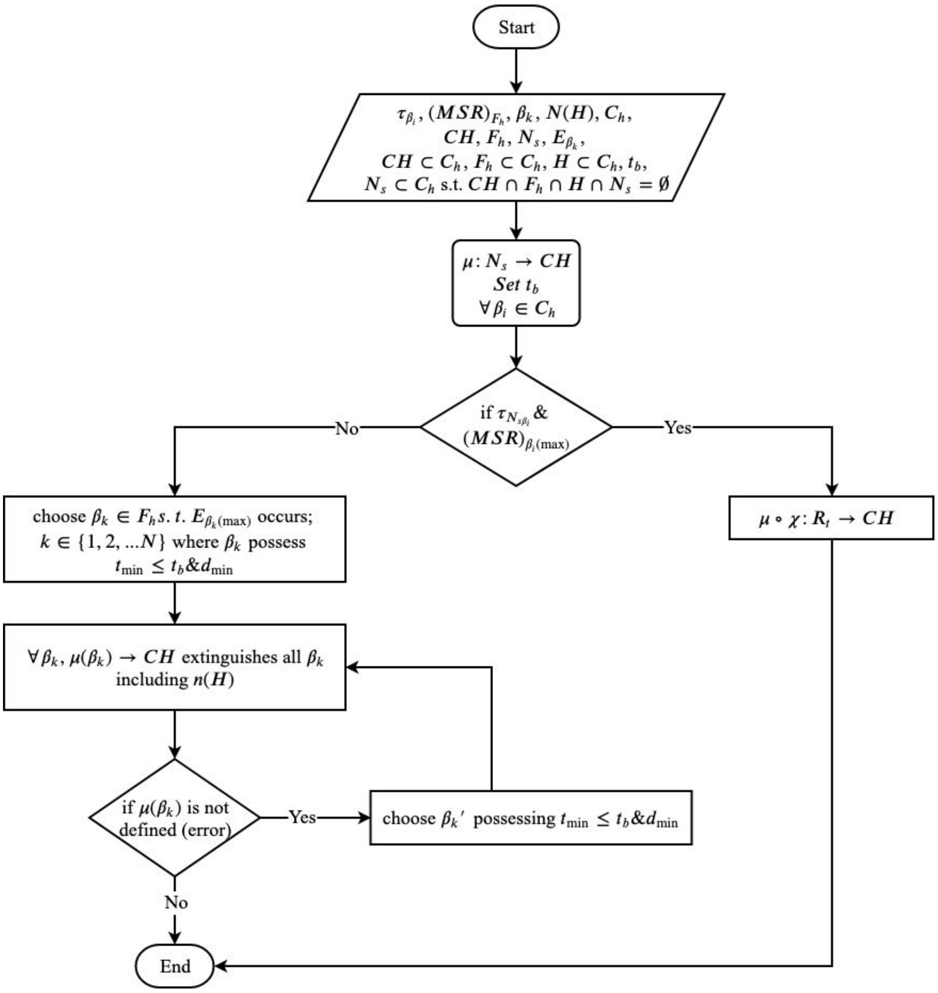


Figure 3.4: FN selection for optimal energy strategy

spectively. These are the same set of parameters considered for evaluation and FND analysis results shown in Figure 3.5. These are the same set of parameters used for traditional routing protocols to estimate the FND analysis listed in Table 3.6.

Few simulation parameters are indicated with $*$ used for FND, LND evaluation. Because, for getting results of stability period (alive nodes, dead nodes), the simulation time t_b^* is increased, the initial energy of node E_0^* is decreased.

Table 3.6: Network parameters used and their values

Parameter Name	**Symbol**	**Value**
Name of the simulator	-	ns-allinone
Base protocol used	-	ORP
Type of the network	-	Wireless
Type of Antenna	-	Omni Antenna
Model used for simulation	-	Energy model
Type of interface	-	Wireless Physical Interface
Type of MAC	-	IEEE - 802:11
Type of Queue	-	Droptail-priorityQueue
Network area	M × M	1000×1000 m^2
Number of SNs	N	100
Initial energy of SNs	E_0, E_0^*	100 J, 1.5 J*
Packet size	l	4000 bits
Radio electronics energy	E_{el}	50 nJ/bit
Free space energy	E_{fs}	10 pJ/bit/m^2
Amplification energy	E_{mp}	0.0013 pJ/bit/m^4
Data aggregation energy	E_{da}	5 nJ/bit/signal
Threshold energy	α	0.85
Idle power of the SN	E_{ip}	0.80 mJ/s
Data transmission rate	L	512 kb/s
Sink node	BS	(500, 500)
Simulation time	t_b, t_b^*	25 s - 175 s; 800 s^*

3.3.4 Evaluation parameters & Criteria

In this simulation, these are the parameters considered for evaluation, in that routing protocol is Opportunistic Routing (OR), number of nodes 100. The evaluation parameters tested on various transmission time cycles starting from 25 s and ending with 175 s. The parameters are EC, PDR,

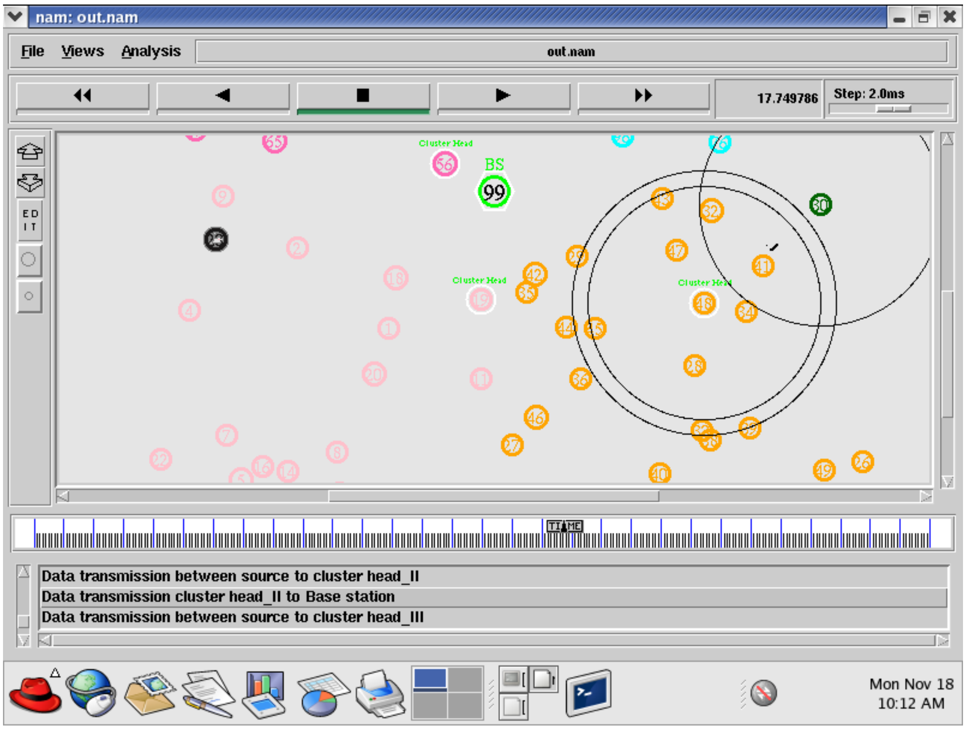


Figure 3.5: AREOR working simulation run of FND

the MSR of packets, E^2 delay, jitter, and PLR are considered to evaluate the proposed protocol performance. The functional parameters used for the AREOR are shown in Table 3.1.

3.3.4.1 Computation of MSR

MSR computed as per the total packets received at the BS from simulation starting until the transmission time ends. The MSR can compute using Eq. (3.12).

$$MSR = \sum_{i}^{N} \frac{N_r}{(N_{sp} - N_{st})} \tag{3.12}$$

3.3.4.2 Computation of PDR

The PDR is the evaluation parameter, which is to compute based on the ratio of a successful number of packets transmitted through each SN, participating in a sensor network. The PDR is defined as the probability of maximum data packets reached at CH and the maximum data packets transferred from the N_s. The PDR computed using Eq. (3.13).

$$PDR = \sum_{i}^{N} (\frac{N_t}{N_r}) * 100 \tag{3.13}$$

3.3.4.3 Computation of EC

In a wireless network, each SN has two major functions, in that one is sensing the packets and the other one data packets sending to CH; during this process, every node has lost some energy. Similarly, CH also loses the energy during the receiving, aggregation, and transmitting the packets to BS. In every round, the node computed the EC using Eq. (3.14), and EC is computed for only those SNs are participating in the transmission.

$$EC = \frac{\sum_{i}^{N} (N_i - N_{re})}{N} \tag{3.14}$$

3.3.4.4 Computation of E^2 delay

E^2 delay is computed as per the total time taken for transmitted packets across a network from the N_s to BS. Hence, the E^2 delay of each packet at each SN during transmission is estimated using Eq. (3.15).

$$E^2 \ delay = \sum_{i}^{N} (N_{sp} - N_{st}) \tag{3.15}$$

3.3.4.5 Computation of jitter

The packet delay of present and previous transmission is called jitter, which leads to the delay between each packet in the transmission. Hence, jitter is defined as a delay in received packets and the packet delay difference between participate SNs. Thus, jitter is estimated using Eq. (3.16), (3.17) & (3.18).

$$D_{pd} = D_{ee} - D_{pee} \tag{3.16}$$

$$P_{id} = P_{pid} - L_{pid} \tag{3.17}$$

$$Jitter = (\frac{D_{pd}}{P_{id}}) \tag{3.18}$$

3.3.4.6 Computation of PLR

The PLR is to identify packet loss during transmissions. The loss ratio is the difference between the total data packets sending and the total packets receiving compared to the actual packets that have to be sent in the transmission cycle. The PLR calculated using Eq. (3.19).

$$PLR = (\frac{N_{sp} - N_{rp}}{N_{sp}}) * 100 \tag{3.19}$$

3.3.4.7 Stability period

The first SN dead time defines the network stability period.

3.3.4.8 The number of alive SNs per cluster round

After each transmission cycle, each node computed its residual energy; suppose SN has left with some power and is used for further communications, which means a few SNs are still alive in the network.

3.3.4.9 The number of dead SNs per cluster round

In WSN, the SNs lose their energy in each cluster round due to sensing, packet sending, and retrieving. After some cluster rounds, the node will run without energy backup, which means the dead SN incurred the network.

3.3.4.10 Throughput

In each cluster round, the number of packets transferred from the selected N_s to the BS is called throughput. The throughput identifies the efficient energy utilized by the network in every cluster round.

3.4 Summary

In this chapter, we suggested two algorithms, AREOR and OFNS. In the next chapter, we will present the result discussions and analysis of the proposed protocol compared with traditional routing protocols.

Chapter 4

Result Discussions and Analysis

In this section, we have shown the performance of the AREOR protocol and traditional routing protocols. The simulation used to determine the performance of these protocols comparison on PDR, E^2 delay, EC, and MSR considered, and the parameter measured like packet loss *w.r.t.* number of nodes, stability period, and dead SNs as evaluation parameters. Moreover, NS2 is used for simulation, and its performance is analyzed based on FND, Tenth Node Dies (TND), LND, stability period, and throughput. The proposed protocol showed a sufficient gain in all the evaluation parameters. The simulation results of the proposed and traditional protocols discussed as follows [1]:

4.1 Evaluation Parameters

In the coming sub-sections, we discussed the simulation setup and evaluation parameters in-detail. The performance of AREOR and traditional protocols based on different evaluation parameters.

4.1.1 Effect on MSR

The MSR can compute using Eq. (3.12), which calculates how many data packets transferred through the participated SNs in transmission time. The AREOR protocol shown the better MSR ranges from 210 bit/s to 230 bit/s during time interval of 25 s to 175 s as shown in Figure 4.1.

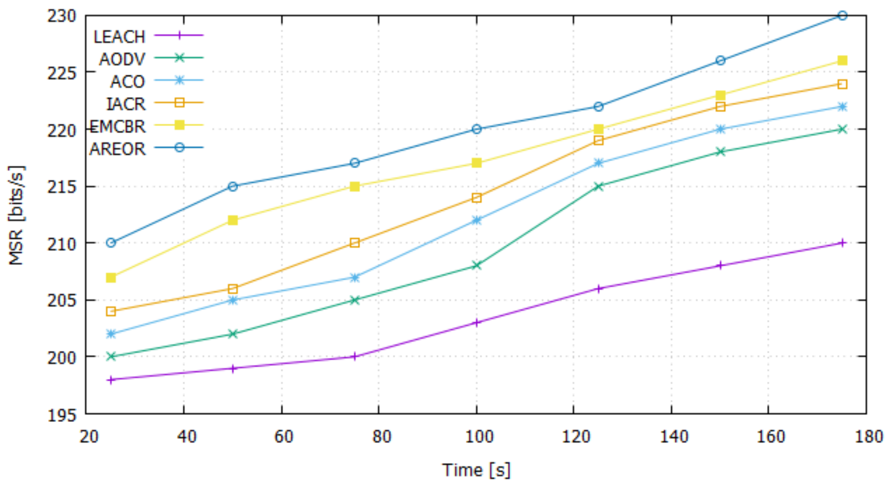


Figure 4.1: Performance variation on MSR

As smaller sized and well-defined clusters are present in a wireless network; traditional routing protocols have failed to obtain a better MSR when compared to the AREOR. The AREOR achieved a good gain of 0.013 compared to existing routing techniques shown in Table 4.1.

Table 4.1: Gain of traditional Vs. proposed protocols based on MSR

Gain on MSR					
Weighted gain range	**LEACH Vs. Proposed**	**AODV Vs. Proposed**	**ACO Vs. Proposed**	**IACR Vs. Proposed**	**EMCBR Vs. Proposed**
0.05 - 0.10	0.078	0.046	0.037	0.028	0.013

4.1.2 Effect on PDR

Eq. (3.13) is used to measure the PDR, to calculate the ratio of packets transferred successfully to CH. The dynamic ranking technique used to select the best-suited FN, the proposed routing protocol, has shown a better PDR achieved than traditional routing protocols. The AREOR protocol shown the considerable gain on PDR, as shown in Figure 4.2.

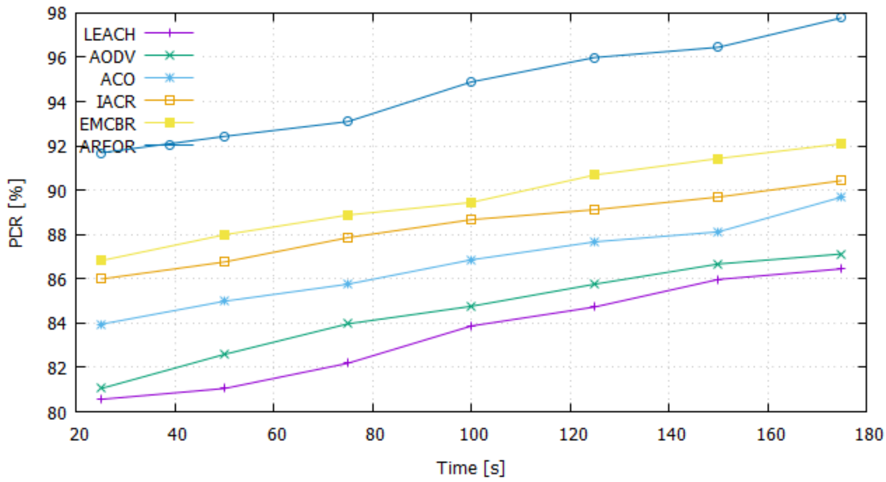


Figure 4.2: Performance analysis on PDR

With the help of the adaptive ranking technique, Table 4.2 shows that AREOR has recorded a substantial gain in a PDR ranging from 0.1 - 0.2 compared to traditional routing protocols.

Table 4.2: Gain of traditional Vs. proposed protocols based on PDR

Gain on PDR					
Weighted gain range	**LEACH Vs. Proposed**	**AODV Vs. Proposed**	**ACO Vs. Proposed**	**IACR Vs. Proposed**	**EMCBR Vs. Proposed**
0.1 - 0.2	0.115	0.106	0.083	0.06	0.053

4.1.3 Effect on EC

The EC computed using Eq. (3.14), which is an important performance parameter in a WSN. The routing queue methodology is used for the FN selection, and it shows that the proposed protocol achieved SN lifetime increased from 30% - 58% compared to the traditional protocols. The AREOR protocol has resulted in EC, which ranges from 84.45 J/bit - 70.89 J/bit when the SNs is varied from 10 to 100, as per Figure 4.3.

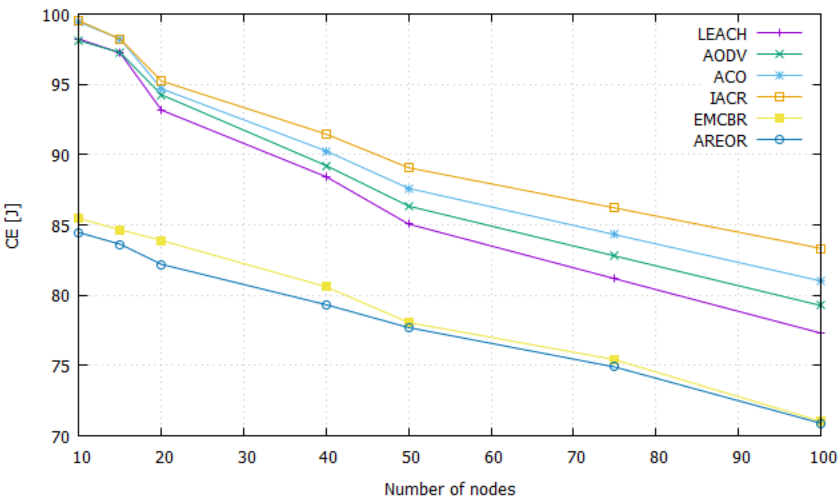


Figure 4.3: Performance analysis of EC

4.1.4 Effect on E^2 delay

Eq. (3.15) is used to computed the E^2 delay. The FN selection is based on threshold limits and position from the N_s to decides the rank in place, choosing each SN randomly, and thus it impacts E^2 delay during transmission of packets. The proposed AREOR protocol took less E^2 delay to send the packets BS when the packet's size increased up to 140 $bits/s$. In Figure 4.4, shows the traditional routing protocols have obtained a maximum E^2 delay compared with the proposed protocol from 44.3 s to 67.5 s.

The simulation results prove that the AREOR has shown effective results on MSR and PDR compared to traditional protocols considered for

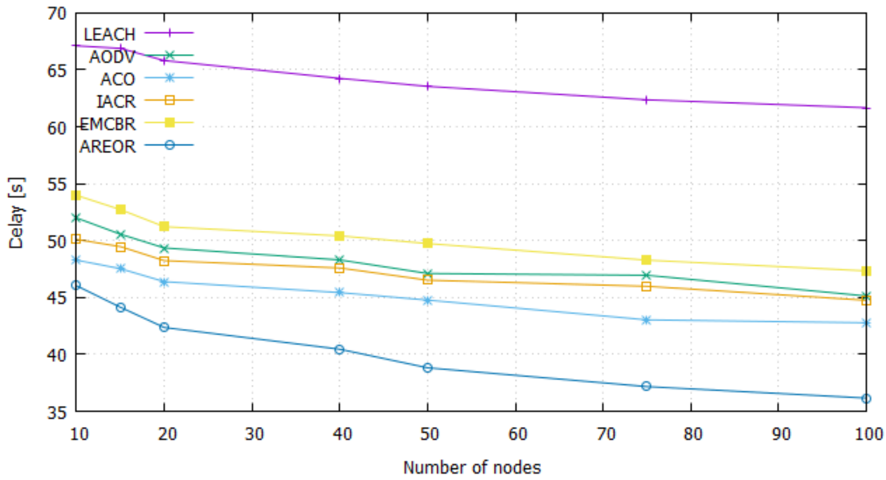


Figure 4.4: Performance analysis of E^2 delay

Table 4.3: Gain of traditional Vs. proposed protocols based on E^2 delay and EC

Gain on EC & E^2 delay						
Performance parameter	**Weighted gain range**	**LEACH Vs. Proposed**	**AODV Vs. Proposed**	**ACO Vs. Proposed**	**IACR Vs. Proposed**	**EMCBR Vs. Proposed**
EC	0.1 - 0.2	0.101	0.138	0.151	0.163	0.010
E^2 delay	0.1 - 0.8	0.631	0.200	0.113	0.189	0.259

existing simulation. The gain achieved on E^2 delay and EC listed in Table 4.3. After observing the results, AREOR has shown better performance compared to traditional routing protocols shown in Table 4.3.

4.1.5 Effect on jitter

Table 4.4 shows better jitter compared with traditional routing protocols and the AREOR protocol over different packet sizes and the number of SNs.

Table 4.4: Performance of traditional Vs. proposed protocols based on jitter

jitter				
Number of SNs	**jitter (s)**			
	LEACH	**AODV**	**ACO**	**Proposed**
10	2.109	0.596	0.407	0.225
15	1.516	0.428	0.355	0.226
20	1.173	0.349	0.294	0.201
40	0.595	0.196	0.178	0.1245
50	0.494	0.165	0.154	0.119
75	0.336	0.130	0.117	0.078
100	0.255	0.089	0.085	0.066

The jitter functioned as per the total SNs that are associated with the CH during transmission. From the simulation results, it is observed that the maximum number of packets sent to the BS in a less amount of time. In the AREOR, the N_s transmitted the packets using FN based on optimal energy strategy (threshold limit to forwarders), adaptive rank assigned to FNs. Figure 4.5 shows that AREOR sends the packets to BS with the least time interval while comparing with the traditional routing protocols.

The proposed protocol shows significant gain on jitter *w.r.t* LEACH is 0.53, AODV is 0.17, and ACO is 0.15 and the comparison results shown in

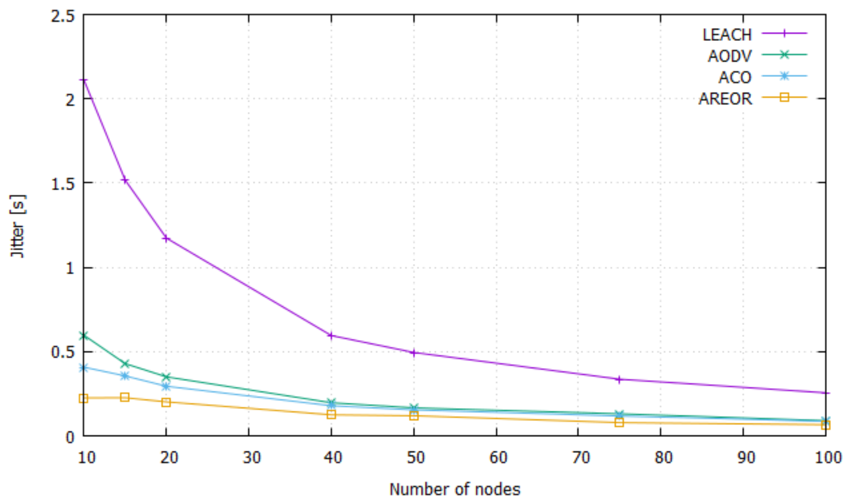


Figure 4.5: Performance analysis of jitter

Table 4.5.

Table 4.5: Gain of traditional Vs. proposed protocol based on jitter

Gain on jitter			
Weighted gain range	**LEACH Vs. Proposed**	**AODV Vs. Proposed**	**ACO Vs. Proposed**
0.1-0.5	0.537	0.175	0.153

4.1.6 Effect on PLR

The PLR of traditional routing protocols and proposed is shown in Table 4.6. The proposed AREOR protocol is used for forwarder selection based on node adaptive ranking, threshold limits, and distance. Finally, AREOR has a lower PLR compared to existing routing protocols.

Table 4.7 shows that AREOR has the lowest packet loss compared to traditional routing protocols.

Table 4.6: Performance of traditional Vs. proposed protocol based on PLR

PLR				
Number of SNs	**Packet loss**			
	LEACH	**AODV**	**ACO**	**Proposed**
10	4.562	4.183	3.846	2.949
15	4.870	4.313	3.995	2.975
20	5.122	4.462	4.154	3.038
40	5.438	4.666	4.306	3.159
50	5.718	4.846	4.563	3.241
75	6.080	5.112	4.643	3.334
100	6.360	5.189	4.874	3.405

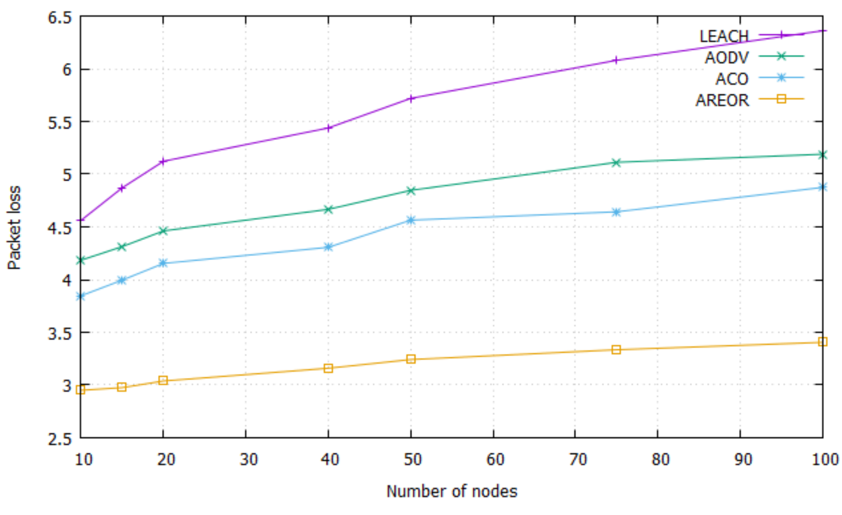


Figure 4.6: Performance analysis of PLR

4.2 Analysis of FND and LND

In wireless networks, the SN responsible for processing data packets to CH, and CH to BS with in a transmission time. Asumed that, as per available energy of each SN, the lifetime is estimated with cluster rounds,

Table 4.7: Gain of traditional Vs. proposed protocol based on PLR

Gain on PLR			
Weighted gain range	**LEACH Vs. Proposed**	**AODV Vs. Proposed**	**ACO Vs. Proposed**
4.0-6.0	5.860	4.926	4.573

and the cluster rounds where at first SNs die is denoted as death periods. As SNs die in each transmission round as per residual energy is denoted as $m(m \leq n)$, and death periods $[dp_0, dp_1, dp_2, ..., dp_{m-1}]$ in the complete network. Thus, the complete network lifetime is $m + 1$, the stages are denoted as $[s_0, s_1, s_2, ..., s_{m-1}, s_m]$. s_p represents the p^{th} network stage in which the last data packet period is the p^{th} death period, for example, the first SN dies after the stage s_0 and the network has died at the stage s_m. $[|s_0|, |s_1|, |s_2|, ..., |s_{m-1}|, |s_m|]$ denotes the number of alive SNs at each stage before the death in the network (example, $|s_0| = n$, $|s_m| = 0$), and $[s_0, s_1, s_2, ..., s_{m-1}, s_m]$ denotes the those SNs are alive in the network. For example, s_0 is the initial SN and $s_m = \theta$ (i.e., empty set) means network is dead. In each stage, the total number of rounds are denoted using [dl_0, dl_1, dl_2, . . . , dl_{m-1}]. Hence, $dl^{(0)}$ is the total network energy before FND.

Various network lifetimes can be denoted from the notations that are defined above. For example, FND is $dl^{(0)}$ and LND is $\Sigma_{p=0}^{m-1}\ dl^{(p)}$, and the network lifetime at the point when fifty percent of the SNs die $\Sigma_{p=0}^{n/2}\ dl^{(p)}$ where $|s_p| \cong$ n/2.

4.2.1 Performance evaluation & Discussion

The following section focuses on the performance of alive & dead node analysis, and throughput is compared with proposed and other traditional routing protocols.

As per the simulation parameters in Table 3.6, the network is deployed in 1000 $\times$ 1000 m^2, and SNs distributed randomly. The wireless network divided into clusters depends on SNs and the BS located at (500, 500). The total SNs in the network is 100, and the selection of the FN threshold is α=0.85%.

The simulation parameters used the radio EC model [32]. To maintain consistency without data loss, the collision-free MAC protocol considered within the network model [27, 32, 102]. The proposed protocol AREOR is compared with traditional protocols like LEACH [144, 145], AODV [146, 147], ACO [148], and IACR, EMCBR, and tested in NS2 simulator.

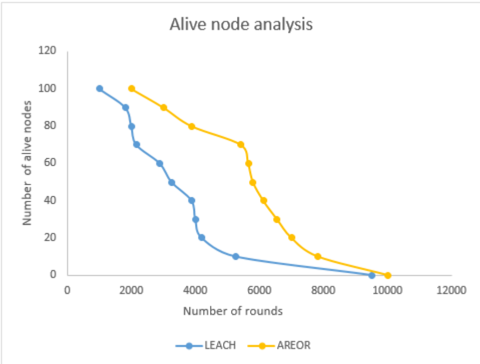
4.2.2 Alive node analysis

The target node lost due to many SNs is running out of energy in the wireless network. It is crucial to have many alive SNs in the wireless network. Thus, it becomes necessary to ensure that enough SNs alive. If SNs are losing the energy, then the entire wireless network becomes dead.

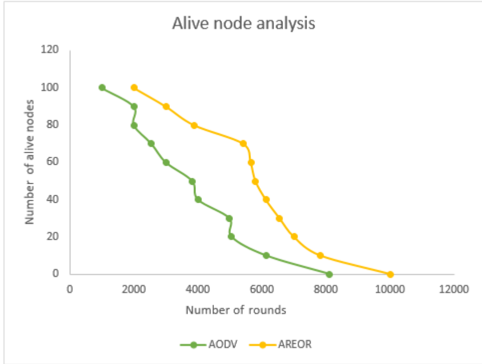
4.2.3 Dead node analysis

In a wireless network, a node that is running without energy is called a dead node. Wireless routing is crucial for sending packets from the N_s to CH or the BS efficiently [23]. Thus, it is necessary to balance energy usage at each SN and increase the lifetime for clustering-based routing protocols. The remaining energy of each SN to calculate to determine the total energy available within a wireless network.

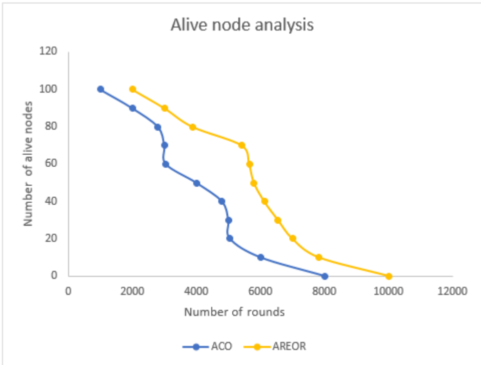
In a wireless network, every cluster consists of SNs and the best SN selected as the CH, which performs the transferring of packets to the BS. Thus, each SN needs a balanced routing scheme and a clustering scheme for extending the lifetime.



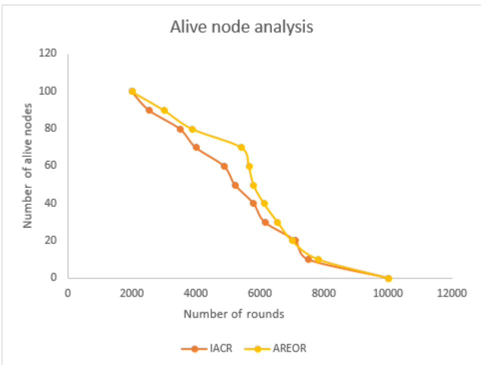
(a) LEACH Vs. Proposed



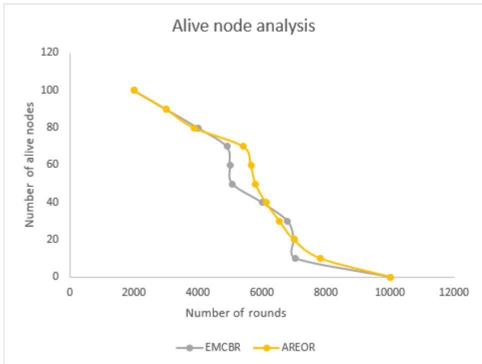
(b) AODV Vs. Proposed



(c) ACO Vs. Proposed



(d) IACR Vs. Proposed

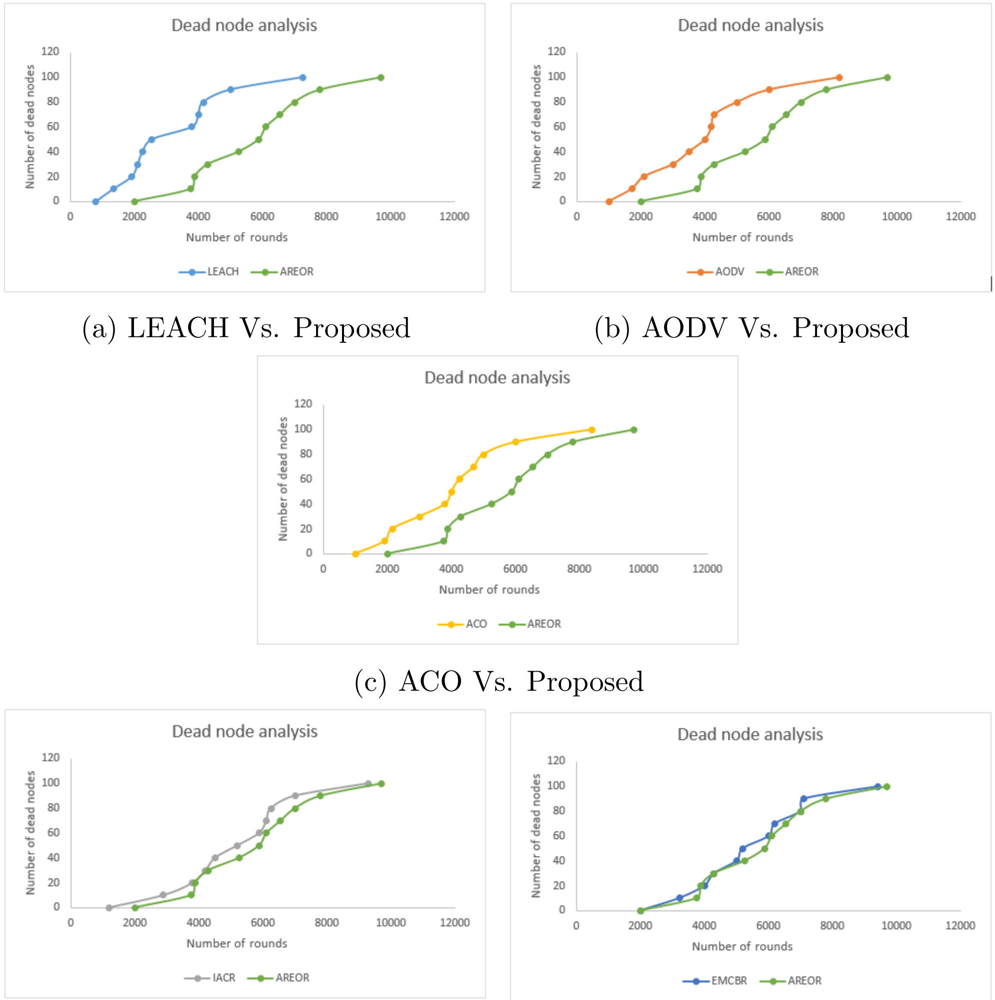


(e) EMCBR Vs. Proposed

Figure 4.7: Alive node analysis

4.2.4 Residual energy analysis

The remaining energy of active SNs after each simulation cycle is nothing but a residual energy [29] and it is the most important parameter to increase the network lifetime. However, the SN residual energy calculated using the linear function of the energy model [22].



(a) LEACH Vs. Proposed

(b) AODV Vs. Proposed

(c) ACO Vs. Proposed

(d) IACR Vs. Proposed

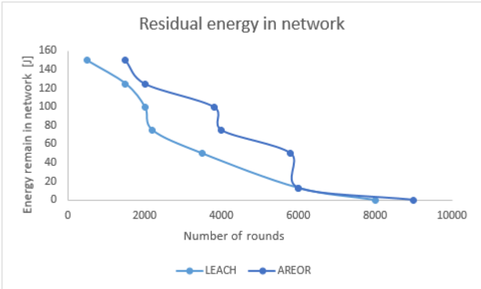
(e) EMCBR Vs. Proposed

Figure 4.8: Dead node analysis

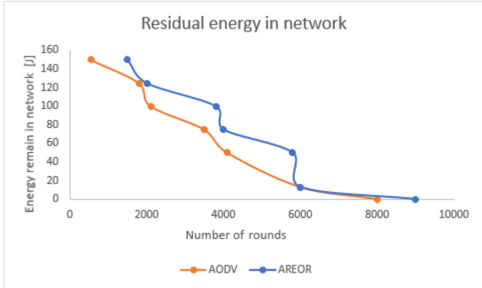
4.2.5 Throughput analysis

The concept throughput is one of the evaluation parameters in network performance. Throughput is nothing but several packets successfully send to the BS per unit amount of time.

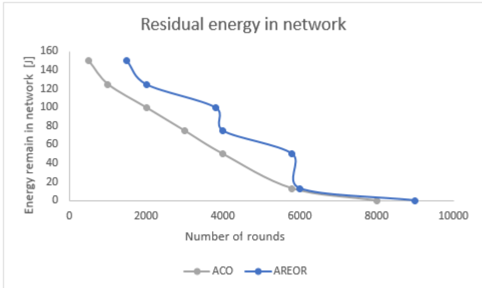
The LEACH is a well-known routing protocol for enhancing the network's lifetime by providing an equal chance to every SN to become a CH [149]. However, the selection of CH is random; the remaining energy and hop-count are considered for selecting CH, but it is not applicable for BS. Thus, the proposed protocol showed better performance than LEACH protocol in the aspect of stability period, and dead node analysis is shown



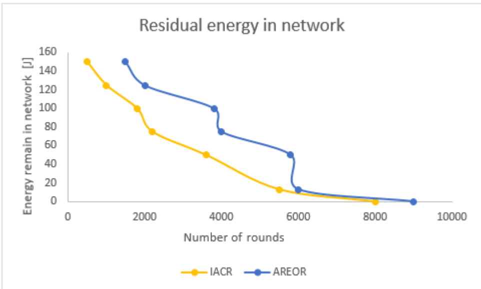
(a) LEACH Vs. Proposed



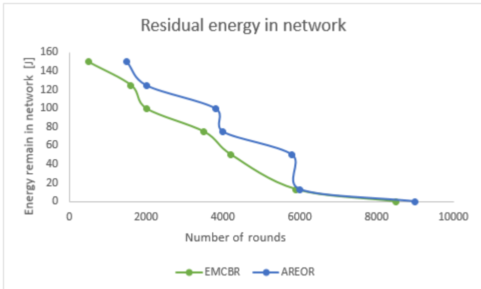
(b) AODV Vs. Proposed



(c) ACO Vs. Proposed



(d) IACR Vs. Proposed

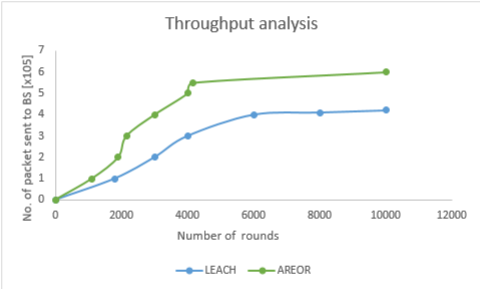


(e) EMCBR Vs. Proposed

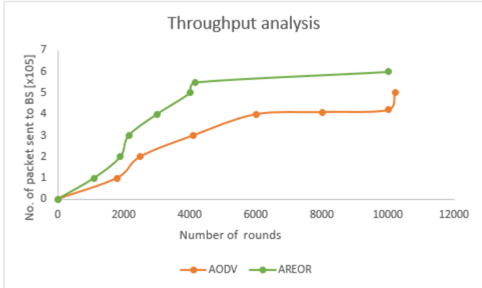
Figure 4.9: Residual energy analysis

in Figure 4.7a and Figure 4.8a. The AREOR is shown better performance in reducing the control overhead and the selection of a CH. Thus, controlled EC is less in the AREOR protocol than LEACH, as shown in Figure 4.9a. Finally, energy utilization is effective and improved for a longer time, improving network throughput. The comparison of network throughput in proposed and LEACH is shown in Figure 4.10a.

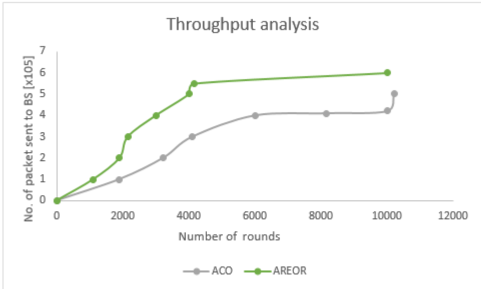
In AODV protocol, the CH is chosen based on remaining energy instead of random selection, and it allows the SN which is best suited to become a CH. LEACH provides an equal probability for every SN to become a CH, but in AODV, the remaining energy of selecting a CH is not the



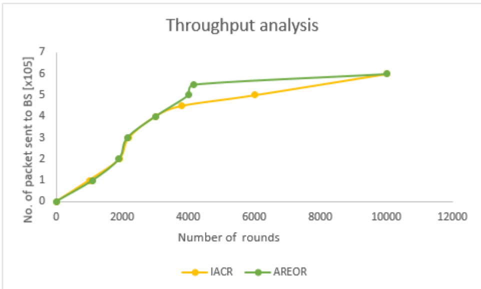
(a) LEACH Vs. Proposed



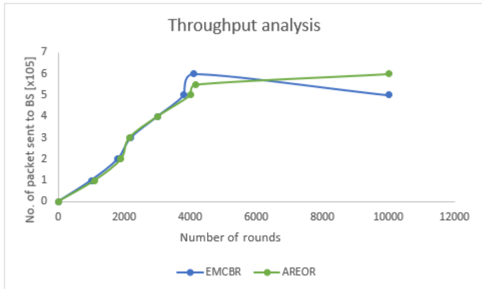
(b) AODV Vs. Proposed



(c) ACO Vs. Proposed



(d) IACR Vs. Proposed



(e) EMCBR Vs. Proposed

Figure 4.10: Throughput analysis

same for two distinct SNs. Hence, AODV leads to better results than the LEACH in a wireless network. AODV introduced to provide energy homogeneity in wireless networks [145]. The AODV protocol consists of different SNs used to distinguish between advanced SNs (available threshold limits) and normal SNs for becoming a CH; due to the identification of CH with distinct SNs, the energy depleted in a rapid manner, which impacts network performance parameters. It usually affects the stability period and dying of dead nodes shown in Figure 4.7b & Figure 4.8b. Figure 4.9b shown the remaining energy of AODV is compared with the AREOR. Figure 4.10b shown the number of packets transferred to the BS in both

AODV and AREOR.

In ACO protocol, the FN selection based on threshold energy and distance [148]. This protocol updating the global knowledge of the network, and the probability threshold function has a crucial role in selecting CH. Thus, it impacts the stability period and dead SNs of ACO protocol and proposed is shown in Figure 4.7c and Figure 4.8c. The residual energy of ACO and proposed protocol in the network is shown in Figure 4.9c. The decrease in the throughput of the traditional protocol is shown in Figure 4.10c.

IACR protocol requires agents to determine a transmission path in between the SN and the BS. While discovering paths, various ants leave SNs to find their neighbors, then communicate with each other, and the R_t updates each SNs energy limits of the pheromone trail. To avoid control overheads and scalability, IACR adopts the hierarchical routing approach.

In a sensor network, the SN loses the energy during sensing, processing, and aggregating packets; due to this, after each transmission, each SN residual energy is calculated and updated in the R_t. As per the R_t information, which SN has the highest remaining energy, that node will become a CH and used in further transmission. The variation of remaining energies in the network shown in Figure 4.9d and Figure 4.8d. The remaining unbalanced energy in the network is shown in Figure 4.9d. The decrease in the throughput of the traditional protocol is depicted in Figure 4.10d. Therefore, the proposed protocol achieved sufficient gain on throughput and network lifetime compared to the IACR protocol.

In EMCBR protocol, which uses the ACO probability function to select a candidate path. If an SN uses the best communication path, it may not lead to optimal results in lifetime and energy loss. If one communication path is used frequently, it will result in depleting the SN's energy levels.

Thus, to improve the lifetime, it becomes crucial to make use of sub-optimal communication paths occasionally.

EMCBR protocol uses different probability functions during transmission of packets and its impact on the network's net energy. Thus, the gain of proposed and EMCBR protocol over stability period and dead node analysis is shown in Figure 4.7e and Figure 4.8e. Unbalancing of EMCBR energy depletion is shown in Figure 4.9e. Figure 4.10e shows the significant throughput achieved by AREOR compared to EMCBR. Therefore, the AREOR is more efficient as compared to EMCBR.

4.3 Discussion

Few values in Table 4.8 measured using the simulation parameters given in Table 3.6. The performance evaluation has shown in three parameters: one is FND, which is the first SN death in the network, and the second one is TND, which identifies the tenth node death at the network, which is used for estimating the average remaining energy in the network. At last, LND time gives the information on the total number of nodes that remains dead, node energy will become zero, and the network has no communications and transmission further. Table 4.8 shows the comparative analysis of FND, TND, and LND *w.r.t* number of rounds on the proposed protocol and traditional routing protocols.

4.4 Summary

This chapter discussed the performance evaluation of the AREOR protocol. The AREOR compared with the traditional routing protocols, and these protocols evaluated on the same simulation setup. The AREOR protocol is compared against the evaluation parameters like MSR, PDR, EC, jitter,

Table 4.8: Performance validation of routing protocols

FND, TND, LND analysis on routing protocols (Number of rounds)							
Performance parameter	**LEACH**	**AODV**	**ACO**	**IACR**	**EMCBR**	**AREOR**	**Remarks**
FND (Stability)	874	1206	1136	1931	2221	2460	300% rise *w.r.t* LEACH
TND	1345	1710	1903	2896	3215	3752	250% rise *w.r.t* LEACH
LND (lifetime)	7254	8199	8375	9284	9428	9713	22% rise *w.r.t* LEACH

PLR, E^2 delay, network lifetime, number of alive nodes, number of dead nodes, and throughput. Results graphically presented and observed that the proposed AREOR protocol is performing better against the traditional routing protocols.

In the next chapter, we present the statistical validation of proposed and traditional routing protocols in WSN.

Chapter 5

Statistical validations

In a WSN, there is a need for research in design a well-suited routing protocol used for remote applications, and it may resolve the issues related to energy, packet delay, throughput. However, the primary constraint of sensor networks has limited energy sources. An approach is required for enhancing the energy usage that leads to improving the network lifetime. An enhanced clustering protocol designed, and it has shown the energy-efficient in terms of reducing energy usage and extending the network lifetime. The proposed protocol consists of two phases, one is an adaptive ranking mechanism to rank FNs and CH, and the other one is the opportunistic forwarding scheme for optimal energy usage of each SN. In the adaptive ranking technique, parameters highest remaining energy and the least distance from the N_s are considered the electing CH in every transmission. The proposed protocol improves the network lifetime and leads to improvement in MSR, E^2 delay, PDR, and EC. It was observed that the AREOR protocol showed the better statistical validation (rejects the null hypothesis) compared to traditional routing protocols with the total number of samples 30 and the confidence interval ($\alpha = 0.85$) considered for simulation.

5.1 Introduction

In a sensor network, SNs are capable of processing, sending, and receiving. However, every wireless network can easily deploy the SNs in a uniform, random, or linear based as per the remote application. Thus, it observed that a sensor network is a cost-efficient solution for updating information within the coverage radius and in the sensing region. However, the limitation of resources is the primary issue encountered in sensor networks or SNs. Usually, the available resources have less processing power, low storage, insufficient energy backup or battery, limited gain, and low communication bandwidth. A few general sensor network applications support surveillance, forestry, weather forecasting, tracking targets in the military, monitoring volcano activity, and habitat monitoring [150–152]. The sensor network has diverse classified applications that are present in Geo-Informatics System (GIS) and Intelligent Transport System (ITS) [152]. Based on the examples, wireless applications categorize into military, GIS, medical, social, industrial, and research fields. Since the wireless network does not consist of SNs, a BS is required for a remote network, giving the information to the requested medium. Systematic energy utilization is very crucial for prolonging the activities of event monitoring and updating the information. Many researchers are involved in designing and implementing an energy-efficient scheme using transmission power control, sleep, wake-up strategy, and multi-hop communication, single-hop communication [150–153].

Clustering-based routing is the best-suited approach for fault tolerance, load balancing, and reliable communication to prolong the sensor network performance parameters. SNs are responsible for sending and forwarding the packets to CH frequently or when information is needed in the clustering scheme. In each cluster, CH is responsible for intimation of power-related information, channel allocation, relay information, reforming the cluster, and controlling the routing activity depending on the BS's distance. At last, the cluster-based routing is well-organized for less usage of energy in a sensor network. Thus, a network having various distinct energy level SNs is called heterogeneous WSN, and it does not support the traditionally designed clustering protocol. A wireless network is similar to a real-time sensor network made up of distinct capability SNs to monitor various parameters. Thus, a researcher's focus is to develop the new cluster-based routing protocol to enhance/extend the network lifetime.

However, the SN with the highest remaining energy is the most optimal-choice for communicating data packets in a wireless network. An SN with higher energy backup is best suited for transmitting packets because energy usage is less at those SNs. Various approaches inferred by researchers for working with the clustering scheme as depicted in [150, 151]. Every approach has its advantages and disadvantages. In a remote application, an SN has limited power, so that which SN consists of the required energy that SN participates in sensing. Hence, the requirement of an energy optimization scheme is realized to minimize the death nodes in a wireless network. A meta-heuristic technique is for enhancing the performance of the wireless network. Heuristic approaches help extract the complete advantages of local energy saving and use its greedy nature to establish communication that is not most suited for saving global energy [154]. The meta-heuristic technique is a complete solution for the reduce energy utilization and extending the network lifetime. The meta-heuristic approach is to select the CH bassed on high residual energy [155,156]. A distributed clustering approach proposed hybrid energy and different thresholds.

5.2 Mathematical Background

5.2.1 P-value

To evaluate the statistical analysis of PDR, MSR, E^2 delay, and EC required to apply the hypothesis test. Generally, the practice stating a null hypothesis, after that, determining whether the data allow the rejection of the hypothesis. A P_{value} represents the probability of the null hypothesis is true. The P_{value} is a measure of simulated data, If, $P_{value} \leq 0.05$, is to reject the null hypothesis [157].

5.2.2 t-Test: Two-Sample Assuming Equal Variances

A paired two protocols simulated data performed using t-Test paired two-sample for means tool for ascertaining to accept or reject the null hypothesis. The given test does not involve assumptions of the variances of both samples being the same. The t-Tests is used for hypothesis validation to check the hypothesis significance of the proposed and traditional routing protocol discussed in the sub-sections.

This standard excel data analysis tool is used for t-value. The results were obtained, either positive or negative, based on the sample data.
Table 5.5 shows every sample's records, and the t-Test equal variance is used for the null hypothesis.

Here H_0: $\mu 1$ - $\mu 2 = 0$; that means the two protocols are not different. Because of the similarity of the sample variances, it is decided that the population variances will also be similar in the same manner, and thus t-Test is applied: Two-Sample Assuming Equal Variances.

Let $\bar{x}$ and $\bar{y}$ are the means of two sample sets $w.r.t$ same size n_x and n_y. If x and y have the same mean, then the time t is computed using Eq.

(5.1).

$$t = \frac{(\bar{x} - \bar{y}) - (\mu_x - \mu_y)}{s\sqrt{\frac{1}{n_x} + \frac{1}{n_y}}} \tag{5.1}$$

has DF is T(n_x + n_y - 2) where,

$$n^2 = \frac{(n_x - 1)n_x^2 + (n_y - 1)n_y^2}{(n_x - 1) + (n_y - 1)} \tag{5.2}$$

Where s is a set of values from the sample, n_x, n_y are two different samples, and n^2 is the mean of two samples. t is the value of the significant value of n^2 is computed using Eq. (5.2).

5.3 Statistical validation of AREOR Vs. traditional routing protocols

Using statistics to show the AREOR protocol's effectiveness is a good idea over MSR, PDR, and EC, E^2 delay. However, the statistics are chosen much about the distribution of data. It would be more complete to include other important statistics such as mean (variable), standard deviation, total number of observations are 30, and confidence interval ($\alpha = 0.05$) shown in the Table 5.1, Table 5.2, Table 5.3 and Table 5.4.

5.3.1 Statistical analysis for MSR

Table 5.1 presents the detailed result and analysis for two-sample assuming equal variances, a lower tailed t-test with a significance level of 5% *w.r.t.* the time of AREOR protocol along with compared traditional routing protocols. An optimal algorithm requires effective MSR; we tested our results and found the AREOR protocol as significant than traditional routing protocols.

Table 5.1: Statistical analysis for MSR

Comparison	**Significance value**	**Rejected Hypothesis**	**Research answer**
LEACH-AREOR	0.028	H_0	Significantly yes
AODV-AREOR	0.036	H_0	Significantly yes
ACO-AREOR	0.04	H_0	Significantly yes
IACR-AREOR	0.042	H_0	Significantly yes
EMCBR-AREOR	0.048	H_0	Significantly yes

Table 5.2: Statistical analysis for PDR

Comparison	**Significance value**	**Rejected Hypothesis**	**Research answer**
LEACH-AREOR	0.014	H_0	Significantly yes
AODV-AREOR	0.021	H_0	Significantly yes
ACO-AREOR	0.05	H_0	Significantly yes
IACR-AREOR	0.4	H_a	Significantly no
EMCBR-AREOR	0.046	H_0	Significantly yes

5.3.2 Statistical analysis for PDR

Table 5.2 presents the detailed result and analysis for two-sample assuming equal variances, a lower tailed t-test with a significance level of 5% *w.r.t.* the time of AREOR protocol along with compared traditional routing protocols. An optimal algorithm requires effective PDR. We tested our results and found the AREOR protocol as significant than traditional routing protocols except for the IACR protocol.

Table 5.3: Statistical analysis for EC

Comparison	**Significance value**	**Rejected Hypothesis**	**Research answer**
LEACH-AREOR	0.024	H_0	Significantly yes
AODV-AREOR	0.036	H_0	Significantly yes
ACO-AREOR	0.009	H_0	Significantly yes
IACR-AREOR	0.034	H_0	Significantly yes
EMCBR-AREOR	0.04	H_0	Significantly yes

5.3.3 Statistical analysis for EC

Table 5.3 presents the detailed result and analysis for two-sample assuming equal variances, a lower tailed t-test with a significance level of 5% *w.r.t.* the consumption of energy of AREOR protocol along with compared traditional routing protocols. An optimal algorithm requires less EC; we tested our results and found the AREOR protocol as significant compared to traditional routing protocols.

5.3.4 Statistical analysis for E^2 delay

Table 5.4 presents the detailed result and analysis for two-sample assuming equal variances, a lower tailed t-test with a significance level of 5% *w.r.t.* the E^2 delay of AREOR protocol along with compared traditional routing protocols. An optimal algorithm requires less E^2 delay; we tested our results and found the AREOR protocol as significant compared to traditional routing protocols except for the ACO and IACR protocols.

Table 5.4: Statistical analysis for E^2 delay

Comparison	**Significance value**	**Rejected Hypothesis**	**Research answer**
LEACH-AREOR	0.03	H_0	Significantly yes
AODV-AREOR	0.042	H_0	Significantly yes
ACO-AREOR	0.056	H_a	Significantly no
IACR-AREOR	0.06	H_a	Significantly no
EMCBR-AREOR	0.05	H_0	Significantly yes

5.4 Discussion

The example data-sets are taken from a population of 30 iterations of each protocol simulation. The paired t-test is used to determine whether the average score of the proposed protocol has shown improvement compared to the average EMCBR score as shown in Table 5.5. The following example is for a better understanding of these results:

In the given example, the Confidence Interval (CI) is fixed with 0.05, if the significance value (P-value) is above the CI, the null hypothesis is accepted, and no considerable difference is noticed in a sample of 30 rounds, that means no significant gain achieved on this evaluation. Our simulation table results show that the P-value is less than or equal to 0.05, which means the AREOR achieved a considerable gain on traditional protocols with a sample of 30 records.

5.5 Summary

In this chapter, we discussed the results of AREOR, and traditional routing protocols are evaluated to justify the statistical validations based on performance parameters. In the next chapter, we presented contributions

Table 5.5: t-Test results on proposed protocol and EMCBR

t-Test: two-sample assuming equal variances	**AREOR**	**EMCBR**
Mean	40.73285714	50.52571
Variance	13.27665714	5.497129
Observations	30	30
Pooled Variance	9.386892857	-
Hypothesized Mean Difference	10	-
df	12	-
t Stat	12.08597195	-
P(T<=t) one-tail	0.05	-
t Critical one-tail	1.782287556	-
P(T<=t) two-tail	4.46599E-08	-
t Critical two-tail	2.17881283	-

and the future scope of this thesis work.

Chapter 6

Conclusions

The proposed work includes an opportunistic routing approach- AREOR to select the best-suited FN for effective transmission. Identification of the next FN used with the help of an adaptive ranking approach. The process of selecting an FN is dependent on residual energy and minimum distance strategy. Implementation of the proposed algorithms executed in NS2 within suitable scenarios and along with testing upon different metrics such as PDR, MSR, EC, jitter, PLR, E^2 delay, alive node, and dead node analysis compared with traditional protocols such as LEACH, ACO, AODV, EMCBR, and IACR. In this manuscript, AREOR and OFNS algorithms are used for the proposed routing scheme, which partially meets the research objectives' objectives. Section 6.1 presents the contributions of this thesis work. Section 6.2 presents a brief on the future scope of this thesis.

6.1 Contribution

The major contributions of the thesis listed below,

I We proposed an opportunistic routing scheme for WSN, using an adaptive ranking approach for FNs selection and FN selection for optimal energy strategy.

II Two schemes AREOR and OFNS are proposed. The rank of an SN is computed with residual energy and distance. This calculated rank helps select efficient FNs. Each SN captures the net residual energy and node-to-node distance for/from every communication. The node has the highest net residual energy compared to other candidate nodes ranked on the top, and so on. The SN has the least rank chosen as the CH. So, the ranking mechanism is used to establish a communication path between selected nodes during transmission. The process of updating the rank is carried out after every round based on the updated remaining energy; in OFNS, communication is initialized by transferring data packets from source to CH. Once the transmission timer starts, the N_s selected the FN from the candidate set, the N_s transfers the packets to CH. In this scenario, if any FN failure, the next FN with the highest energy within the time cycle is chosen. So, the selected FN will take the opportunity to aggregating data packets and send them to CH. In case of any current FN failure within the transmission time, the FN selection process is repeated.

III In the proposed AREOR algorithm, the message success rate has shown the incremental gain of 0.078 over the existing protocols based on SN ranking and specific FNs. The gain of 0.115 for PDR as per R_t updates on every transmission. In every cluster round, N_s will select the FN for sending a maximum of packets to CH. This change will reflect on energy usage as well as the network lifetime.

IV AREOR technique shown the better performs compared with the traditional routing protocols based on FND, alive SNs, LND, and network lifetime. FND is increased up to 300%, *w.r.t* LEACH, & LND increased 22% *w.r.t* LEACH. Hence, the network availability for processing and forwarding data packets is ensured.

6.2 Future Scope

The major difficulties faced by homogeneous WSNs are listed below,

I Communication protocols require a generic SN to await its time-slot for participating in the transmission. SNs are frequently encountered by idle times because of the designated time slot mechanism, which leads to EC. An SN waiting is a limitation in both non-autonomous and autonomous routing protocols.

II In energy-efficient routing protocols, sometimes the CH receives data packets from its neighbors, then CH aggregates and sends it to the BS. If the BS is far away from the CH, it loses more energy for transmitting packets, impacting the network lifetime.

III In large networks, wastage of memory is quite routine due to SN information updates in the R_t in every transmission, and it shows the impacts on more packet loss and control overhead on the process of sending packets from N_s to CH, and CH to BS. Thus, efficient routing is required in autonomous routing protocols with confining parameters such as time delays for forwarding, energy threshold, and distance.

IV In energy-aware routing protocols, the packet forwarding is based on the shortest and some energy parameters considered in the routing algorithm, while considering these two parameters, no effective transmission takes place, and it impacts less throughput during the transmission.

V In a wireless network, every SN calculates the elapsed time at the last packet was sent, which causes more transmission delay.

VI Still forwarding strategy may be improved further by selecting dynamic CH.

VII Since in the given work limited SNs with high energy & least distance can become CH, whereas SNs located far-away with higher energies cannot become CH.

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