SCHOOL OF BUSINESS AND SOCIAL SCIENCES
AARHUS UNIVERSITET

GREEN MULTI-OBJECTIVE HYBRID ROUTING IN WIRELESS SENSOR NETWORK WITH CROSS-LAYER OPTIMIZATION APPROACH

A thesis submitted to the
School of Business and Social Sciences,
Department of Business Development and Technology
Aarhus University

In the partial fullfilment of requirements fo the degree of

DOCTOR OF PHILOSOPHY

June 2018

Nandkumar Prabhakar Kulkarni

CTIF Global Capsule,
Department of Business Development and Technology,
School of Business and Social Sciences
Aarhus University, Herning, Denmark

GREEN MULTI-OBJECTIVE HYBRID ROUTING IN WIRELESS SENSOR NETWORK WITH CROSS-LAYER OPTIMIZATION APPROACH

A thesis submitted to the
School of Business and Social Sciences,
Department of Business Development and Technology
Aarhus University
In the partial fullfilment of requirements fo the degree of

DOCTOR OF PHILOSOPHY

June 2018

Nandkumar Prabhakar Kulkarni

CTIF Global Capsule,
Department of Business Development and Technology,
School of Business and Social Sciences
Aarhus University, Herning, Denmark

Thesis submitted:

PhD supervisor: Professor Ramjee Prasad,
CTIF Global Capsule (CGC), Department of Business Development and Technology, Aarhus University, Herning, Denmark.

PhD co-supervisor: Professor Neeli Rashmi Prasad,
International Technological University (ITU),
San Jose, USA.

PhD committee: Dr. Sofoklis Kyriazakos,
Associate Professor, Business Development and Technology, Aarhus University,
Chairman of Assessment Committee

Professor Kwang Cheng Chen,
Department of Electrical Engineering,
University of South Florida,
Member of Assessment Committee

Professor Frederic Harris,
Department of Electrical and Computer Engineering,
University of California San Diego,
Member of Assessment Committee

PhD Series: Future Technologies for Business Ecosystem Innovation (FT4BI), Department of Business Development and Technology (BTECH), School of Business and Social Sciences, Aarhus University, Herning, Denmark.

CV

Nandkumar Kulkarni received a Bachelor of Engineering (B.E.) degree in Electronics Engineering from Walchand College of Engineering, Sangli, Maharashtra, (India) in 1996. He has been with Electronica, Pune from 1996 -2000. He worked on retrofits, CNC machines and was also responsible for PLC programming. In 2000, he received the Diploma in Advanced Computing (C-DAC) degree from MET's IIT, Mumbai. In 2002, he became Microsoft Certified Solution Developer (MCSD). He has over 20 years of experience both in industry and academia. From 2002 onwards he is working as a faculty in Pune University. From 2002 to 2005 he worked as faculty in Electronics and Telecommunications Department at GSMCOE, Pune. In 2005, he joined Electronics and Telecommunications Department at RSCOE, Pune and worked as a faculty till 2007. Since 2007, he is working in SKNCOE, Pune as a faculty in IT Department. He completed a Master of Technology (M.Tech) degree in Electronics Engineering from College of Engineering, Pune (India) in 2007. Currently, he is a Ph.D. scholar in Center for TeleInfrastruktur (CTIF), Electronic Systems Department at Aalborg University, Aalborg, Denmark. His area of research is WSN, VANET, and Cloud Computing. He has more than 30 journals and conferences publications.

DANSK RESUME

Nandkumar Kulkarni modtog en bachelor i ingeniørfag (B.E.) i elektronikingeniør fra Walchand College of Engineering, Sangli, Maharashtra (Indien) i 1996. Han har været hos Electronica, Pune fra 1996 -2000. Han arbejdede med eftermontering, CNC-maskiner og var også ansvarlig for PLC programmering. I 2000 modtog han Diploma i Advanced Computing (C-DAC) grad fra MET's IIT, Mumbai. I 2002 blev han Microsoft Certified Solution Developer (MCSD). Han har over 15 års erfaring både i industri og akademi. Fra 2002 arbejder han som fakultet i Pune Universitet. Fra 2002 til 2005 arbejdede han som fakultet i Elektronik og Telekommunikationsafdelingen på GSMCOE, Pune. I 2005 sluttede han Electronics and Telecommunications Department på RSCOE, Pune og fungerede som fakultet indtil 2007. Siden 2007 arbejder han i SKNCOE, Pune som fakultet i IT-afdelingen. Han gennemførte en Master of Technology (M.Tech) grad i Electronics Engineering fra College of Engineering, Pune (Indien) i 2007. I øjeblikket er han ph.d. Lærer i Center for TeleInfrastruktur (CTIF), Afdeling for Elektroniske Systemer på Aalborg Universitet, Aalborg, Danmark. Hans forskningsområde er WSN, VANET og Cloud Computing. Han har mere end 15 tidsskrifter og konferencer publikationer.

ENGLISH ABSTRACT

The Internet of Things (IoT) has pinched substantial attention from the researchers recently. IoT is well thought-about as a part of the future Internet and will encompass billions of smart/intelligent heterogeneously connected physical objects or devices. These device, known as ‘things, are capable of intermingling without human involvement. According to McKinsey Global Institute, research supports IoT will have an enormous impact on global economy and the estimation is as high as $6.2 trillion by 2025. In endowing the dream of IoT, the thesis contributes in three different phases, Wireless Sensor Networks (WSNs), Cloud and Vehicular Adhoc Network (VANET).

Preliminary applications developed in IoT are in healthcare, transportation, automotive industries smart infrastructure, supply chains/ logistics, and social applications. WSNs is one of the key enabling technologies for the IoT paradigm. WSN take along more affluent skills for both detecting and actuation for IoT applications. The requirements of WSN routing protocols vary depending on the application. Aspects such as energy-efficiency, latency, Quality of Service (QoS), mobility, distribution density or cost, all influence the choice of routing protocol and its parameters. Therefore, no single routing protocol that matches with different types of WSNs and the best results can only be achieved by tailoring the routing protocols for a particular application or scenario.

The major contribution of the thesis lies in designing Multi-Objective hybrid routing methods that are energy efficient. Interactions between the layers of WSN are required to imitate energy efficient routing methods. Further, this thesis explores the use of cross-layer optimizations to enhance energy efficiency of the proposed routing methods.

In the first part, this thesis presents original MOHRA designed in view of hierarchical, cluster-based networks. Based on a critical analysis Multi-objective Hybrid Solutions for WSNs provides significant improvements regarding energy savings, throughput, and packet delivery. The thesis proposes the second algorithm MMOHRA designed for hierarchical network topologies with mobile sensor nodes. MMOHRA deals with dynamically changing connections due to mobility. The thesis also put forwards the third routing mechanism called as G-MOHRA uses hierarchical clustering for static sensor nodes. G-MOHRA utilizes independent metrics those are said to be clashing with one another and delivers Pareto-optimal solutions. The thesis explores the fourth algorithm entitled QoS Assured MOHRA designed for Heterogeneous WSN. Q-MOHRA balances the performance of the network in different traffic conditions. Satisfying linking among the nodes and exploiting the network lifespan is needed consideration in WSN. To tackle these two problems, the thesis explores MOHRA for heterogeneous WSNs (H-MOHRA).

All proposed schemes extend the network lifetime, and they are efficient despite the scarcity of resources.

In WSN, the position of sensor nodes affects several QoS parameters such as coverage, energy consumption, delay, connectivity and throughput. Deciding ideal node location is a very exciting and difficult task. The research investigates different deployment strategies and recommends an innovative positioning policy called as QRD to escalate the lifespan of WSN. The performance of QRD compared with the traditional random and fixed node deployment strategies in WSN.

A novel idea for the convergence of VANET and Cloud is presented here as a case study for MOHRA, taking into accounts IoT vehicular applications. The prime goal of this work is utilize MOHRA for routing VANET data to the sink and further sending it on cloud. Further the contribution of the proposed system is that it reduces storage overhead on the cloud server. Taxonomy of VCC is also the substantial contribution of this thesis to give scope to VANET and Cloud researchers.

Keywords: Cross-Layer Optimization, Multi-Objective, Hybrid, Cluster, Energy Efficiency, QoS, Green Routing, Mobility, Heterogeneous, VANET, cloud, vehicular cloud, deployment, quasi, compression, encryption, storage overhead, and Wireless Sensor Network (WSN).

DANSK SUMMARY

Internet of Things (IoT) har på det seneste fået en betydelig opmærksomhed fra forskerne. IoT er i høj grad tænkt som en del af det fremtidige internet, og vil omfatte milliarder af smarte/intelligente heterogene, forbundene fysiske objekter eller enheder. Disse enheder, der er kendt som "ting" (things), er i stand til at forbinde sig/blande sig uden menneskelig inddragelse. Ifølge McKinsey Global Institute vil forskningsstøttet IoT have en enorm indvirkning på den globale økonomi, og estimatet er så højt som $ 6,2 billioner i 2025. Ved at udnytte drømmen om IoT bidrager afhandlingen i tre forskellige faser Wireless Sensor Networks (WSNs), Cloud, og Vehicular Adhoc Network (VANET).

De første basisapplikationer udviklet i IoT er inden for sundhedssektoren, transport, bilindustrien, smart infrastruktur, forsyningskæder/logistik og sociale applikationer. WSNs er en af de vigtigst aktiverende teknologier til IoT-paradigmet. WSN omfatter flere og mere rummelige færdigheder til både detektion og aktivering af IoT applikationer, end man hidtil har kunne opnå. Kravene til WSN routing protokoller varierer afhængigt af applikationen. Aspekter som f.eks. energieffektivitet, ventetid, servicekvalitet (QoS), mobilitet, distributionstæthed eller omkostning har alle indflydelse på valget af routingprotokol og dets parametre. Derfor kan en routingprotokol, selv om den matcher forskellige typer WSN'er og de bedste resultater, kun opnås ved at skræddersy routingsprotokollerne til et bestemt program eller scenario.

Det primære bidrag i afhandlingen ligger i at designe Multi-Objective hybrid routing metoder, der er energieffektive. Interaktioner mellem lagene af WSN er nødvendige for at efterligne energieffektive routing metoder. Desuden undersøger denne afhandling brugen af tværlagsoptimeringer for at forbedre energieffektiviteten af de foreslåede routingmetoder.

I første del præsenterer denne afhandling original MOHRA, designet i lyset af hierarkiske, klyngebaserede netværk. Baseret på en kritisk analyse giver Multi-Objective Hybrid Solutions for WSNs betydelige forbedringer vedrørende energibesparelser, gennemstrømning og ’pakke levering’. Afhandlingen foreslår den anden algoritme MMOHRA, designet til hierarkiske netværks-topologier med mobile ’sensor nodes’. MMOHRA beskæftiger sig med dynamisk skiftende forbindelser på grund af mobilitet. Afhandlingen fremsætter også den tredje rutemekanisme, der kaldes G-MOHRA, som bruger hierarkisk klyngedannelse (clustering) til statiske sensorknudepunkter. G-MOHRA udnytter uafhængige matrixer, som siges at støde sammen med hinanden, og leverer Pareto-optimale løsninger. Afhandlingen undersøger den fjerde algoritme med titlen QoS Assured MOHRA designet til Heterogene WSN. Q-MOHRA afbalancerer netværkets ydeevne under forskellige trafikforhold. Tilfredsstillende forbindelse mellem knuderne og udnyttelse af netværkets levetid er en nødvendig overvejelse i WSN. For at løse disse to problemer udforsker afhandlingen MOHRA for heterogene WSNs (H-MOHRA). Alle foreslåede systemer udvider netværkets levetid, og de er effektive på trods af manglen på ressourcer.

I WSN påvirker positionen af sensor noder flere QoS parametre såsom dækning, energiforbrug, forsinkelse, tilslutning og gennemstrømning. Beslutning om ideel nodeplacering er en meget spændende og vanskelig opgave. Forskningen i denne opgave undersøger forskellige implementeringsstrategier og anbefaler en nyskabende positioneringspolitik kaldet QRD for at eskalere levetiden for WSN. Ydelsen af QRD er her sammenlignet med de tilfældige, traditionelle strategier og fast node-implementering i WSN.

En ny ide for konvergensen af VANET og Cloud præsenteres her som et casestudie for MOHRA, idet der tages hensyn til IoT-køretøjsapplikationer. Hovedformålet med dette arbejde er at udnytte MOHRA til at dirigere VANET-data til modtageren og sende det videre til skyen. Endvidere er det foreslåede systems bidrag, at det reducerer lager-overhead på cloudserveren. VCC's taxonomi er også det væsentlige bidrag af denne afhandling for at give plads til VANET og Cloud forskere.

Nøgleord: Cross-Layer Optimization, Multi-Objective, Hybrid, Cluster, Energieffektivitet, QoS, Green Routing, Mobilitet, Heterogen, VANET, Cloud, Vehicle Cloud, Deployment, Quasi, Komprimering, Kryptering, Storage Overhead og Wireless Sensor Network WSN).

ACKNOWLEDGEMENTS

In Indian philosophy, God, Guru (teacher), family and friends are the three principle factors behind the success of any endeavor. First and foremost, I wish to thank the Almighty God, who has guided me through the good and bad periods.

I am very much blessed to have Prof. Ramjee Prasad, Founder President, CTIF Global Capsule, Aarhus University, Herning, Denmark as my supervisor. I learned a lot from him, and my learning was not limited to the thesis work. He educated me the value of hard work and the right meaning of research ethics.

I express my deep sense of gratitude and respect to Prof. Neeli Rashmi Prasad. It was not possible to complete the work without her support and guidance. My thank goes to her for keenly observing and participating in my progress. She helped me in the formulation of the problem and deciding the path.

I express sincere thanks to Dr. Nisha Gupta for guiding and helping me in this work. I am very much thankful for her cooperation. I am very much grateful to Prof. Horia Cornean for guiding and helping me to complete my research.

I am thankful to the management of STES, Pune. I am indebted to Hon. Founder President of STES, Prof. M. N. Navale, Founder Secretary of STES, Dr. Mrs. S. M. Navale, Vice President (HR), Mr. Rohit M. Navale, Vice President (Admin), and Mrs. Rachana Navale- Ashtekar. The Institution has provided a doorstep opportunity to enhance technical knowledge and upgrade the qualification with full funding.

I offer my respect to Dr. A.V. Deshpande, Dr. S. S. Inamdar and Dr. S. D. Markande - the source of inspiration, Dr. M.S. Gaikwad - strong supporter, and Dr. K. R. Borole - Motivator, and well-wisher and all my GISFI fellow colleagues.

My special thanks to Mrs. Jyoti Prasad, Mr. Rajiv Prasad and Mrs. Mayuri Prasad for making my visit much comfortable with their love and support. Their affection and care were memorable.

Finally, I acknowledge blessings of my father Mr. Prabhakar Kulkarni, mother Mrs. Hemlata Kulkarni and brother Dattatray, Shreeyash with family. I would like to thank my in-laws Mr. Bhalchandra Kulkarni, and Mrs. Surekha Kulkarni for their support. I recognize the encouragement, and moral support, provided by beloved life partner Dr. Sushama, and son Soham from the bottom of the heart, their smile always helped me to come out of difficulties – Good Motivators.

My special thanks go to Dnyaneshwar his invaluable advice, constant support, and encouragement. I also thank all my department colleagues at SKNCOE, Pune especially, Sara, Pranav, Lalit, Ravindra, Nivedita for their motivation, and kind support. Last but not the least; I would like to thank all helping hands involved in the journey of thesis and research work.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

Acronyms	**Abbreviations**
$	Dollar
AACOCM	Advanced Ant Colony Algorithm based On Cloud Model
ACQUIRE	ACtive QUery forwarding In Sensor nEtworks
AEC	Average Energy Consumption
AODV	Adhoc On-demand Distance Vector
BAN	Body Area Network
BEENISH	Balanced Energy Efficient Network Integrated Super Heterogeneous
CADR	Constrained Anisotropic Diffusion Routing
CASER	Cost-Aware-SEcure-Routing
CBL	Chain Based Leach
CC	Cloud Computing
CDL	Color theory based Dynamic Localization
CEER	Color-theory based Energy Efficient Routing
CH	Cluster Head
CLO	Cross-Layer-Optimization
CMWSN	Cluster-based Mobile Wireless Sensor Networks
DCRP	Direct Communication Routing Protocols
DD	Directed Diffusion
DSDV	Destination Sequenced Distance Vector
DSR	Dynamic Source Routing
DSRC	Dedicated Short Range Communication
DyMORA	Dynamic Multi-Objective Hybrid Routing Algorithm
EDCS	Efficient and Dynamic Clustering Scheme
EDDEEC	Enhanced Developed Distributed Energy-Efficient Clustering
EDFCM	Energy Dissipation Forecast and Clustering Management
EEHC	Energy Efficient Heterogeneous Clustered scheme
EE-SEP	Energy Efficient Stable Election Protocol
EMRP	Evolutionary Mobility aware multi-objective hybrid Routing Protocol
ERP	Evolutionary based clustered Routing Protocol
ETORA	Energy-aware Temporarily Ordered Routing Algorithm
FARS	Fatal Analysis Reporting System
GAF	Geographic Adaptive Fidelity
GBR	Gradient Based Routing
GEAR	Geographical and Energy Aware Routing
G-MHORA	Green-Multi-Objective Hybrid Routing Algorithm
HAT	Hierarchical Addressing Tree
HDMRP	Heterogeneous Disjoint Multipath Routing Protocol
H-MOHRA	Hybrid-Multi Objective Hybrid Routing Algorithm
HP	Hybrid Protocol

HRA	Hybrid Routing Algorithm
HRS	Hybrid Routing Scheme
ICT	Information and Communication Technology
IoT	Internet of Things
ISP	Internet Service Provider
LEACH	Low Energy Adaptive Clustering Hierarchy.
LRC	local route constraints
MANET	Mobile Ad hoc NETworks
MEMS	Micro-Electro-Mechanical-Systems
MERR	Minimum Energy Relay Routing
MMHORA	Mobility-aware Multi-Objective Hybrid Routing Algorithm
MOEA/D	Multi-Objective Evolutionary Algorithm based on Decomposition
MOHRA	Multi-Objective Hybrid Routing Algorithm
MOO	Multi-Objective Optimization
MOPSO	Multi-Objective Swarm Optimization
MOR	Multi-Objective Routing
MQoSR	Multi-Objective QoS Routing
MWSN	Mobile Wireless Sensor Network
NIST	National Institute of Standards and Technology
NRL	Normalized Routing Load
NW	Network
ODMs	Original-Device Manufacturers
OEMs	Original-Equipment Manufacturers
PaaS	Platform-as-a-Service
PAH	Power Aware Heuristic
PDR	Packet Delivery Ratio.
PEGASIS	The Power-Efficient GAthering in Sensor Information Systems
PRA	Proactive Routing Algorithm
Q-MOHRA	QoS Assured Multi-Objective Hybrid Routing Algorithm
QoS	Quality of Service
QRD	Quasi-Random Deployment
RD	Random Deployment
REDM	Robust and Energy efficient Dynamic routing
RO	Routing Objective
RR	Rumor Routing
RREQ	Route Request
RSSI	Received Signal Strength Indicator
SaaS	Software-as-a-Service
SEER	Simple Energy Efficient Routing
SELAR	Scalable Energy-Efficient Location Aided Routing Protocol
SHRP	Simple Hybrid Routing Protocol
SOF	Single Objective Function
SOP	Self-Organizing Protocol
SOR	Single Objective Routing

SPIN	Sensor Protocols for Information via Negotiation
STaaS	Storage-as-a-Service
TEEN	Threshold sensitive Energy Efficient sensor Network
THCHP	Two level Hierarchical Clustering based Hybrid routing Protocol
TORA	Temporarily Ordered Routing Algorithm
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle communication
V2X	Vehicle-to-Everything
VANET	Vehicular Ad-hoc Network
VCC	Vehicular Cloud Computing
VGA	Virtual Grid Architecture Routing
WAM	Weighted Average Method
WSN	Wireless Sensor Network

CHAPTER 1. INTRODUCTION

This chapter sets the platform and describes the motivation and aim of the thesis. It highlights the key challenges of Routing Protocols (RPs) in Wireless Sensor Network (WSN). The research objectives are established. The problem statement is put into words, and the scope of the research is defined in this chapter. The scientific contributions of the work are explained in support with publications. To clarify the structure of thesis and to help readers to focus, the outline of the thesis is also provided.

1.1. INTRODUCTION

The next generation network (NW) is moving towards the Internet of Things (IoT) where all kinds of network objects will be connected to each other seamlessly [1]. Many researchers in the field expect that IoT will drive the deployment of trillions of connected devices in near future [10]. The pillars of IoT are shown in Figure1- 1

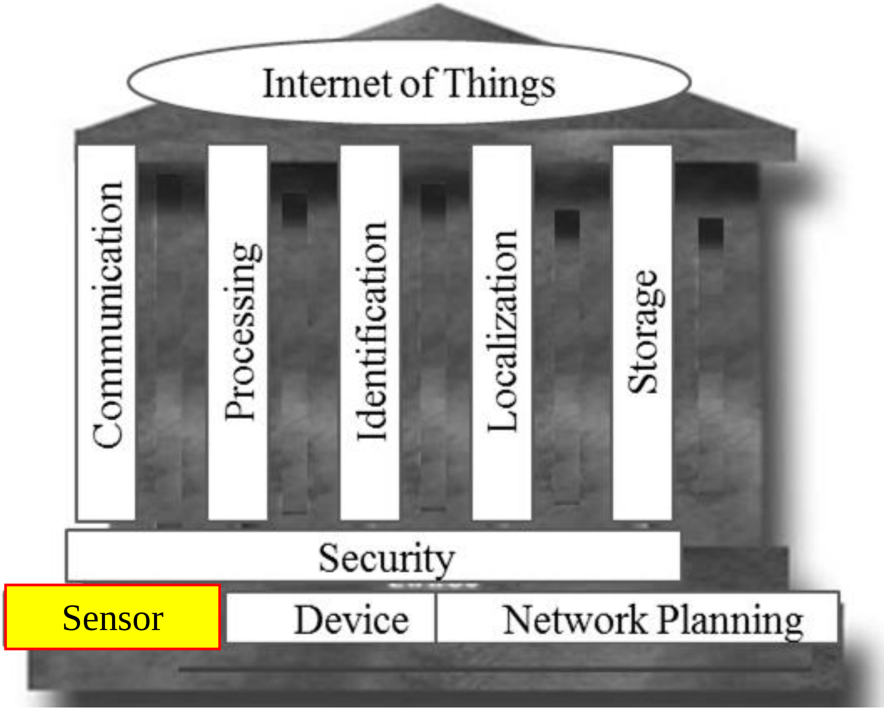


Figure 1- 1 Different Pillars of IoT.

In IoT, the core technologies for instance sensor networks, pervasive computing, augmented intelligence, augmented behavior, standards, protocols, and embedded systems are transforming traditional objects into smart/ intelligent objects[2]. The IoT facilitates these physical things to realize, make out, think and accomplish jobs by allowing them "dialogue" with each other, to share info as well as to harmonize judgments [1-3]. Applications of WSN (Ref. Figure 1-2) are wide spreading in transportation, vehicle monitoring, industrial, business application, building-, home-, weather-, and city- monitoring, and so on. [4-9].

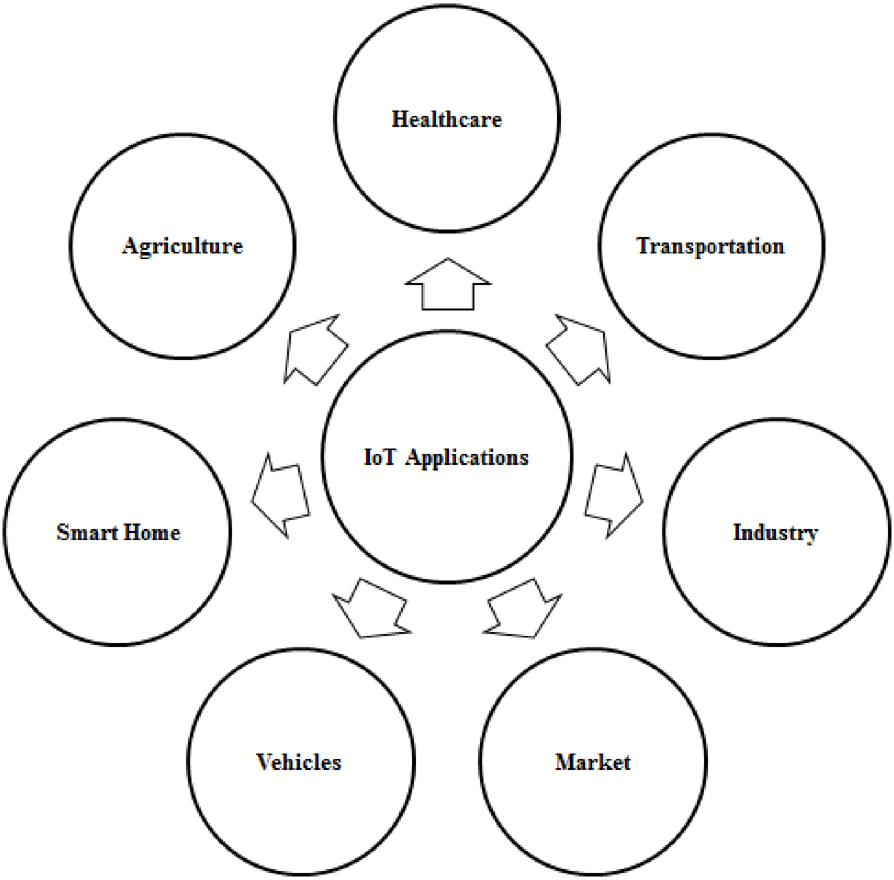


Figure 1- 2 IoT application [4-9].

The IoT offers an abundant market opportunity for the semiconductor industry, ISPs and application developers, Original-Equipment Manufacturers (OEMs), Original-Device Manufacturers (ODMs) [10].

The future lies with wireless sensors built with Micro-Electro-Mechanical-Systems (MEMS) technology and they will have an enormous impact in the construction of IoT application. By the end of 2020, the number of smart objects in IoT is expected to reach 212 billion [11].

WSNs are one of the crucial technologies for realization of the IoT paradigm [12]. In fact, WSN already cover a very wide range of applications. WSN applications for IoT such as healthcare monitoring and manufacturing are projected to have growth of $1.1–$2.5 trillion annually in the global economy by 2025 [3]. Many WSN applications have rigorous requirements, such as dense network, low cost, energy efficient, unattended service, ease of positioning of the sensor nodes, lower maintenance cost, scalable, etc. These stringent requirements make use of WSN in IoT thought-provoking.

1.2. MOTIVATION AND NEED

Now a day, WSN is an innovative area in wireless technology. WSN can give a minimal effort answer for collecting data of everyday problems, for example, e.g. Habitat-, battlefield-, disaster-, health- monitoring, and so on. WSNs comprise of widespread number of sensor nodes distributed over a terrestrial region. As shown in Figure 1-3 every modest sensor nodes comprises of Sensing-, Processing-, Communication-, and power-, and sub-systems [13].

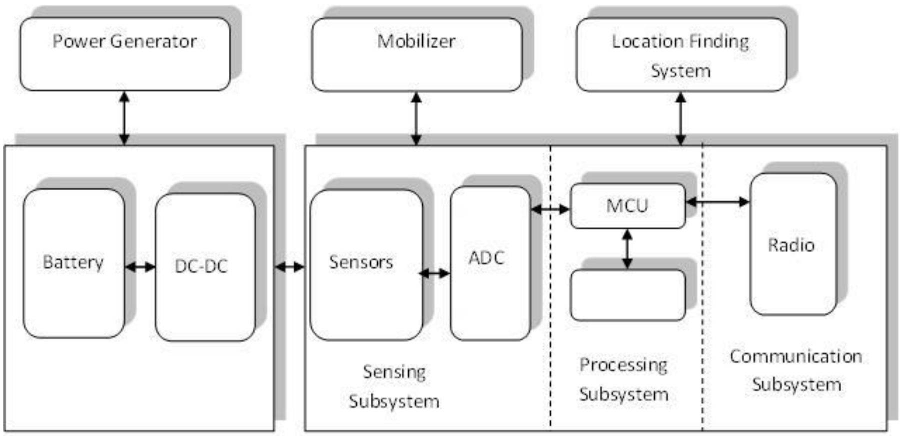


Figure 1- 3 Physical view of sensor node (source [13]).

With WSN, fundamental concern for increasing the network lifetime are detection range, placement, memory-, energy- utilization, computational- , and communication- difficulty, and so on [14][15]. A sensor can detect-, compute-, also transmits- information. Within utmost circumstances, that is challenging to rejuvenate or replace the cell as it has limited power. With exhausted batteries the sensor nodes are impractical. Therefore, it is exciting and thought-provoking to propose everlasting WSN by means of the energy imperatives [16-17].

Every protocol at every layer within WSN ought to be energy competent. The data forwarding mechanism vary subject to the application and the network. Characteristics such as energy-efficiency, latency, QoS, mobility, distribution density or cost, all influence the choice of routing protocol. In the strategic planning utmost care ought to be taken for selection of the mechanism for forwarding data to improve the lifespan of the NW [18].

To take care of the routing in WSN needs scheduling, policy, and deployment. Optimization plays a vital part in WSNs. The route optimization problem typically offers Multi-Objective-Optimization (MOO) wherever many required intents contend by means of one another [19-23]. The choice taker has to pick one compromised way out. The MOO depends on the type of the usage, the detecting setup and put-in/put-out of the issue. The problem of enhancement in WSNs routing can be roughly characterized within Single-Objective-Optimization (SOO) also MOO. In SOO, the focal point of the optimizer is to pick the path reinforced on either minimizing or maximizing specific objective under numerous constraints. Most of the practical routing issues comprise multiple objectives. In MOO the selection of route is based on numerous intents, wherever all intents must be enhanced together. In routing the packets, this optimization criterion in MOO makes it a hard mission also indeed a burning theme of research [24-29]. In MOO there exists several finest solutions, and one has to choose the best among them. In MOO the optimization task can be attempted using various methods [30]. One method is to club several objectives to one performance metric by allocating different weights to dissimilar objectives and then carry out SOO. In this thesis this policy of MOO is adopted. Weights can be allotted to several contradictory objectives using numerous ways viz. direct assignment, Min-Max etc. [31]. MOO problem in WSN is described in general in Figure 1- 4 where likelihoods of Input, Output, Constraint and Objective section are given.

1.3. RELATED WORK

Multi-Objective Routing (MOR) mechanisms are classified based on the type of sensor node either homogeneous- heterogeneous-, hybrid- type. The MOR is also dependent on deployment (Ref. Figure 1-5). The comparison and classification of various MORs is illustrated in Table 1-1

1. MORs mechanisms based on the Homogeneous type of Sensor Nodes

In this category of MOR mechanisms, most of the algorithms use flat topography and used for generic purpose except few. In flat topography, the designers consider the entire topography as one NW, and all the nodes are identical. These MOO mechanisms consider energy-efficiency as a prime goal of optimization along with the secondary goals such as enhancing lifespan, reliability, delivery ratio in the NW, and reducing the latency [32-38].

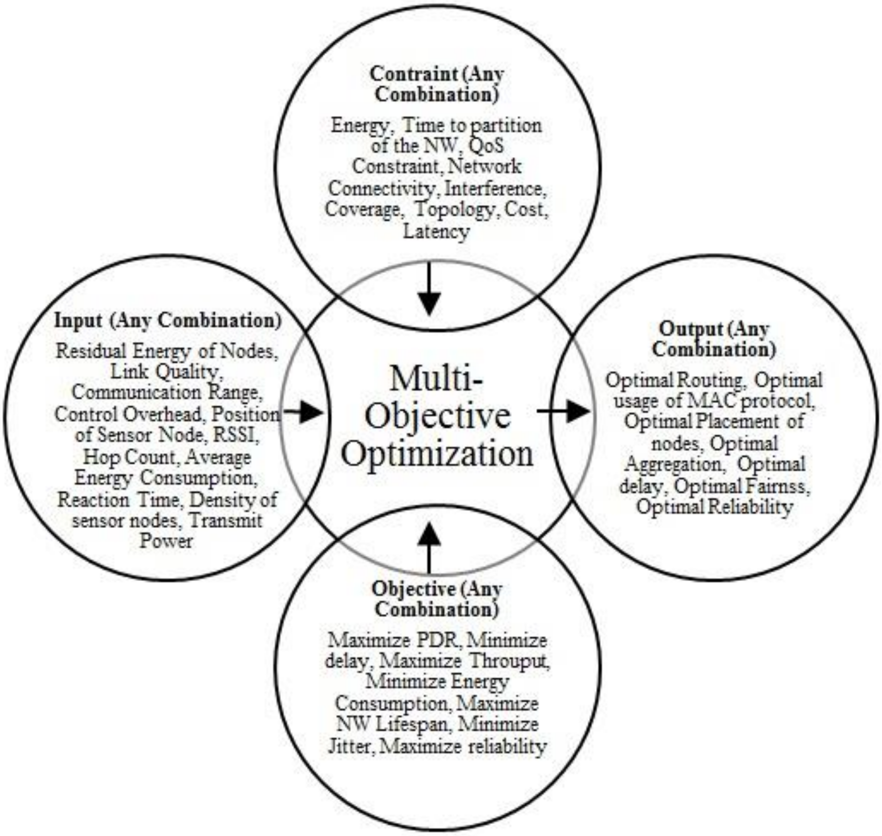


Figure 1- 4 MOO Problem in WSN.

In [32], the authors offered a time critical service scheme for duty-cycle WSNs, which takes concurrently benefit, consistency, interval, and price in concern. Under this scheme, authors developed a repetitive procedure to calculate the effectiveness of every message transported. Depending on this concept, the authors proposed two time-sensitive-utility-based routing mechanisms for the not-allowed/allowed retransmission to enhance the predictable usefulness of every message transported. A unique a safe and well-organized Cost-Aware-SEcure-Routing (CASER) mechanism is proposed in [33] for WSN. The purpose is to even-up the energy depletion and increase NW lifespan. It provisions several routing schemes in dispatching the information without banking on overwhelming the NW. It uses random-walk and deterministic forwarding. The authors have formulated a measurable structure to stabilize the energy depletion. The authors claim to develop hypothetical formulas to evaluation the hop- and security- requirements. Based on the energy depletion fraction the authors have proposed a non-uniform node placement strategy. In [34] the authors have considered a new active, multi-way, and potential-based mechanism for dispatching the information named reliable delay discriminated mechanism for WSNs. The intention is to enhance

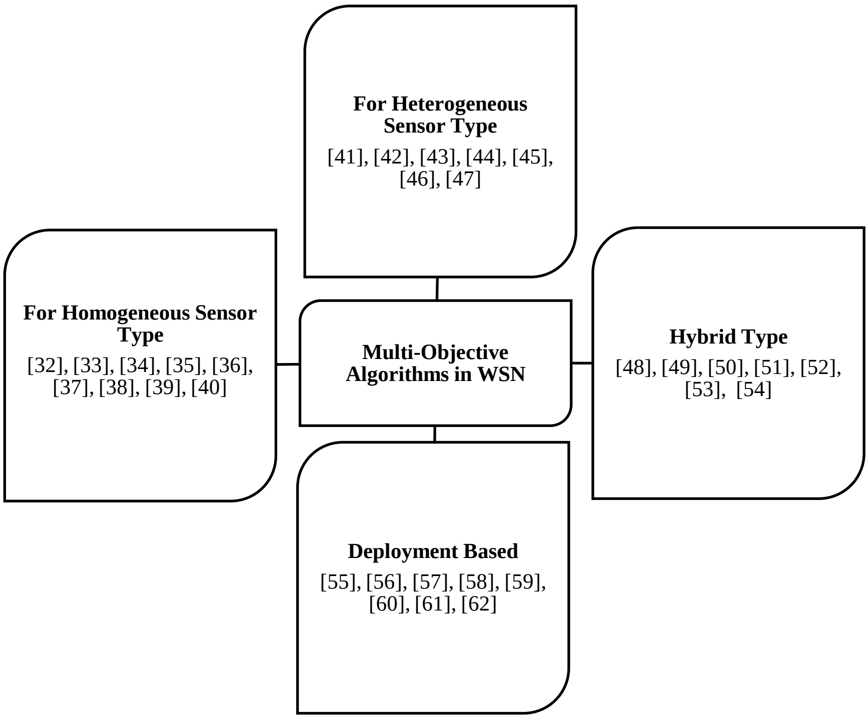


Figure 1- 5 Types of MO Routing Algorithms in WSN.

trustworthiness of the data, also to condense the latency at the same time. The proposed algorithm is based on Lyapunov-drift philosophy. The proposed strategy streamlines the operation as it only depends on native info. It has decent scalability and satisfactory communication operating cost. The authors in [35] projected a disseminated and adaptive data-centric MO QoS-aware, flexible routing mechanism for BAN, for numerous traffic classes. In this a lexicographic enhancement strategy is used for improving the QoS necessities and energy overheads. The data dispatching mechanism is native and free from traffic classes. The authors considered physical positions of the nodes to get native info. This strategy is beneficial for flat topography where enhancing trustworthiness is a major goal. A dispersed many to one multi-way scheme for forwarding the data is proposed in [36]. The purpose of the proposed mechanism is to condense hop count, to improve the energy depletion and the free-space-loss. These MO were further improved by the SPEA2 algorithm aiming to reduce the packet-dropping rate. This strategy is convenient for flat topography and for generic applications. A routing strategy built on Fuzzy Logic, namely the Fuzzy-MOR-max-lifespan-min-delay (FMOLD) is proposed in [37] for discovering a route from source-to-sink to enhance lifespan and latency. Fuzzy membership functions, as well as guidelines, are utilized for the cost calculation for MOO along with gathering function. This scheme is an example of on-demand protocols where it tries to find the best route without a priori knowledge of any forthcoming routing requirements. Further, this routing mechanism has no knowledge about data rates at the starting node. This scheme has little complexity, fast confluence time, and low scalability. In [38] the authors discuss mainly about NW lifespan expansion and the rate sharing mission aiming with consistent data transportation. A NW utilization-maximization (NUM) framework for imposing equality on source rate is a major contribution of this research. To assure consistency in dialogue, hop-by-hop retransmission method is implemented. The authors have tackled the entire issue from the transport layer's perception. A well-organized and fully scattered rate allocation scheme is suggested to approximate the MOO solution. The convergence time using the NUM framework is less. INSPSO [39] uses upgraded non-dominated sorting PSO method applied to uneven clustering in order to resolve hot-spot problem. INSPSO adopted MOO to extend n/w lifespan. The aim of INSPSO is to decrease the extreme no of hops utilized by N gateways, decrease the energy depletion as well as inconsistencies of energy dissipated via every single gateway during intra-cluster exchange, to enhance the lifespan of the gateway that has smallest lifespan in the n/w. MOSFP by Shehadeh et al. [40] is a MOO algorithm developed to mitigate glitches of smart grid applications. MOSFP enhances end-to-end delay as well as latency, n/w throughput, and energy efficiency. The researchers utilized diverse packet payload and obtained paramount value. Through trials, they computed knee and crossing point that accomplishes the trade-offs amid the four objective functions.

2. MORs mechanisms based on the Heterogeneous type of Sensor Nodes

In this group of MOR mechanisms, the designers have considered hierarchical topography. They are used for large WSNs, for self-healing NWs, for real-time and online query applications. In hierarchical topography the designers consider the logical arrangement of nodes to form a tree-like structure to cut back the energy depletion. In this type, increasing the lifespan of the NW is the prime goal. The secondary goals may be enhancing energy efficiency, maximizing the coverage etc. [41-47].

In the article [41], the authors offered a routing mechanism using intra-clustering. For that they derived original cost-function for stabilizing latency between CM and CH, also to improve the NW lifespan. The authors have taken effort in calculating a threshold for finding the effect of uninterrupted communication between CH and CM. If the cluster has a narrow topographical region then uninterrupted communication is efficient otherwise a greedy indirect-communication mechanism is used based on the outcome of the cost-function. The authors have considered the guidelines from queuing theory for determining latency. For simulation the NW the authors have considered heterogeneous-static NW with flat topography. A MOR model is established in [42] that depend on the latency, energy depletion, and packet dropping rate as its MO metrics for optimization. The article proposes an enhanced mechanism based on ACO protocol built on a cloud model. By regulating the precise parameters of every cost procedure, the mechanism adjusts skilfully to several utilities having diverse MO metric requirements. The algorithm is not light-weight. It has modest convergence time and it is adaptive to growing NW. In [43] the authors have concentrated on the data-rate-designating issue in multiple-path data dispatching in WSNs. They have assumed time-varying channel environments to enhance aggregate function and NW's lifespan. They divided the MOO issues by taking help of the standard Lagrange bifold decay technique also implemented the stochastic method for cracking the issue. This methodology has benefits of both layered- and cross-layer- design. The authors in [44] have established a QoS-aware MOR for a two-tier WSN. The planned protocol uses the NSGA-II algorithm to optimize trustworthiness and latency while reducing AEC within nodes that well enhanced the period of the NW. A large flow may be managed by a connection at the cost of reduction in delivery, and/or accumulated AEC, that successively shrinks the NW life-period. The authors have tried to optimize the data-rate, trustworthiness, and NW life-period in concurrently. The proposed protocol is adaptive with fast confluence time and modest complication during implementation. In [45] the researchers studied the effect of NW lifespan and reasonable rate-distribution in WSN as a limitation in MOO with the weighting-methodology. The problem is divided into three sub-goals by using Lagrange-dual-decomposition-strategy. The three problems namely rate-allocation mechanism, MAC conflict handling problem, and energy depletion control problem have been allocated cost using some pricing-model. They cooperate to resolve the original problem via pricing. For solving the problems distributed algorithmic rules are applied along with NUM framework. In this article, the authors have focused on cross-layer-optimization. The crucial aim of this study is to check the trade-offs between NW utilization and its lifespan [46]. The authors proposed cross-layer design structure based on the radio-resource-sharing problems and developed a distributed strategy banking on dual-decomposition tactics. By means of dual-decomposition tactics, MOO problem is divided into three sub-problems viz. combine transport and NW layer issue, a radio-resource-sharing issue, and a NW life enhancing issue. The authors have utilized dual- pricing model for the bandwidth of links and battery capabilities. An integrated Pareto MOO methodology is utilized in [47] in order to catch a combined solution for both the clustering and routing faults. The authors have anticipated multi-objective protocol based on PSO named SMPSO-CR. The protocol is framed targeting energy proficiency, consistency and scalability. SMPSO-CR design concerns no of CHs, no of CMs, link quality. The researchers have projected a healing function and an innovative encoding arrangement for building of a routing tree.

3. MORs mechanisms based on Hybrid type of Sensor Nodes

In this class of routing the developers have treated the WSN as a collection of similar- or dissimilar- or the combination- nodes. Hybrid MORs makes use of the processing intellect of more than one algorithm to get the benefit of all of them. Most of the hybrid MORs use flat- or Hierarchical- topography. These type of mechanisms are used for detection -, monitoring-, agricultural-, applications [48-55]. The primary goal of these algorithms is to curtail latency-, to improve energy efficiency and life of NW.

CIVA was developed for movable WSNs in [48] to resolve extent and lifespan issue in MOO. The operating of CIVA is modeled in two phases viz. regulate the positions and detecting range of nodes and adjusts the PTX of alive/dozing movable nodes to reduce the no of alive nodes. This algorithm uses the MO immune procedure utilizing the Voronoi figure to reposition movable nodes after original erratic placement of sensor nodes. Binary and Probabilistic model is incorporated within development of this algorithm to tackle the extent issue in the presence/ absence of obstacles. The advantage of this algorithm is being less complex and adaptive. The drawback is slow confluence time. In [49] the developers have tried to optimize the placement of transfering nodes for the purpose of energy harvesting for solving the battle within the MO design issues such as AEC, average detecting region and NW trustworthiness. Two MO meta-heuristics strategies namely ABC and FA were used for handling the problem. The work is compared with six MO meta-heuristics strategies applied to easily obtainable dataset. The authors in [50] have designed MO hybrid routing as a Fuzzy-RandoM-MOO (FRMOO) issue. The proposal concurrently handles MO particularly latency, consistency, energy, jitter, the interfering and also the energy stability side of a route. The authors assume Fuzzy-Random-Optimization (FRO) and MOO. They have presented fuzzy-random variables to outline each fuzziness and randomness of connection, latency, link consistency and nodes' enduring energy. They have also considered fuzzy-random predictable cost and standard-deviation-model. For expressly explaining the meaning of the unsure routing model, the scalar predictable cost and discrepancy of the fuzzy-random variable are announced so, the proposed routing mechanism is converted from the unclear MOO to the firm MOO. Also, a hybrid genetic mechanism supporting Pareto-optimal answer is planned for examining the optimal paths. The MOO hybrid technique banking on PSO and FL for node placement to enhance coverage, affinity and lifespan is projected by the authors in [51]. A fuzzy-inference-rule is written relying on the input parameters comparable to degree-, balance energy- of node and connection quality. Subject to the results of this logic, the nodes are classified as good, normal and bad. The good nodes are placed within the region first then the MO-PSO formula is applied for the positioning of remaining nodes. The good nodes act as the locus points. MO-PSO connects every normal and bad node to at least one good node. The authors have proved through simulation that it is reliable and proficient in node placement. FL has fast confluence time compared with PSO. In the article [52], the authors have attempted to position nodes and to fine-tune their detecting span for increasing the coverage, and lifespan with least no of nodes. They have formulated a problem for covering the target region even when few nodes become dead. Experimentation is carried out using the new proposal and existing MOO techniques such as NSGA-II, SPEA-II and MOACO. The results depict that MOACO generates more precise solution with reduced complexity. Mobile-agent-data-forwarding issue is modeled in [53] as a MOO problem. The purpose of this work is to enhance total-sensed-signal-energy whereas shrinking energy depletion and path-loss. The authors have solved this MOO problem and they have demonstrated through simulation using novel MOA such as EMOCA and NSGA-II. This tactic also enables in deciding on which forwarding algorithm is better from two alternative solutions. The decision is based on sensing accuracy. The authors have projected two new fault tolerable approaches specifically randomized-censored-averaging and median-filtering-approach. The results depict that the first approach outperform the second. Xua et al. [54] studied the extent enhancement problem in WSN keeping the balance amid n/w lifespan and range. The prime objective of this study is curtailing the energy utilization and exploiting the range. Xua et al. anticipated two algorithms namely Hybrid-MOEA/D-I and Hybrid-MOEA/D-II centered on MOEA/D. Hybrid-MOEA/D-I modeled using genetic and a differential evolutionary algorithm. By incorporating a particle swarm algorithm into Hybrid-MOEA/D-I a new Hybrid-MOEA/D-II algorithm is developed.

4. MORs mechanisms based on node deployment in WSN

As the resources on board are restricted the deployment, and to perform the task becomes challenging while fulfilling the stringent QoS requirements. In this section, the MOR criteria and policies regarded for node deployment in WSNs are surveyed [55-62] while considering multiple contradictory goals namely enhancing coverage, throughput, reliability, and reducing the requirement of no of nodes.

The trade-offs between latency, throughput, and lifespan are computed in [55] by means that of a stochastic NW design method. Quantile and Quantile-Interval metrics are used to capture the fidelity and likelihood of the proposed method. An empirical multiple native search technique is attempted for getting the answer to the MOO drawbacks. The authors got motivation from the notion of potential-field in physics for this work. In [56] the researchers adopted a replacement strategy to tackle MOO issues referred to as multi-mode-switching. It incorporated the metrics comparable to energy depletion, consistency, concentration of nodes and latency. This strategy is employed for flat-topography and for generic applications. In [57] the authors have incorporate novel heuristic technique MOEA/DFD reliant on

Fuzzy-Dominance methodology. Further, they have proposed Fuzzy-Pareto-Dominance methodology to distinction over more than one solution. Scalar-Decomposition strategy is employed in a situation when one of the solutions becomes ineffective. The purpose of this MOO methodology is to reinforce coverage, lifespan, and cut back energy depletion, and also the no of nodes, while not hampering the connectivity between nodes. The proposed algorithm is flexible in a way that the judgment maker can set the limit for the metrics being employed. In [58] the investigators have deliberated the MOEA to stability small placement-cost and high consistency. To seek out the desirable solution the gap between populations from a reference set is measured, and additionally the range is taken under consideration. This strategy is appropriate for flat topography and for generic applications. This article proposes a new MO Deployment-Power-Assignment-Problem (DPAP) [59]. It's derived from MOEA/D and further molded within a group of variable sub-issues. These may be classified on priority of purpose, and handled concurrently. These sub-problems take input as native knowledge and the operators to progress the performance of MOEA/D. Evolutionary-MO-Crowding-Algorithm (EMOCA) for cracking the node positioning problem is designed in [60]. The main objectives of this design are making the most of the likelihood of universal object detection, curtailing the total energy depleted in the NW and the no of nodes to be positioned. The MOO approach at once tries to improve the three objectives to obtain numerous Pareto-optimal solutions. In [61] a precise deployment procedure centered on novel MOBSO algorithm is presented. The motivation for this deployment is scavenging activities of honey bees. The authors have well thought of two goals i.e. n/w connectivity and range. The trials are conducted in 3D and non-uniformed surroundings. MOBSO covers entire events by means of least no of sensors. In [62] the researchers offer a new technique for sensor placement, called DeVForce-AP for diverse WSN. The technique is a fusion of Delaunay-triangulation-method (D) and extended-Virtual-Force algorithm (eVForce), with the Adaptive-Parameter (AP) regulation mechanism in order to enrich detection range and n/w lifespan in presence of obstacles. The technique removes the coverage void and preserves the n/w connectivity. The complexity of the projected technique is estimated of the order of BigO of n^2.

Table 1- 1 Classification and comparison of MO routing protocols in WSN

1. **Survey of Multi-Objective Routing Algorithms for Homogeneous type of Sensor Nodes**						
Ref. [Year of Publication]	**Improvement Goal**	**Algorithm**	**MO Metric Used**	**Topography**	**Assessment Method**	**Usage**
32 [2015]	Enhance Energy Efficiency	Time-sensitive	Transferal Value, Usage, Authenticity and Delay.	Flat	Simulation	Generic
33 [2015]	Enhance Lifespan	Cost-aware	Location, Cost, Security			Generic
34 [2015]	Reduce latency	Delay differentiated	Potential field, Delay			For validity and accuracy checking
35 [2011]	Enhance Reliability	Lexicographic approach	QoS Parameters, Energy			BAN
36 [2011]	Enhance Energy Efficiency, PDR	SPEA2	Hops, Energy_Utilization and Free Space Loss			Generic
37 [2009]	Reduce latency, Enhance Energy Efficiency	FL	Residual_Energy, Lifetime_Membership			Real time
38 [2008]	Enhance Lifespan	NUM framework	Fairness of Rate Allocation			Massive WSN
39 [2017]	Prolong Lifespan, min-max no-of-hops, minimize -inter-cluster energy depletion, -variances of the energy	INSPSO	Sum_of_Left over_Energy of CH, Energy depletion of the data sent			Generic
40 [2018]	Reduce end-to-end delay as well as latency. Capitalize the n/w throughput and energy efficiency	MOSFP	crowding value, $\in -$ dominance archive, mutation operations, spread (SP), and inverted generational distance (IGD)	Grid		Smart Grid Applications

2. Survey of Multi-Objective Routing Algorithms for Heterogeneous type of Sensor Nodes

Ref. [Year of Publication]	Improvement Goal	Algorithm	MO Metric Used	Topography	Assessment Method	Usage
41 [2011]	Reduce latency, Enhance Energy Efficiency	Queuing theory	Cluster_Lifespan, Latency Between CM and Head	Hierarchical	Simulation	Generic
42 [2010]	Enhance Energy Efficiency, PDR, Reduce latency	Enhanced ACO Built on cloud architecture	Delay, Energy_ Consumption, Data- Packet-Loss	Flat	Simulation	Massive WSN
43 [2010]	Enhance Lifespan, and Aggregation	Stochastic Quasi Gradient	Random Factors of NW Message Exchage, and Environmental Elements	Hierarchical	Simulation	Online Query Apps
44 [2010]	Reduce latency, Enhance Reliability	NSGA –II	Reliability and End-to-End Delay			Real-time Apps
45 [2007]	Enhance Lifespan and NW utility	Gradient-projection	NW Lifespan and Fare_Rate_ Allocation			Cross-layer Apps
46 [2006]	Enhance Lifespan and NW utility	Sub gradient	Radio Resource Allotment Issues			Self-healing WSN
47 [2018]	Energy efficiency, reliability and scalability	SMPSO-CR	No of CHs as well as nodes, link quality	Flat	Simulation	Manufacturing Industry

3. Survey of Multi-Objective Routing Algorithms for Hybrid WSN

Ref. [Year of Publication]	Improvement Goal	Algorithm	MO Metric Used	Topography	Assessment Method	Usage
48 [2016]	Enhance Lifespan, and Coverage	CIVA	Position and the Detecting Ranges, P_{TX} of Active/Sleep Movable Nodes	Flat	simulation	Generic
49 [2015]	Enhance Energy Efficiency, Sensing Area	ABC and FA	AEC, Average Sensing Area and NW Reliability.			Agriculture
50 [2014]	Reduce latency, Enhance Energy	Fuzzy Random MOO and GA	Delay, Link-Reliability and Nodes’	Hierarchical	Simulation	Monitoring

	Efficiency		Residual-Energy,			
51 [2012]	Enhance Coverage, Connectivity, lifespan	Hybrid FL and PSO	Node Placement, Estimation error	Flat	simulation	Generic
52 [2011]	Enhance Coverage, lifespan, minify no of nodes	NSGA-II, SPEA2, ACO	Connectivity of NW, Lifetime Based on Transmission Consumption	Flat	Experiment	Generic
53 [2005]	Enhance Energy Efficiency, detection Accuracy, Reduce path loss	EMOCA, NSGA-II	Energy-Consumption, Path-Loss and Detection-Accuracy.	Hierarchical	Simulation	Generic
54 [2018]	Condense energy consumption, enhance coverage rate as well as balance of energy consumption	Hybrid-MOEA/D-I and Hybrid-MOEA/D-II	Genetic Algorithm (GA) and DifferentialEvolution (DE)	Flat	Simulation	Generic

4. Survey of Multi-Objective Routing Algorithms for optimal deployment in WSN

Ref. [Year of Publication]	Improvement Goal	Algorithm	MO Metric Used	Topography	Assessment Method	Usage
55 [2015]	Enhance lifespan, Coverage, Throughput, minify latency	Heuristic-based multiple native search	network lifetime, end-to-end communication delay and network throughput	Flat	Simulation	Real Time WSN
56 [2013]	Enhance Energy Efficiency, Coverage, minify Latency	Multimode switching protocol	energy consumption, reliability, coverage intensity, end-to-end delay			Generic
57 [2013]	Enhance Coverage, lifespan, minify energy consumption, no of nodes	MOEA/DFD	coverage, energy consumption, lifespan and the number of nodes, while maintaining the connectivity between each			Generic
58	minify no of nodes,	MOEA	Distance measure of a			Generic

[2010]	Guarantee Reliability		population from a reference set, diversity			
59 [2010]	Enhance Lifespan, and Coverage	MOEA/D	Total energy consumed by the sensor nodes and the non-coverage of the demand points			Generic
60 [2010]	minify no of nodes, Guarantee Energy Efficiency, Enhance probability of global target detection, and minify no of nodes	EMOCA	Sinal Strength, Path Loss			Event Detection
61 [2018]	Enhance network connectivity and coverage	MOBSO	bees' population proportions, maximum no of iteration as well as non-dominated bees.			Generic
62 [2018]	To advance the detecting region and n/w lifespan	DeVForce-AP	Sensor Node location, detecting range, repulsive distance of obstacle.			Generic

1.4. RESEARCH HYPOTHESIS AND METHODOLOGY

The green MO, and hybrid routing protocol are designed to obtain the energy efficiency in WSN. It decides the routing structure based on different metrics.

1.4.1. PROBLEM STATEMENT

To Design and Develop a Green (Energy Efficient) Multi-Objective Hybrid Routing Mechanism for WSN to increase the lifetime of WSN for various parameters including energy efficiency, Link-Quality, reaction-time, control-overhead and Mobility by incorporating cross-layer optimization approach.

The problem statement is divided into different sub-problems and following research questions are addressed in this thesis:

- Will hybrid routing algorithms improve the energy consumption of resource-constrained WSN?
- What will be the effect of multi-Objective routing mechanisms on the performance of WSN?
- Are Multi-Objective and Hybrid Routing Mechanisms suitable for both homogeneous and heterogeneous WSN?
- Will Multi-Objective and Hybrid Routing mechanism help to improve the performance of MWSN?
- Will the role of Cross-Layer-Optimization (CLO) approach support the MOO?
- Will this research has any business scope? Which Business-Model (BM) building blocks and types are the most significant when evolving BM?

1.4.2. RESEARCH HYPOTHESIS

Based on the previous overview of WSNs focusing on Routing algorithms including the key requirement, the research hypotheses have been identified as developing a green, and Multi-Objective Hybrid Routing Algorithm (MOHRA).

- It is hypothesized that Multi –Objective Algorithm (MOA), which is capable of considering multiple optimization criteria at the same time for routing in WSNs can help in tackling the problem of energy efficiency and throughput while providing a reasonable performance that is comparable to existing routing algorithms.
- It is also hypothesized that hybrid routing solution is energy efficient for resource constrained WSNs.
- The proposed MOA approach based on optimization theory, and it will address the energy efficiency problem in the routing of WSN.
- It is hypothesized that the proposed design of new cluster-based hierarchical routing scheme will perform better in the resource-constrained WSN.

- It is hypothesized that the CLO approach will enhance the QoS goals.
- It is hypothesized that the research has business potential.

1.4.3. METHODOLOGY OVERVIEW

The purpose of this investigation work is to build a MOHRA for WSN, which is energy efficient. The foremost contribution of the work is the design and implementation of MOHRA. The first phase of research is to analyze the current state of the art single–objective and multi-objective algorithms those are suitable for routing in WSNs with a special focus on hybrid algorithms, in particular, algorithms; those are capable of dealing with multiple objectives. The study depicted the first conclusion that multi-objective routing has a considerable influence on the overall WSN lifecycle, and providing energy efficient routing algorithm remains an apparent problem. The meticulous study had a second conclusion that energy efficiency in routing algorithm can be enhanced through the use of cross-layer optimizations. This exhaustive study has also been done to know the techniques, metrics, simulation tools and test beds used for implementation of the routing algorithm. This homework furnished an understanding of how routing algorithms are categorized, and a reference point was decided to implement the multi-objective routing algorithm using the NS-2 simulator to confirm benefit of MO mechanism algorithm. This study also gave the motivation to address hybrid routing along with multi-objective routing. The research modeled MOHRA for hierarchical clustering based WSN for the homogeneous and heterogeneous scenario. The most important task acknowledged in hybrid multi-objective routing algorithm was energy efficiency (Green), PDR, Lag, and data forwarding Overhead.

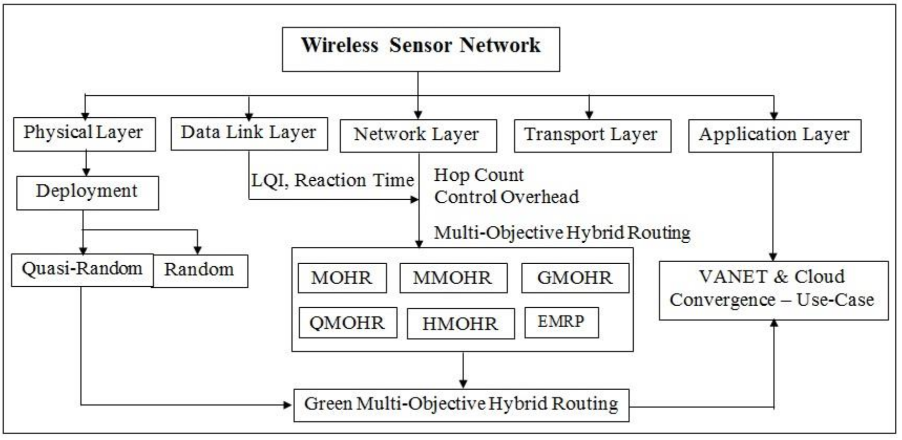


Figure 1- 6 Problem evolution

The designed routing algorithm was gauged using the NS-2 simulator. The recital of the offered routing algorithm is evaluated by considering static and mobile scenarios and the results are equated with contemporary mechanisms. The research is motivated by the fact that WSNs has widespread applications in the field of IoT in particular vehicular applications. The research proposed a framework for the convergence of Vehicular Adhoc Network (VANET) and Cloud and the business viewpoint of this framework. The evolution of the problem statement and the CLO approach is given away in Figure 1- 6.

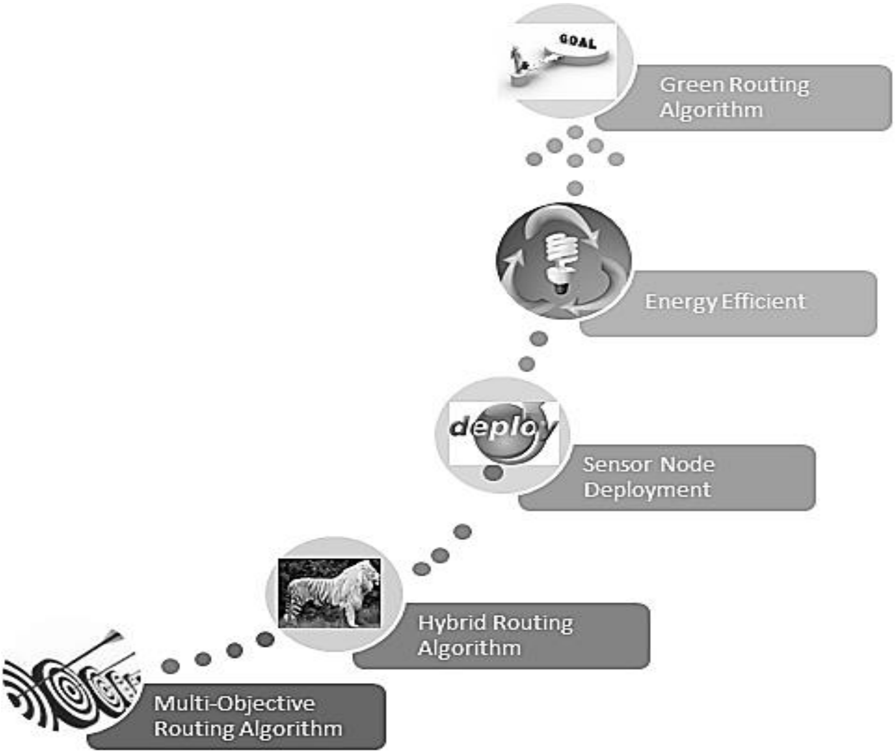


Figure 1- 7 Structure of green multi-objective hybrid routing

1.4.4. MULTI-OBJECTIVE ALGORITHM

Single-Objective-routing-Algorithms (SOA) forward the information in light of single metric, and they utilize a few settings far beyond the reference esteem. In SOA, a slight fraction of overall nodes are included in conveying information commencing the physical region to sink, and remaining nodes are futile producing network segregation or connection failure. The contribution of this thesis is routing mechanism fueled by numerous goals. Multi-Objective-Algorithm (MOA) utilizes decision science to help in consolidating, configuring, and cracking decision that includes various criteria. MOA uses AEC, Overhead, rtime, LQI, and HOP Count for choosing the finest way from point of orifin upto sink.

Movement and diverseness of the sensors laid down innovative research threats for finding power competent way outs to increase network life. The suggested Heterogeneous MOHRA (H-MOHRA) [66-68] for MWSN exploits ordered grouping. In H-MOHRA information packets are forwarded to the base station utilizing a weight function based on various parameters. The influence of energy diversity and movement of nodes on MOR is assessed in H-MOHRA. The simulation outcomes ascertain usefulness of H-MOHRA.

The second proposed contribution is an innovative QoS assured MOHRA (Q-MOHRA) [69-72] meant for WSNs. Essential objective of Q-MOHRA can be to ensure QoS even though picking an ideal path upto target in view of multiple metric criteria. The rendition of Q-MOHRA is assessed over and done with escalated simulation. Q-MOHRA dominates when contrasted with the up-to-the-minute solutions. Q-MOHRA is energy competent.

1.4.5. DEPLOYMENT

In WSN, the act of forwarding protocols is meticulously associated to the sensor distribution. The placement of nodes contrast contingent upon the applications and the network design. It is obligatory in WSN that every algorithm at every layer energy competent. In this way, in the outlining of WSN, a large portion of the consideration ought to be given placement of nodes in the target region to build the life expectancy of the network. The contribution of this research is an innovative positioning scheme known as QRD for nodes. The QRD creates profoundly uniform positions, and it scientifically fills the target area. QRD builds the network lifetime with a smallest number of nodes [70, 73]. The performance of MOHRA is equated with random and Quasi-Random positioning of the nodes.

1.4.6. CONVERGENCE OF VANET AND CLOUD

Applications of WSNs are prevalent in all fields of IoT. It has full recognition in vehicular applications too. A novel idea for the convergence of VANET and Cloud is presented in this thesis, which has broad scope in IoT applications. The primary motto of this work is to reduce storage overhead on the cloud server. Taxonomy of Vehicular Cloud Computing (VCC) is also the significant contribution of this thesis to help researchers in the field of VANET and Cloud [71].

1.5. PUBLICATIONS

The contributions have been and are in the process of being, validated through peer-review publications in book chapter, journals and conference proceedings. The relevant publications are listed below:

A. Book Chapter

1. **Nandkumar Kulkarni**, Neeli Rashmi Prasad, Tao Lin, Mahbubul Alam, Ramjee Prasad, **"Convergence of Secure Vehicular Ad-Hoc Network and Cloud in Internet of Things",** River Publications, Role of ICT for Multi-Disciplinary Applications in 2030, Edited by Leo P. Ligthart, and Ramjee Prasad, ISBN: 9788793379480, 2016.

B. Journal Publications:

1. **Nandkumar Kulkarni,** Neeli Rashmi Prasad, & Ramjee Prasad, "An Evolutionary Mobility Aware Multi-Objective Hybrid Routing Algorithm for Heterogeneous Wireless Sensor Networks", International Journal of Rough Sets and Data Analysis (IJRSDA), Volume 4, Issue 3, Article 2, Special Issue Submission: Internet of Things, Next Generation Networks, Data Mining and Cloud Computing, 2016.

2. **Nandkumar Kulkarni,** Neeli Prasad, Ramjee Prasad, "Q-MOHRA: QoS Assured Multi-Objective Hybrid Routing Algorithm for Heterogeneous WSN", An International Journal of Wireless Personal Communications, Springer Journal, ISSN 0929-6212, pp. 1-12, DOI 10.1007/s11277-017-5064-8, 2017.

3. **Nandkumar Kulkarni,** Neeli Rashmi Prasad, and Ramjee Prasad, "A Novel Sensor Node Deployment using Low Discrepancy Sequences for WSN", An International Journal of Wireless Personal Communications, Springer Journal, ISSN 0929-6212, pp. 1-14, DOI 10.1007/s11277-017-5063-9, 2017.

4. **Nandkumar Kulkarni,** Neeli Rashmi Prasad, Ramjee Prasad, "Business Model Perception of Convergence of VANET and Cloud in IoT" (To be Submitted)

C. International conferences

a. First author

1. **Nandkumar Kulkarni**, Ramjee Prasad, Horia Cornean, Nisha Gupta, "**Performance Evaluation of AODV, DSDV & DSR for Quasi Random Deployment of Sensor Nodes in Wireless Sensor Networks**", IEEE

International Conference on Devices and Communications (ICDeCom-11), PP. 1-5, 2011.

2. **Nandkumar Kulkarni**, Neeli Prasad, Ramjee Prasad, "**MOHRA: Multi-Objective Hybrid Routing Algorithm for Wireless Sensor Network**", 3rd IEEE International Conference on Wireless Communications, Vehicular Technology, Information Theory and Aerospace & Electronics Systems (VITAE), Atlantic City, NJ, USA, PP. 1-6, 2013.

3. **Nandkumar Kulkarni**, Neeli Prasad, Ramjee Prasad, "**MMOHRA: Mobility Aware Multi-Objective Hybrid Routing Algorithm for Wireless Sensor Networks**", 4th IEEE International Conference on Wireless Communications, Vehicular Technology, Information Theory and Aerospace & Electronics Systems (VITAE), Aalborg University, Denmark, PP. 1-5, 2014.

4. **Nandkumar Kulkarni**, Neeli Prasad, Ramjee Prasad, "**G-MOHRA: Green Multi-Objective Hybrid Routing Algorithm for Wireless Sensor Network**", IEEE 3rd International Conference on Advances in Computing, Communications and Informatics (ICACCI), Greater Noida, Delhi, India, PP. 2185–2190, 2014.

5. **Nandkumar Kulkarni**, Neeli Prasad, Ramjee Prasad, "**H-MOHRA: Heterogeneous Multi-Objective Hybrid Routing Algorithm for Mobile Wireless Sensor Networks**", 1st IEEE Global Conference on Wireless Computing & Networking (GCWCN), Lonavala, India, PP. 249 – 253, 2014 (Best Paper Award).

6. **Nandkumar Kulkarni**, Neeli Prasad, Ramjee Prasad, "**An Evolutionary Mobility Aware Multi-Objective Hybrid Routing Algorithm for Heterogeneous Wireless Sensor Networks**", International Conference on Internet of Things, Next Generation Networks and Cloud Computing (ICINC 2016), 2016.

b. As Co-author

1. Vandana Rohoakale, **Nandkumar Kulkarni**, Horia Cornean, Neeli Prasad, "**Cooperative Opportunistic Large Array Approach for Cognitive Radio Networks**", 8th IEEE International Conference on Communications, Bucharest, Romania, PP. 513-516, 2010.

1.6. THESIS OUTLINE

The following section provides an outline of the thesis with a brief description of the individual chapters as shown in Figure 1-8 with individual chapter contributions.

Chapter 2: Multi-Objective Hybrid Routing in WSN

Chapter 2 sets the platform for MOHRA by defining the requirement for multi-objective hybrid routing. The chapter surveys different multi-objective and hybrid routing algorithms in WSN providing a comparative analysis of MOHRA. The chapter proposes MOHRA for WSN. The next part of Chapter 2 provides a comparative evaluation of MOHRA with other MO strategies for homogeneous WSN. The comparison is carried out for with and without mobility scenario to measure the performance of MOHRA with factors such as energy consumption, delay, and throughput with erratic density of sensors.

Chapter 3: Mobility and heterogeneity aware Routing in Wireless Sensor Network

Chapter 3 deliberates the idea of QoS-aware MOHRA for dissimilar nodes within WSN. This chapter classifies different QoS algorithms. The chapter proposes two novel routing algorithms; Q-MOHRA and H-MOHRA. The chapter gives a detailed description about the conventions, network model in developing both the algorithms. The proposed algorithms are implemented using the simulator for both stationary and mobile sensor nodes. The obtained results are contrasted using the contemporary solutions. The performance of the novel routing algorithms; Q-MOHRA and H-MOHRA are better as compared with the contemporary algorithms.

Chapter 4: Deployment of Sensor Node Using quasi Sequences

Chapter 4 surveys the different node deployment strategies in WSN. The deployment of sensor nodes has crucial part in increasing/ decreasing lifespan of WSN also coverage. The chapter introduces a novel concept of sensor node deployment. The proposed deployment strategy is simulated, and results show that the proposed deployment strategy increases the coverage, connectivity, and lifetime of the sensor network

Chapter 5: Business model perspective of MOHRA: Use case of Convergence of VANET and CLOUD

Chapter 5 is an extension of the previous chapters and provides a use-case for MOHRA in IoT domain. WSNs are one of the key enabler technologies for the IoT paradigm. Applications of WSNs are widespread in all domains of IoT. It has wide acceptance in vehicular applications too. This chapter contributes facts about the cloud, vehicular cloud. A novel idea for the convergence of VANET and Cloud is presented in this chapter, which has wide scope in IoT applications. WSN is crucial building VANET. In this chapter VANET is thought of as a collection of sensors and for forwarding sensory data MOHRA is used. This chapter describes the business angle of this convergence. The simulations and results given in the chapter illustrate the performance measurement of reducing storage overhead on the cloud server. Taxonomy of VCC is also the significant contribution of this thesis to give scope to VANET and Cloud researchers. This chapter describes the various data compression techniques used on the internet and summarizes compression techniques based on different metrics such as compression ratio, compression & decompression time, throughput, buffer, and complexity, etc.

Chapter 6: Conclusions and Future Outlook

The chapter concludes the thesis and provides a summary of the research and recommendations to develop energy efficient MOHRA for WSN. The chapter also provides the future work.

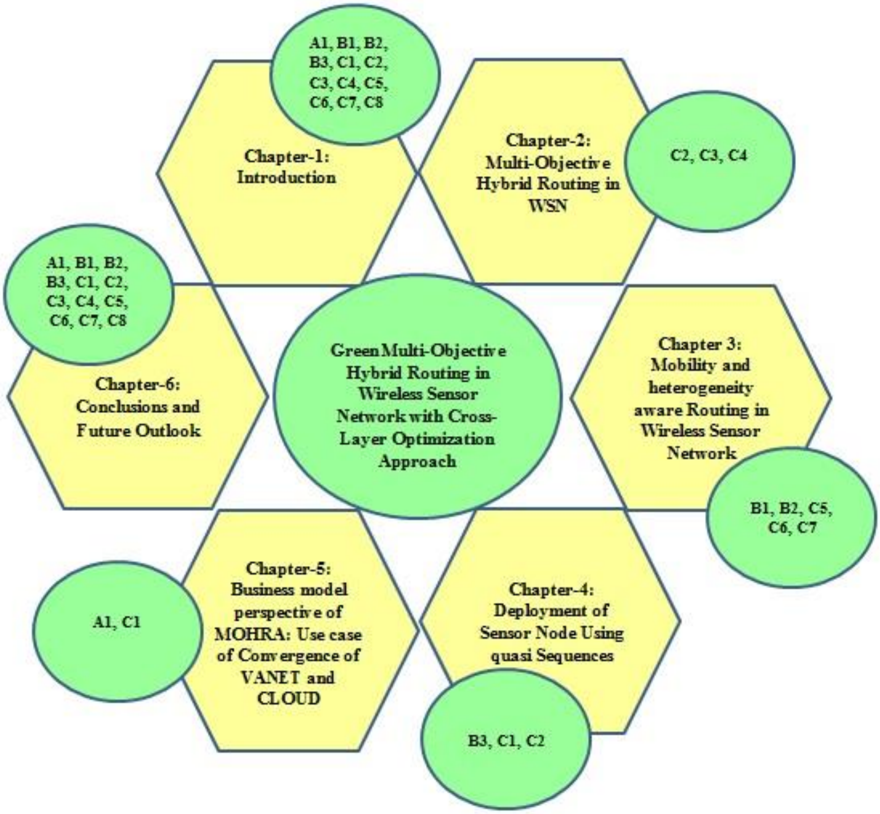


Figure 1- 8 Organization of thesis and contribution of papers published chapter wise [17, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73]

1.7. REFERENCES

[1] S. Li, L. D. Xu, and S. Zhao, "The Internet of Things: A Survey", Springer Science Business Media, New York, Vol. 17, PP. 243–259, 2015.

[2] B. N. Silva, M. Khan, and K. Han, "Internet of Things: A Comprehensive Review of Enabling Technologies, Architecture, and Challenges", Journal of IETE Technical Review, Vol 35(2), PP. 1-16, 2017.

[3] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and Moussa Ayyash, "Internet of Things: A Survey on Enabling Technologies, Protocols,

and Applications”, IEEE Communication Surveys & Tutorials, 17 (4), PP. 2347-2376, 2015.

[4] W. He, G. Yan, and L. Xu, “Developing vehicular data cloud services in the IoT environment”, IEEE Transactions on Industrial Informatics, 10(2), PP. 1587– 1595, 2014.

[5] G. P. Joshi, and S. W. Kim, “Survey, nomenclature and comparison of reader anti-collision protocols in RFID”, IETE Technical Review, 25(5), PP. 234-243, 2013.

[6] K. Pretz, “The next evolution of the internet”. IEEE Magazine The institute, [online], http://theinstitute.ieee.org/technology-focus/technology-topic/the-next-evolution-of-the-internet, 2013.

[7] J. Liu, X. Li, X. Chen, Y. Zhen, and L. Zeng, “Applications of Internet of Things on smart grid”, Proceedings of the 13th International Conference on Advanced Communication Technology (ICACT), PP. 13-17, 2011.

[8] M. Darianian, and M. P. Michael, “Smart Home Mobile RFID based internet-of-things systems and services”. Proceedings of International Conference on Advanced Computer Theory and Engineering (ICACTE), Vol. 17, PP. 116-120, 2008.

[9] X. Li, R. Lu, X. Liang, X. Shen, J. Chen, and X. Lin, “Smart community: an internet of things application”, IEEE Communications Magazine, 49(11), PP. 68–75, 2011.

[10] H. Bauer, M. Patel, and J. Veira, “The internet of things: Sizing up the opportunity”, Online Available at http://www.mckinsey.com/insights/high_tech_telecoms_internet/the_internet_of_things_sizing_up_the_opportunity, 2015.

[11] J. Gantz and D. Reinsel, “The digital universe in 2020: Big data, bigger digital shadows, and biggest growth in the far east,” IDC iView: IDC Anal Future, PP. 1–16, Dec. 2012.

[12] M. T. Lazarescu, “Design of a WSN Platform for Long-Term Environmental Monitoring for IoT Applications”, IEEE Journal On Emerging and Selected Topics in Circuits and Systems, 3(1), PP. 45-54, 2013.

[13] G. Anastasi, M. Conti, M. Di Francesco and A. Passarella, “Energy conservation in wireless sensor networks: A survey”, Ad Hoc Networks, Vol. 7, PP. 537–568, 2009.

[14] C. Y. Wan, A .T Campbell, and L. Krishnamurthy, “PSFQ: A reliable transport layer protocol for Wireless Sensor Networks”, ACM, WSNA’02, September 28, 2002, Atlanta, Georgia, USA, PP. 1-11, 2002.

[15] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, “Wireless Sensor Network:A Survey, Computer Networks”, Vol. 38(4), PP. 393-422, 2002.

[16] M. Harish, B. Srikanth, and R. Bhattacharjee, “An Energy efficient WSN with cooperative relaying technique”, National Conference on Communications (NCC), PP. 1-5, 2012

[17] V. Rohoakale, N. Kulkarni, H. Cornean, N. R. Prasad, “Cooperative Opportunistic Large Array Approach for Cognitive Radio Networks”, 8th IEEE International Conference on Communications, Bucharest, Romania, PP:513-516, 2010.

[18] W. Ye, and J. Heidemann, “Medium Access Control in Wireless Sensor Networks”, USC/ISI Technical Report ISI-TR-580, PP. 1-8, Oct. 2003.

[19] L. Paull, S. SaeediGharahbolagh, M. Seto, and H. Li, “Sensor driven online coverage planning for autonomous underwater vehicles”, In Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Vilamoura-Algarve, Portugal, PP. 2875–2880, 2012.

[20] A. J. Garcia-Sanchez, F. Garcia-Sanchez, D. Rodenas-Herraiz, and J. Garcia-Haro, “On the Optimization ofWireless Multimedia Sensor Networks: A Goal Programming Approach”, Sensors, PP. 12634–12660, 2012.

[21] Z. Fei, B. Li, S. Yang, C. Xing, H. Chen, and L. Hanzo, “A survey of multi-objective optimization in wireless sensor networks: Metrics, algorithms, and open problems,” Commun. Surveys Tuts., vol. 19, no. 1, PP. 550–586, 2017.

[22] R. Tharmarasa, T. Kirubarajan, P. Jiming, and T. Lang, "Optimization-based dynamic sensor management for distributed multitarget tracking", *IEEE Trans. Syst. Man Cybern.*, vol. 39, no. 5, PP. 534-546, 2009.

[23] B.Y. Qu, Y.S. Zhu, Y. C. Jiao, M. Y. Wu, P. N. Suganthan, and J. J. Liang, “A survey on multi-objective evolutionary algorithms for the solution of the environmental/economic dispatch problems”, Elsevier Journal of Swarm and Evolutionary Computation, Vol. 38, PP. 1–11, 2018.

[24] V. Guliashki, H. Toshev, C. Korsemov, "Survey of evolutionary algorithms used in multiobjective optimization", Probl. Eng. Cybern. Robot., vol. 60, PP. 42-54, 2009.

[25] E. Zitzler, M. Laumanns, S. Bleuler, "A tutorial on evolutionary multiobjective optimization" in Metaheuristics for Multiobjective Optimisation, Berlin:Springer, vol. 535, PP. 3-37, 2004.

[26] R. T. Marler, and J. S. Arora, "Survey of multi-objective optimization methods for engineering", Structural and Multidisciplinary Optimization, vol. 26, no. 6, 2004.

[27] C. A. C. Coello, "An updated survey of GA-based multiobjective optimization techniques", ACM Comput. Surv., vol. 32, no. 2, PP. 109-143, 2000.

[28] A. Zhou, B. Qu, H. Li, S. Zhao, P. Suganthan, and Q. Zhang, "Multiobjective evolutionary algorithms: A survey of the state of the art", Swarm and Evol. Comput., vol. 1, no. 1, PP. 32-49, 2011.

[29] C. A. C. Coello, "A Comprehensive survey of evolutionary-based multiobjective optimization techniques", Knowledge and Information Systems. An International Journal, vol. 1, no. 3, pp. 269-308, Aug. 1999.

[30] J. Andersson, "Survey of Multiobjective Optimization in Engineering Design", Technical Report, Department of Mechanical Engineering, Linkoping University: Linkoping, Sweden, 2000.

[31] K. C. Tan, T. H. Lee, E. F. Khor, "Evolutionary algorithms for multi-objective optimization: Performance assessments and comparisons" in Congress on Evolutionary Computation (CEC2001), NJ, Piscataway: IEEE Press, pp. 979-986, 2001.

[32] M. Xiao, J. Wu, and L. Huang, "Time-sensitive utility-based single copy routing in low-duty-cycle wireless sensor networks", IEEE Trans.Parallel Distrib. Syst., vol. 26, no. 5, PP. 1452–1465, 2015.

[33] D. Tang, T. Li, J. Ren, and J. Wu, "Cost-aware secure routing (CASER) protocol design for wireless sensor networks", IEEE Trans. Parallel Distrib. Syst., vol. 26, no. 4, PP. 960–973, 2015.

[34] J. Zhang, F. Ren, S. Gao, H. Yang, and C. Lin, "Dynamic routing for data integrity and delay differentiated services in wireless sensor networks", IEEE Trans. Mobile Comput., vol. 14, no. 2, PP. 328–343, 2015.

[35] M. A. Razzaque, C. S. Hong, and S. Lee, “Data-centric multiobjective QoS-aware routing protocol for body sensor networks”, Sensors, vol. 11, no. 1, PP. 917–937, 2011.

[36] C. Lozano-Garzon and Y. Donoso, “A multi-objective routing protocol for a wireless sensor network using a SPEA2 approach”, in Proc. Int. Conf. Appl. Numer. Comput. Math. (ICANCM)/ Int. Conf. Comput. Digit. Commun. Comput. (ICDCCC), Barcelona, Spain, PP. 39–44, 2011.

[37] M. R. Minhas, S. Gopalakrishnan, and V. C. M. Leung, “Multiobjective routing for simultaneously optimizing system lifetime and source-to sink delay in wireless sensor networks”, in Proc. 29th IEEE Int. Conf. Distrib. Comput. Syst. Workshops (ICDCS Workshops), Montreal, QC, Canada, PP. 123–129, 2009.

[38] J. H. Zhu, K.-L. Hung, B. Bensaou, and F. Nait-Abdesselam, “Ratelifetime tradeoff for reliable communication in wireless sensor networks”, Comput. Netw., vol. 52, no. 1, PP. 25–43, 2008.

[39] M. Li, C. Wang, W. Wang, C, Qin, X, Li, “Multi-objective clustering and routing for maximizing lifetime of wireless sensor networks”, 9th International Conference on Advanced Infocomm Technology (ICAIT), Chengadu, China, PP. 159-164, 2017.

[40] H. A. Shehadeh, M. Y. I. Idris, I. Ahmedy, R. Ramli, and N. M. Noor, “The Multi-Objective Optimization Algorithm Based on Sperm Fertilization Procedure (MOSFP) Method for Solving Wireless Sensor Networks Optimization Problems in Smart Grid Applications”, MDPI Journal of Energies, vol 11(1), PP. 1-35, 2018.

[41] A. Shahraki, M. K. Rafsanjani, and A. B. Saeid, “A new approach for energy and delay trade-off intra-clustering routing in WSNs”, Comput. Math. Appl., vol. 62, no. 4, PP. 1670–1676, 2011.

[42] X. Wei and L. Zhi, “The multi-objective routing optimization of WSNs based on an improved ant colony algorithm”, in Proc. 6th IEEE Int. Conf. Wireless Commun. Netw. Mobile Comput. (WiCOM), Chengdu, China, PP. 1–4, 2010.

[43] S. He et al., “A stochastic multiobjective optimization framework for wireless sensor networks”, EURASIP J. Wireless Commun. Netw., vol. 2010, Art. no. 9, 2010.

[44] G. H. EkbataniFard, R. Monsefi, M.-R. Akbarzadeh-T, and M. H. Yaghmaee, “A multi-objective genetic algorithm based approach for energy efficient QoS-

routing in two-tiered wireless sensor networks", in Proc. 5th IEEE Wireless Pervasive Comput. (ISWPC), Modena, Italy, PP. 80–85, 2010.

[45] J. Zhu, S. Chen, B. Bensaou, and K.-L. Hung, "Tradeoff between lifetime and rate allocation in wireless sensor networks: A cross layer approach", in Proc. 26th IEEE Int. Conf. Comput. Commun. (INFOCOM), Anchorage, AK, USA, PP. 267–275, 2007.

[46] H. Nama, M. Chiang, and N. Mandayam, "Utility-lifetime tradeoff in self-regulating wireless sensor networks: A cross-layer design approach", in Proc. IEEE Int. Conf. Commun. (ICC), Istanbul, Turkey, PP. 3511–3516, 2006.

[47] R. Elhabyan, W. Shi, and M. St-Hilaire "Pareto optimization-based approach to clustering and routing in Wireless Sensor Networks", Elsevier, Journal of Network and Computer Applications, Vol. 114, PP. 57–69, 2018.

[48] M. Abo-Zahhad, N. Sabor, S. Sasaki, and S. M. Ahmed, "A centralized immune-Voronoi deployment algorithm for coverage maximization and energy conservation in mobile wireless sensor networks", Inf. Fusion, vol. 30, PP. 36–51, 2016.

[49] J. M. Lanza-Gutierrez and J. A. Gomez-Pulido, "Assuming multiobjective metaheuristics to solve a three-objective optimisation problem for relay node deployment in wireless sensor networks", Appl. Soft Comput., vol. 30, PP. 675–687, 2015.

[50] J. Lu, X. Wang, L. Zhang, and X. Zhao, "Fuzzy random multi-objective optimization based routing for wireless sensor networks", Soft Comput., vol. 18, no. 5, PP. 981–994, 2014.

[51] K. S. S. Rani and N. Devarajan, "Multiobjective sensor node deployment in wireless sensor networks", Int. J. Eng. Sci., vol. 4, no. 4, PP. 1262–1266, 2012.

[52] M. L. Berre, F. Hnaien, and H. Snoussi, "Multi-objective optimization in wireless sensors networks", in Proc. IEEE Int. Conf. Microelectron. (ICM), Hammamet, Tunisia, PP. 1–4, 2011.

[53] R. Rajagopalan, C. K. Mohan, P. Varshney, and K. Mehrotra, "Multi-objective mobile agent routing in wireless sensor networks", in Proc. IEEE Congr. Evol. Comput. (CEC), Edinburgh, U.K., PP. 1730–1737, 2005.

[54] Y. Xua, O. Dinga, R. Qub, and K. Lia, "Hybrid multi-objective evolutionary algorithms based ondecomposition for wireless sensor network coverage

optimization ", Elsevier, Journal of Applied Soft Computing, Vol. 68, PP. 268–282 , 2018.

[55] Y. Wang, M. C. Vuran, and S. Goddard, "Stochastic performance tradeoffs in the design of real-time wireless sensor networks", in Proc. IEEE Int. Conf. Comput. Netw. Commun. (ICNC), Garden Grove, CA, USA, PP. 931–937, 2015.

[56] M. S. Ansari, A. Mahani, and Y. S. Kavian, "Energy-efficient network design via modelling: Optimal designing point for energy, reliability, coverage and end-to-end delay", IET Netw., vol. 2, no. 1, PP. 11–18, Mar. 2013.

[57] S. Sengupta, S. Das, M. D. Nasir, and B. K. Panigrahi, "Multi-objective node deployment in WSNs: In search of an optimal trade-off among coverage, lifetime, energy consumption, and connectivity", Eng. Appl. Artif. Intell., vol. 26, no. 1, PP. 405–416, 2013.

[58] M. Woehrle, D. Brockhoff, T. Hohm, and S. Bleuler, "Investigating coverage and connectivity trade-offs in wireless sensor networks: The benefits of MOEAs", in Multiple Criteria Decision Making for Sustainable Energy and Transportation Systems (Lecture Notes in Economics and Mathematical Systems), vol. 634, M. Ehrgott, B. Naujoks, T. J. Stewart, and J. Wallenius, Eds. Heidelberg, Germany: Springer, PP. 211–221, 2010.

[59] A. Konstantinidis, K. Yang, Q. Zhang, and D. Zeinalipour-Yazti, "A multi-objective evolutionary algorithm for the deployment and power assignment problem in wireless sensor networks", Comput. Netw., vol. 54, no. 6, PP. 960–976, 2010.

[60] R. Rajagopalan, "Multi-objective optimization algorithms for sensor network design", in Proc. 11th IEEE Annu. Wireless Microw. Technol. Conf. (WAMICON), Melbourne, FL, USA, PP. 1–4, 2010.

[61] N. Hajizadeh , P. Jahanbazi , and R. Javidan, "Controlled deployment in wireless sensor networks based on a novel Multi Objective Bee Swarm Optimization algorithm", 3rd IEEE Conference on Swarm Intelligence and Evolutionary Computation (CSIEC), Bam, Iran, PP. 1-5, 2018.

[62] R. Kuawattanaphan, P. Champrasert, and S. Aramkul, "A Novel Heterogeneous Wireless Sensor Node Deployment Algorithm With Parameter-Free Configuration", IEEE Access, Special Section on Convergence of Sensor Networks, Cloud Computing, and Big Data in Industrial Internet of Thing, vol. 6, 2018.

[63] N. Kulkarni, N. R. Prasad, and R. Prasad, "MOHRA: Multi Objective Hybrid Routing Algorithm for Wireless Sensor Network", 3rd IEEE International Conference on Wireless Communications, Vehicular Technology, Information Theory and Aerospace & Electronics Systems (VITAE), Atlantic City, NJ, USA, PP: 1-6, 2013.

[64] N. Kulkarni, N. R. Prasad, and R. Prasad, "MMOHRA: Mobility Aware Multi-Objective Hybrid Routing Algorithm for Wireless Sensor Networks", 4th IEEE International Conference on Wireless Communications, Vehicular Technology, Information Theory and Aerospace & Electronics Systems (VITAE), Aalborg University, Denmark, PP: 1-5, 2014.

[65] N. Kulkarni, N. R. Prasad, and R. Prasad, "G-MOHRA: Green Multi Objective Hybrid Routing Algorithm for Wireless Sensor Network", IEEE, 3rd International Conference on Advances in Computing, Communications anf Informatics (ICACCI), Greater Noida, Delhi, India, PP: 2185–2190, 2014.

[66] N. Kulkarni, N. R. Prasad, and R. Prasad, "An Evolutionary Mobility Aware Multi-Objective Hybrid Routing Algorithm for Heterogeneous Wireless Sensor Networks", International Journal of Rough Sets and Data Analysis (IJRSDA), Special Issue on IoT, 2016.

[67] N. Kulkarni, N. R. Prasad, and R. Prasad, "H-MOHRA: Heterogeneous Multi-Objective Hybrid Routing Algorithm for Mobile Wireless Sensor Networks", 1st IEEE Global Conference on Wireless Computing & Networking (GCWCN), Lonavala, India, PP: 249 – 253, 2014.

[68] N. Kulkarni, N. R. Prasad, and R. Prasad, "An Evolutionary Mobility Aware Multi-Objective Hybrid Routing Algorithm for Heterogeneous Wireless Sensor Networks", International Conference on Internet of Things, Next Generation Networks and Cloud Computing (ICINC 2016), February 26-28, 2016

[69] N. Kulkarni, N. R. Prasad, and R. Prasad, "Q-MOHRA:QoS Assured Multi-Objective Hybrid Routing Algorithm for Heterogeneous WSN", International Conference on Wireless Communications, Vehicular Technology, Information Theory and Aerospace & Electronics Systems (VITAE), Hyderabad, India, December 13-16, 2015.

[70] N. Kulkarni, R. Prasad, H. Cornean, and N. Gupta, "Performance Evaluation of AODV, DSDV & DSR for Quasi Random Deployment of Sensor Nodes in Wireless Sensor Networks", IEEE International Conference on Devices and Communications (ICDeCom-11, PP. 1-5, 2011.

[71] N. Kulkarni, N. R. Prasad, T. Lin, M. Alam, and R. Prasad, “Convergence of Secure Vehicular Ad-Hoc Network and Cloud in Internet of Things”, River Publications, Role of ICT for Multi-Disciplinary Applications in 2030, Edited by Leo P. Ligthart, and Ramjee Prasad, ISBN: 9788793379480, 2016.

[72] N. Kulkarni, N. R. Prasad, and R. Prasad, “Q-MOHRA: QoS Assured Multi-Objective Hybrid Routing Algorithm for Heterogeneous WSN”, An International Journal of Wireless Personal Communications, Springer Journal, ISSN 0929-6212, pp. 1-12, DOI 10.1007/s11277-017-5064-8, 2017.

[73] N. Kulkarni, N. R. Prasad, and R. Prasad, “A Novel Sensor Node Deployment using Low Discrepancy Sequences for WSN”, An International Journal of Wireless Personal Communications, Springer Journal, ISSN 0929-6212, pp. 1-14, DOI 10.1007/s11277-017-5063-9, 2017.

CHAPTER 2. MULTI-OBJECTIVE HYBRID ROUTING IN WSN

The primary objective of this chapter is to explain the need, requirements and challenges of multi-objective (MO) hybrid routing. The chapter surveys in-depth different hybrid and multi-objective routing algorithms and put forwards a novel approach. The contribution of this chapter is that it proposes two routing algorithms G-MOHRA and MMOHRA. The chapter talks about the multi-objective function and the efficient route selection mechanism. The chapter also provides a comparative evaluation of G-MOHRA, MMOHRA with reference to the contemporary solutions considering NRL, AEC, PDR, and Jitter. Finally, concludes on future research scope.

2.1. INTRODUCTION

WSNs can give a minimal effort answer for diverse real-world issues, e.g. Health-, Habitat- monitoring, battlefield inspections, calamity management, industrial control, and so forth [1, 2, 3]. In WSN, substantial quantities of sensors are spread spatially [1]. Information gathered by sensors is directed to the sink, which connects the sensory arena to the outside world where information can be gathered, broken down, and conclusions are drawn. In a small coverage area, the sensors communicate with the sink directly, as single-hop communication, and the information is sent. In most of the applications, direct communication with the sink is not energy effective. Thus, multihop communication to communicate and to relay information is used [4].

WSNs have few limitations as far as nodes are concerned i.e. inadequate computation-, stored-energy, restricted memory-, data transfer- capacity [1, 5]. Individual data-forwarding mechanisms can’t accomplish all the necessities of an application. Several researchers have proposed distinct routing protocols in view of topology, mobility, security, and applications [6]. In the plan of WSN, the greater part of the consideration should be given for designing green (energy efficient) routing protocols to prolong the network lifetime [7, 8]. In WSN, the routing mechanisms are categorized as Information-, Tree- Based, Position-aware-, QoS aware-, Single Objective-, Hybrid-, and Multi-objective- protocols [9, 10, 11, 12, 13, 14]. This chapter presents the need of MO and Hybrid routing mechanism. The development of MO hybrid routing mechanism is shown in Figure 2.1. This diagram will make the understanding of multi-objective and hybrid data forwarding mechanism easier, and will provide way for understanding different MO hybrid routing mechanisms in the further chapters.

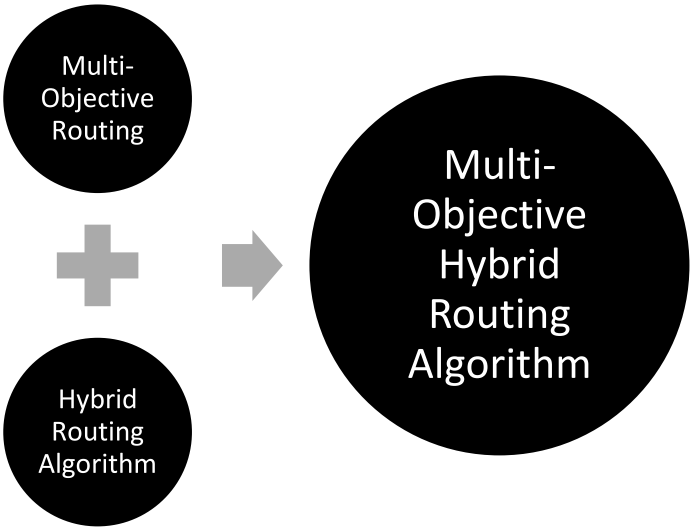


Figure 2- 1 Development of Multi-Objective Hybrid Routing Algorithm

2.1.1. HYBRID ROUTING ALGORITHM

Hybrid Routing is a combination of two different routing protocols from two different categories. It has benefits of both the protocol to enrich the performance of the network. Many researchers working on the hybrid approach are of the opinion that if multiple metrics from different layers of the WSN are combined to find the optimal path, then it is also a hybrid mechanism. The advantages of hybrid routing algorithms are discussed below.

- **The hot spot problem is almost negligible**

In WSN multi-hop communication is energy efficient where the amount of traffic the sensor nodes need to forward, increments drastically as the distance between the sensor nodes and sink shortens. Thus, sensor nodes near the sink tend to die prematurely as the energy is not uniformly distributed. So the network gets partitioned, and part of the network is left unmonitored. If the sensor far from the sink communicates directly with the sink then they will die much more quickly than those closer to the sink. Hybrid Routing uses more sensible power control policy during transmission to balances the energy between the nodes and to improve network lifetime.

- **More strong to the topology changes**

In WSN, sensor nodes are power constrained and It’s hard to refill the battery. When the sensor node (nodes) becomes dead, the network may become sparse, and route stability becomes important criteria. Same routing protocol design may not apply for sparse and dense network. Performance of hybrid routing protocol is better for both sparce and dense networks.

- **Almost all the techniques use aggregation to reduce the energy consumption during relaying**

Sensors nodes may produce huge duplicated data. Data accumulation comprises handling the data as of diverse sources for producing meaningful information. All hybrid routing techniques support data aggregation. Significant power can be conserved as the communication messages are reduced.

- **Hybrid mechanisms support for time crucial applications**

In a cluster-based network, the information moves quicker to the sink that reduces latency. In this model, cluster-heads performs, information accumulation unlike in the multi-hop communication model each sensor node in between performs information assembly. Thus, the hybrid mechanisms supporting cluster-based model can be used for time-crucial applications.

2.1.2. MULTI-OBJECTIVE ROUTING ALGORITHM

Foremost aim of Single-Objective Routing (SOR) is to discover the finest path from the point of origin to ending node that targets minimum or most worth of one objective operation of a Single-Objective-Function (SOF). SOF merges altogether completely dissimilar goals. This kind of path enhancement is accountable for path-selection also to provide the insight of the problem, however generally it cannot provide a collection of completely different alternate paths where diverse contradictory objectives negotiate with one another. In contrast, in a multi-objective routing (MOR) with contradictory goals, provide alternative sub-optimal solutions [15].

The advantages of using MOR over SOR are:

- MOR identifies a variety of routes.
- MOR can detect total trade-off surface.
- No need to set preferences for multiple objectives.
- MOR provides more realistic solutions.
- MOR uses conflicting nature of parameters in deciding the route

2.1.3. MULTI-OBJECTIVE HYBRID ROUTING ALGORITHM (MOHRA)

MOHRA is a combination of Multi-Objective Algorithm (MOA) and Hybrid Routing Algorithm (HRA) [16]. MOHRA combines the best features of both MOA and HRA to upgrade the performance of the network.

Figure 2.1 shows the chapter 2 contributions with challenges addressed, and cost control-, route selection-, and low layer- components used in the research. The leftover of the chapter is outlined subsequently. Section 2.2 focuses on classification of different multi-objective, hybrid routing algorithms. Section 2.3 depicts the suppositions, the framework, communication model, methodology, and notations used. Section 2.4 gives the details of MOHRA with comparative analysis. Section 2.5 describes G-MOHRA with flowchart and algorithm. Section 2.6 gives information about MMOHRA. Section 2.7 presents the comparative results of G-MOHRA and MMOHRA with state of the art solutions under static and mobile scenarios. Lastly, Section 2.8 summarizes the work.

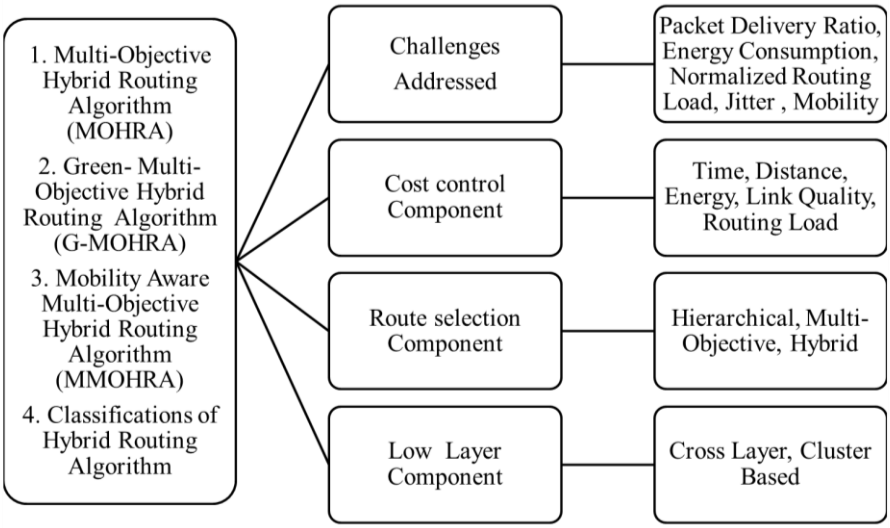


Figure 2- 2 Contribution of chapter 2

2.2. RELATED WORK

2.2.1. ROUTING ALGORITHMS IN WSN

In WSN, routing algorithms are regarded as as proactive, reactive, and hybrid [17]. Proactive-Routing-Protocols (PRP) utilizes table-driven approach, uninterruptedly acquires the topography information of the network by exchanging messages amongst the NW nodes. In PRP, on receiving a request, no need to explore the path as it proactively keeps up the topology data of all nodes. Routing Table is periodically refreshed. Low-Energy-Adaptive-Clustering-Hierarchy (LEACH) is case of PRP [18]. Detected information is directed to Cluster-Heads (CHs) intermittently. Subsequently after gathering the information it is handed towards sink intended for storage. For the mission critical applications LEACH is not suitable. In Reactive Routing (RR) protocol, well-known as on-demand data forwarding mechanism, data aggregation is aperiodic and it depends on the event of occurrence. RR depends upon query-reply negotiation. On receiving a request, RR discovers the potential routing paths for forming path (s) to the destination. Here, sensors must react to the time critical events.

In WSN, Simple Hybrid Routing Protocol (SHRP) [21] is green routing mechanism. SHRP elects the route based on battery lifespan, number of hops, and link quality. In SHRP, detected information is directed via a route having smallest hop count in a situation if the information has transformed from the previous one. SHRP chooses a path that has more accessible energy among all the available paths up to the sink. If the detected information doesn't vary in a given duration, then it is occasionally sent, to test the connectivity issue among the nodes. SHRP utilizes minimum threshold to limit selfish nodes so as to prevent them to forward table. Here every node must choose the next stage in light of the inherent data they have.

APTEEN, derived from TEEN [19], and uses the best features of PRA and RRA. So in WSN, it is termed as Hybrid Routing Algorithm (HRA). It not just sends information occasionally to the sink but, it reacts to quick fluctuations in the surroundings, forming it more reasonable for mission critical usage.

THCHP is a updating of APTEEN [20]. APTEEN utilizes lone level grouping and with the arbitrary rotation of the responsibility of CHs among the nodes. THCHP utilizes couple of levels for grouping. THCHP is suitable for both usages when the data is periodically checked and also data might be time critical. THCHP has reduced query reaction time and wide variety of enquiry rates by means of a minor rise in the response time.

DyMORA [21] is the advanced form of SHRP. It operates similar to HRA, which is base form of SHRP. It has superior reliability when contrasted with SHRP. It utilizes lesser energy level at the cost of higher handling time. It uses several metrics to choose the finest path to the sink within critical conditions amid energy crunches.

Chain Based Leach (CBL) enhances LEACH protocol greatly to cut back the power utilization so as to improve the NW lifespan. This is a hybrid protocol that fuses the superlative attributes of LEACH, as well as PEGASIS. It keeps away the drawbacks of both. CBL creates a chain of nearby CHs and has additional feature of aggregating data amongst them. One after another the CHs communicate the accumulated info up-to sink. In CBL average energy consumption of different sensor nodes would be a similar.

Table 2- 1 Comparison of HRAs in WSN

Sr. No.	1	2	3	4	5	6	7
Name of the Hybrid Protocol	APTEEN	THCHP	DyMORA	SHRP	HRS	HP	CBL
Approach \ Mechanism	Proactive + Reactive	Proactive + Reactive	Multi-Objective	Multi-Objective	Clustering + Flat Routing	Diffusion + Rumor	Clustering + Chaining
Power Usage	Moderate	Minimum	Minimum	Minimum	Moderate	Moderate	Minimum
Hotspot Problem	No	Yes	No	No	No	No	No
Aggression	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Scalability	No	No	No	No	Ltd	Ltd	High
All nodes must Compete in Transmit	Yes	Yes	No	No	Yes	Yes	No
Equal Energy Consumption All over Network	Yes	No	Yes	Yes	No	No	Yes
Delay	Moderate	Minimum	Maximum	Maximum	Moderate	Moderate	Moderate
Security	No	No	No	No	No	No	No
Query Based	No	Yes	No	No	No	Yes	No
Type of Nodes Used	Homogeneous.	Homogeneous.	Homogeneous.	Homogeneous.	Homogeneous.	Homogeneous.	**Homogeneous.**
Useful for Time Critical Applications?	Yes	No	Yes	No	No	No	No

HRS [22] joins the supreme attributes of cluster- and flat- based data forwarding. Cluster based- and flat- strategies utilized in case the NW is impenetrable as well as sparse respectively.

HP [23] is a mixture of DD, and RR. In DD, the monitoring center broadcasts packet to all sensors in the region Sensors form gradient (links) for reporting. In RR, sensor nodes spread the news of an event happening. HP attempts to harmonize features of DD and RR. It utilizes hop count as a metric for path selection. In the event that the count is lesser, then more sensors utilizes RR, if not, they utilize DD. Table 2-1 compares all the HRAs in WSN.

2.2.2. ROUTING ALGORITHMS WITH ENERGY HOMOGENEITY IN WSN

In WSN, because of the fundamental power limitations of the sensor node, network topology and modus operandi are essential perspectives [1]. They substantially affect the energy depletion and lifespan of complete network. In sensor network battery-, computation- capacity is critical issue. Despite the fact that the data forwarding mechanisms are usage specific, they ought to be green. Researchers proposed numerous energy efficient routing protocols built on usage, constraint, and design. Energy optimized mechanisms are characterized as cluster dependent, flat, and location-based [7].

Flat Data Forwarding Strategies

In this strategy all sensors are equivalent. They're acting either as sensing or transferring devices. TORA [8], ETORA [18], and SEER [24] are the cases of green FRP. Rather than intermittently sending the routing upgrades, TORA progresses the data forwarding updates whenever there’s topographical amendment, and it utilizes the pathway that has smallest hop number. ETORA is an improvement of TORA. ETORA utilizes a technique not to utilize the same routes again once it is utilized. In SEER one or the other node triggers the process or incident focused recording is employed. Gain of SEER is that the number of data packets transferred diminishes. SERR utilizes leap number.

Green Data Forwarding Mechanisms reliant on Clustering

Keeping in mind the end goal to accomplish capacity harmonizing and energy proficiency, these mechanisms compose the nodes in the group known as clusters. LEACH, LEACH-C, APTEEN are the examples of green data forwarding mechanisms reliant on clustering. In LEACH-C [14], sink construct groups. LEACH-C has the advantage that it coordinates among nodes to resolves the energy issue in the network.

Location Aware Green Data Forwarding Mechanisms

Here, nodes utilize positional data to send information. GEAR [25], Scalable SELAR [26], and MERR [27] are the illustrations of position aware green data forwarding mechanisms. In [25], every node notices position and the residual energy levels of its own and adjoining nodes. GEAR tries to settle the energy in the midst of the nodes keeping in mind the end goal to enhance the lifespan of the NW. [26] is a blend of energy-, position- data forwarding strategy. It picks suitable path among the nodes withholding greatest energy. It isn't applicable for dynamic NWs. In [27], P_{Tx} is balanced to cut back the energy depletion once the separation amongst transmittal nodes is identified. It is reasonable for modest topography and isn't applicable for an impenetrable NW as more energy is lost.

2.2.3. ROUTING ALGORITHMS WITH ENERGY HOMOGENEITY AND MOBILITY IN WSN

Numerous investigators have projected green routing protocols in WSN depending on use, norms and configuration. A particular routing protocol cannot be utilized for all applications and purposes. Mobility assumes a critical part in relocating and refilling the energy assets [28]. The data forwarding mechanism in Mobile Wireless Sensor Network (MWSN) are grouped keeping in mind communication-, topology-, strategy-, mobility- utilized for minimizing energy consumption.

Data forwarding mechanisms depending on the kind of communication

The nodes impart directly with sink or the NW is split within very little clusters wherever they impart with CH. The data forwarding mechanisms are Direct-Communication-Routing-Mechanisms (DCRM) and Hierarchical-Routing-Mechanisms (HRM).

DCRM isn't utilized for routing as sensor node’s power utilization is more, and the network lifetime is less compared with HRM. In HRM, the CH collects the information from various sensor nodes and directs aggregated information towards sink. In HRM, the energy utilization of the nodes is less, network lifetime is more, and administrative complexity is less when equated with DCRP [29].

In M-Geocast [30] all sensor nodes are GPS empowered, and any node can be mobile. By utilizing the route knowledge, and location-based improvement strategies, M-Geocast discovers the destination. M-Geocast employs prediction of the route from past routes in addition topography. LEACH is not reasonable as it expects a homogeneous distribution, stationary nodes. Modified- LEACH (M-LEACH) [31] is projected to sustain movement in clustering atmosphere. The CH selection is supported on the basis of price factor C_{ij}. The sink calculates this price and it communicates this cost to every node. The selected CH can combine the data as well as impart it to sink. M-LEACH has enhanced NW lifespan than LEACH.

Data forwarding mechanism depending on the kind of topography used

These mechanisms are classified as table-driven, on-demand and hybrid mechanisms. In table-driven mechanisms, the road upto the target is known in advance. Occasionally nodes may alter the forwarding tables. In on-demand data forwarding mechanism, the path is learned on request. Hybrid data forwarding mechanisms is a mixture of each table-driven and on-demand. CEER [32] is a table-driven mechanism. It exploits stage count as a cost of forwarding. CEER incorporates CDL [32] strategy. It searches related RGB values between the nearby nodes and chooses an appropriate forwarding path.

Data Forwarding Mechanisms depending on energy sustaining methods

The nodes use energy for detecting, conveying and data processing as well as when they are in idle mode. In this class numerous data forwarding mechanisms attempt to decrease the energy utilization throughout when the data is imparted. When the nodes are not active, they can go in sleep mode and conserve energy. The position aware green data forwarding mechanisms [33] utilizes energy levels, and position data of sensor nodes using GPS. It accepts that each node is aware of its own energy, position and the position of the sink to reduce intersection space, and total no of nodes participating in routing. This strategy cut backs energy depletion of NW. REDM [34] maintains a strategic distance from the energy hole issue, that is the quick depletion within the energy among the nodes nearby sink. It additionally projects PAH [34] calculation. Depending on the left over energy, hop no, sink selects quality route. Mobility of the sink cuts back the load of the nodes.

Data forwarding mechanisms depending on the kind of mobility

In this category the mechanisms support sink-, node- movement. This data forwarding mechanism strengthens the controlling of movement. A tree-reliant mechanism [35] cares for imparting data in both directions proactively. HAT divides nodes either in fixed or mobile category. Fixed nodes are responsible for formation of data forwarding tree, and mobile nodes be part of the formed tree. This restrains the impact of weakening delivery of the data.

2.3. METHODOLOGY

MO routing comprises multiple goals to be enhanced concurrently when there is a compromise between at least two or more opposing goals. The enhanced strategy must be energy efficient with respect to usage and communication. The problem of energy efficiency can be improved using the following MO hybrid routing algorithms

- Multi-Objective Hybrid Routing Algorithm (MOHRA [3])
- Green - Multi-Objective Hybrid Routing Algorithm (G-MOHRA [1])
- Mobility-Aware Multi-Objective Hybrid Routing Algorithm (MMOHRA [4])

2.4. MOHRA IN WSN

Objective of most of the routing protocols is to accomplish energy competency by means of evenly spreading energy among the nodes. In utmost all the present energy competent routing mechanisms, the information is sent on a way from point of origin to a target that require least energy for transmission. This methodology will expand the NW lifespan. As appeared in Figure 2-3, after successive rounds of communication among the nodes, it will bring about uneven division of energy, within the cluster, and it will cause division of the network, despite the fact that there might be sufficient residual energy at each node.

The expectation of the energy harmonizing data forwarding mechanisms is to expand the NW lifetime using identical dissemination of energy among the nodes and design long lived WSN [36]. As shown in Figure 2-4 the event is happening in the cluster-no 3, and 5.

The node that has noticed the incident from cluster-no 5 is forwarding the information to sink through a node within cluster-no 2 since it is shorter and energy efficient way back to sink. After a couple of transmissions, the energy of most of the nodes within cluster-no 2 will be exhausted as they need to transfer an excessive number of packets. Along these lines, the nodes within cluster-no 1, 3, and 5 will be unable to forward the information upto sink by means of cluster-no 2. Despite the fact that there is sufficient remaining energy within the nodes in cluster-no 1, 3, and 5 the NW is divided. In the event that the energy is disseminated consistently in the cluster, the nodes within cluster-no 5 would have sent the information upto sink using a substitute path from cluster-no 4. This methodology will enhance the availability, and NW lifespan. In MOHRA, delaying period of segmenting the NW is a major goal.

2.4.1. OVERVIEW OF MOHRA

The primary aim of MOHRA is to choose the enhanced path by utilizing subsequent metrics

- Average Energy Consumption (energy) – This is a correspondence of overall energy utilized by every node to the total incidents sensed.

- Control Overhead (overhead) – It is a ratio of no of control- , data- messages transferred.

- Reaction Time (rtime) – It is interval lapsed when an incident took place, and the data is collected at NW.

- Link Quality Indicator (LQI) – It is accessible by link layer parameters and it is a major of instantaneous superiority of the acquired signal.
- HOP Count (hops) – Number of jumps from the source node to the destination node.

2.4.2. MULTI-OBJECTIVE FUNCTION

Let P be a predetermined set. Assume m is a collection of constraints and R is a workspace. Assume i, k, m can be assigned values as (Ref. Eq 2-1, 2-2) [16]

$$m: p \to p^k \tag{2–1}$$

$$m(p) = (m_1(p), . m_k(p)) = m_i : P \to R \tag{2–2}$$

At this point k is the no of constraints where $2 \leq i \leq k$. Let p, q be two values within P. Let q take over p i.e. (Ref. Eq 2-3 – 2-5) [16]

$$p \prec q \leftrightarrow \left(\begin{array}{c} (\forall\, i: 2 \leq i \leq k) \wedge (\forall\, j: 2 \leq j \leq k): \\ \left(\exists \left(m_i(p) \leq m_i(q) \ \wedge m_j(p) \neq m_j(q) \right) \right) \end{array} \right) \tag{2–3}$$

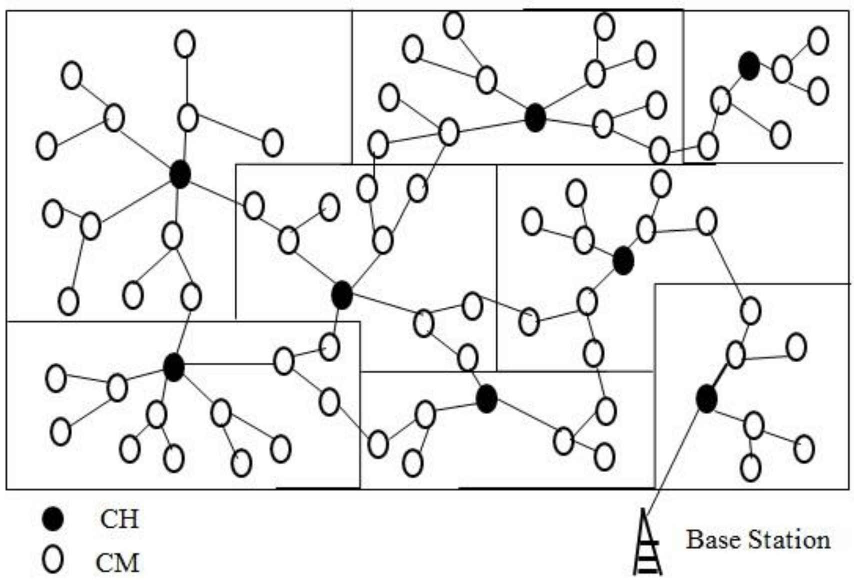
Let F be the subsection of non-dominated elements of P

$$\therefore F = \{ (p \in P) \wedge (q \ \in P) | \left(\exists q: (q \prec p) \right) \} \tag{2-4}$$

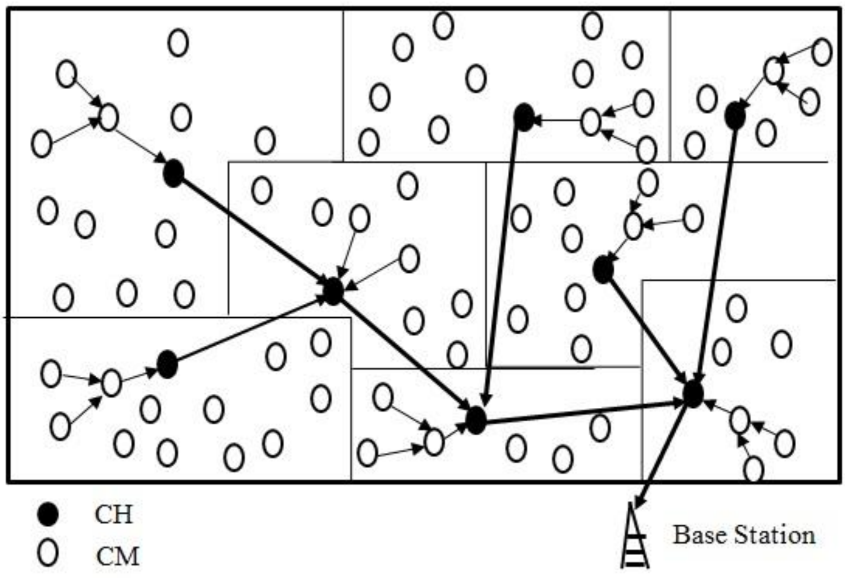
The subsection F is termed as Pareto-optimal-solutions.

$$\mathrm{m{:}p{\to}R^k,\ m(p){=}m_1(p), m_2(p), ...m_k(p)} \tag{2-5}$$

Let $f\!: \mathrm{F} \to \mathrm{R}$ then $\mathrm{f(p) = m_k(p)}$ is defined as MO function.



a) Network model



b) Communication model.

Figure 2- 3 Network and communication model.

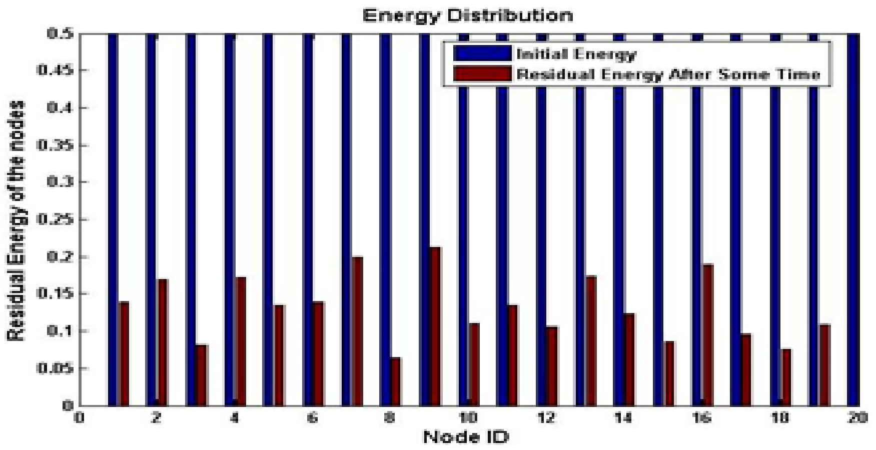


Figure 2- 4 Energy_distribution.

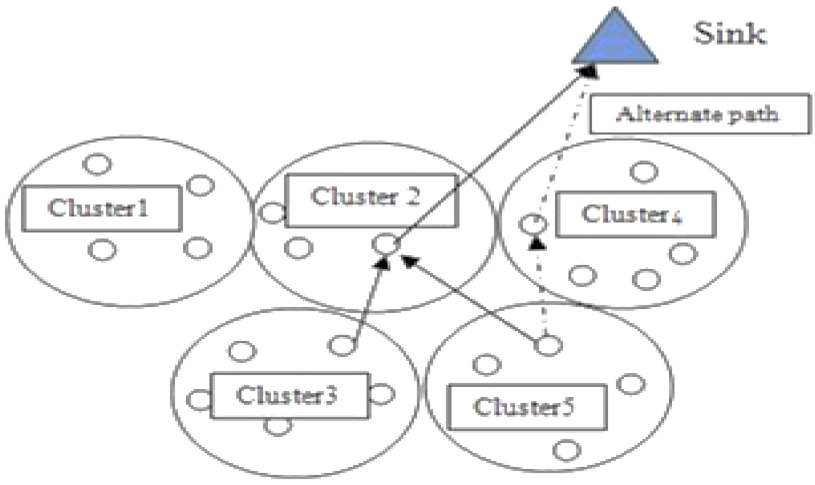


Figure 2- 5 Clustered WSN.

2.4.3. DETERMINING ROUTE USING MOHRA

Here WSN is considered to be a graph G where G is a gathering of nodes and edges. G= (N, E) assume N= {n_1.....n_2} is collection of nodes, and E ⊆ {(n_i, n_j) ∈ N x N | i ≠ j} is a collection of edges. Here n_i, and n_j are point of origin and an end-points of communication respectively. For every node n_i the association among the i^{th}, and j^{th} node can be well-defined as (Ref. Eq 2-6) [16]

$$U_i = \{ n_{i_j} \in N \,|\, (n_j, n_i) \in E \} \tag{2-6}$$

Assuming a node n_i and its collection of neighbor U_i, choice of the most effective path between n_i upto sink is determined depending on collection of diverse collection of measures. For doing this node n_i should have been calculated beforehand. Source neighbor association for n Node is given by (Ref. Eq 2-7) [16]

$$U_i = \{ n_{i_1}, n_{i_2}, n_{i_3} \ldots . n_{i_v} \} \tag{2-7}$$

Every node n_i estimates these metrics by means of a cost-function ∈ {overhead, rtime, hops}. Here $cost_{min}$ is that the lowest price of the measure. The cost-function is assessed over and done with a function as mentioned below (Ref. Eq 2-8) [16]

$$m_{cost}: N \to \mathbb{R}$$

$$m_{cost}(n_i) = \begin{cases} cost_{min} & if\ i = 1 \\ \max\{cost(n_i), \min\{m_{cost}(n_{i_j}) | n_{i_j} \in U_i\}\} & if\ i \neq 1 \end{cases} \tag{2-8}$$

The measure hops(n_i), and energy (n_i) of the intermediate nodes is evaluated through the function (Ref. Eq 2-9, 2-10) [16]

$$m_{lqi}: Nodes \to \mathbb{N}$$

$$m_{lqi}(n_i) = \max\{m_{lqi}(n_i) | n_{i_j} \in U_i\}\ if\ i \neq 1 \tag{2-9}$$

$$m_{energy}: Nodes \to \mathbb{N}$$

$$m_{energy}(n_i) = \max\{m_{energy}(n_i) | n_{i_j} \in U_i\}\ if\ i \neq 1 \tag{2-10}$$

At this point i=1 designates the sink. For i^{th} node, this info is arranged in data forwarding table belonging to node n_i (Ref. Eq 2-11 – 2-13) [16].

$$Table_i = \left\{ \left(n_{i_j},\ m\left(n_{i_j}\right) \right) | n_{i_j} \in U_i \right\} \tag{2-11}$$

Where the function

$$m\left(n_{i_j}\right) = \left(\begin{matrix} m_{energy}\left(n_{i_j}\right), m_{overhead}\left(n_{i_j}\right), \\ m_{rtime}\left(n_{i_j}\right), m_{lqi}\left(n_{i_j}\right), m_{hops}\left(n_{i_j}\right) \end{matrix} \right) \quad (2\text{-}12)$$

is an input to the forwarding table for it's realization. Each single node preserves the recent values in the forwarding table to enhance the path up to the sink. After realization of the table, i^{th} node forwards updates utilizing following function

$$m(n_i) = \begin{pmatrix} m_{energy}(n_i), m_{overhead}(n_i), \\ m_{rtime}(n_i), m_{lqi}(n_i), m_{hops}(n_i) \end{pmatrix} \quad (2\text{-}13)$$

Every single node with n_i as a neighbor will fill in their tables.

2.4.4. ALGORITHM FOR DETERMINING THE ROUTE IN MOHRA

Algorithm 1 [16] is used to construct Max-Heap. MOHRA utilizes this algorithm data forwarding purpose. The procedure of construction of Max-Heap is explained later in the chapter. The nodes are arranged to form a logical heap tree. The process of creation of max-heap is repeated by means of MaxHeap in a downward-upward approach. Build-Max-Heap function executes Max-Heap algorithm on every of the nodes. The symbols utilized within the algorithm are briefed in section 2.3.1.

.

Algorithm 1: Algorithm of MOHRA

Input: N= {$n_1 \ldots\ldots n_2$} set of all vertices, S- Set of processed nodes, $m_{cost}(n_i)$ Multi-objective cost function
Output: Heap Tree
Max-Heap (S, i):

$leftchild = 2i$
$rightchild = 2i + 1$
biggest $\leftarrow$ *i*
If $leftchild \leq$ *heap_length and* $m_{cost}(leftchild) > m_{cost}(biggest)$)
then:
  biggest$\leftarrow$ $leftchild$
else
  biggest$\leftarrow$ *i*
end if
if ($rightchild \leq$ *heap_length and*
$m_{cost}(rightchild) > m_{cost}(biggest)$) *then:*
  biggest$\leftarrow$ $rightchild$
else
  biggest$\leftarrow$ *i*
end if
if biggest $\neq$ *i then:*
  swap n_i *[i]* $\leftrightarrow$ n_i *[biggest]*

```
        end if
        Max-Heap (S, biggest)
End
Build-Max-Heap (N) [16]:
        heapsize ← size [N]
        for i ← floor (size/2) down-to 1 do
                Max-Heap(S, i)
        end for
end
```

2.4.5. COMPARATIVE ANALYSIS OF MOHRA

In SHRP, criteria for picking up the path upto sink work in stages. SHRP utilizes four measurements (i) Remaining-Energy (ii) Hop no (iii) LQI (iv) RSSI The calculation in SHRP endeavors to choose the path depending on the choice taken at the primary level. SHRP will manage to achieve the following level if the past level has the same performance. The upper limit on the performance major of SHRP method is of order O (N). Here choices made to choose the best path are quick due to the fact that the decision is made at the first stage of the organization. The negative point of this approach is that it won't give an exact MO solution.

DyMORA chooses the premier path in light of concurrent utilization of the numerous parameters considered by SHRP. In DyMORA on every node MOO process is applied and therefore the new answer is contrasted with the recent one. Here, new answer implies the answer obtained subsequently by executing the MOO process to every node. The benefit is that all the nodes cut back energy, and the performance is nearer to SHRP. The downside of it is that it requires long handling time, and therefore the complexity order is O (kN^2), wherever k is the no of criteria's.

MOHRA chooses the most effective path in view of concurrent utilization of the different parameters (Ref. Section 2.4.1). Overhead metric utilized is related with cost, and enhancement of the NW. rtime parameter manages time assessment norms. In MOHRA, by synchronous handling of different parameters, holds the best elements of SHRP and DyMORA, and it tries to cut back the overhead and boost the capability. The complexity of MOHRA with N nodes may be stated in terms of edges |E|, and nodes |N|. The complexity is of the order of O ($|N|^2+|E|$) =O ($|N|^2$), for thin WSN where no of edges is less than |N/2|. The max heap algorithm requires O ((| E | + | N |) log | N |) time. The complexness of MOHRA is over SHRP and smaller than DyMORA. MOHRA utilizes two-level hierarchy where every node is arranged to form max-heap (logical arrangement) depending on the cost function. The energy utilization is smaller within the network, and also the energy is distributed constantly within the NW.

2.5. ASSUMPTIONS, NETWORK MODEL

To formulate the hybrid MO routing algorithm for WSNs node and NW level assumptions with notations, network model, and methodology is explored in detail.

2.5.1. NODE ASSUMPTIONS, NETWORK ASSUMPTIONS, NOTATIONS

To implement MOHRA some node and network level assumption are

Node Assumptions [16]

- All nodes are homogeneous.
- Nodes positioning is at random in the sensing area.
- Nodes are static in G-MOHRA and In MMOHRA mobility is given to few CMs.

Network Assumptions [16]

- The entire sensing region partioned into smaller clusters.
- The Sink is a node having high capability and it is positioned in any one corner of the target region. The Sink can convey to whichever CH or CM it want to.
- There are same links. For intra-cluster and inter-cluster communication bidirectional links are used.

Communication flow within G-MOHRA and MMOHRA is described in Figure 2-6 [38].

Notations [16]

- G = (N, E) is a graph of N vertices and E edges. Here G models WSN as a graph.
- N= $\{n_1 \ldots\ldots n_2\}$ is collection of all nodes including Cluster Member, Cluster Head, and Base Station.
- $E \in \{(n_i, n_j) \in N \times N \mid i \neq j\}$ is the collection of edges which includes different links between the vertices v_i, v_j.
- CM - Cluster Member
- CH - Cluster Head
- S - Set of processed nodes
- $m_{cost}(n_i)$ MO Cost-Function
- L_{child} - Node linked on the left-hand-side of the present node (logical)
- R_{child} - Node linked on the right-hand-side of the present node (logical)
- m_{cost} is an secondary input of every node n_{ij}
- $\alpha, \beta, \gamma, \delta, \varepsilon$ balancing factors

- Table – Routing Table of every node
- MO – Multi-Objective

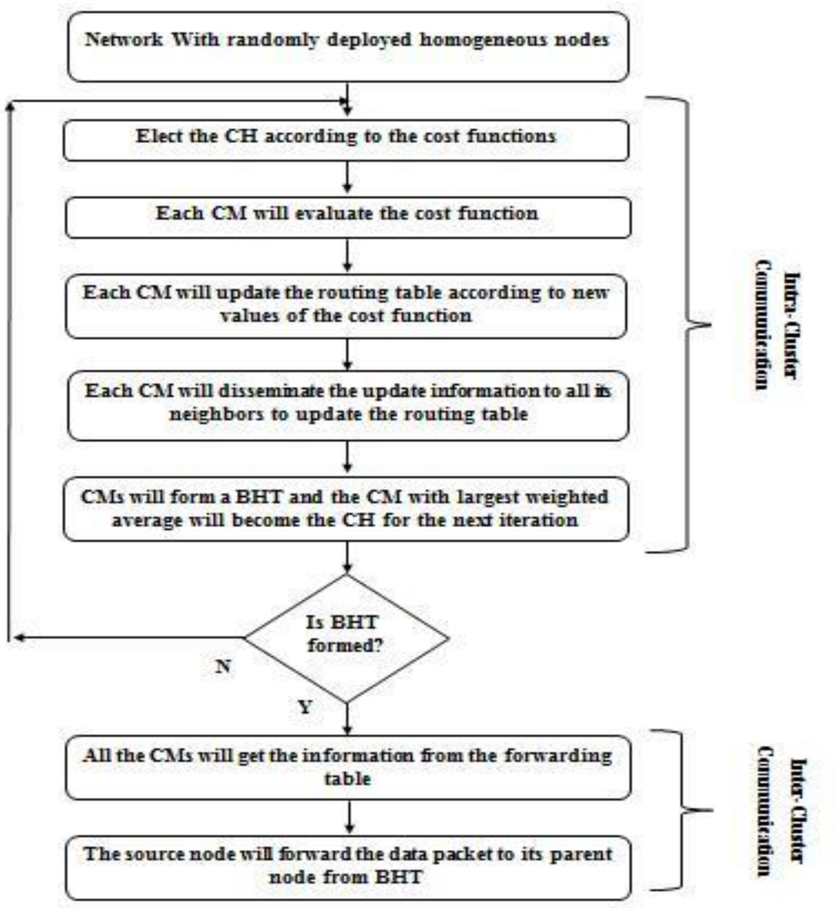


Figure 2- 6 Intra and inter-cluster communication in G-MOHRA.

2.5.2. NETWORK MODEL

The nodes are positioned unevenly within the objective region. They are accountable to detect the incidents in the objective region. Whole detecting region is separated into the smaller clusters. Every cluster has a CH. Rest of the nodes in the cluster is called as CMs. CMs elect the CH. In MOHRA, The conversation among the CMs and CH within and outside the cluster is ranked. At initial stage, CMs are set to form logically a Binary-Heap-Tree (BHT). CMs utilize average of MO depending on the weights assigned, as declared in segment 2.4.1. CMs are organized such manner that for each CM, the weighted average is more significant or equivalent to every child. The node which has highest weighted total can turn out to be CH within that cluster. The node arrangement to form BHT is a logical arrangement and the sensor nodes are not forming a tree like structure physical. At the second level, the selected CHs within various clusters will form a BHT. CH with biggest weighted average is going to be chosen as CH among all CHs at second level. The chosen CH can send the collective info to the sink. CMs can have conversation with CH selected in their cluster. CMs can't speak to the other CMs in a same or distinctive group. They even can't speak to CH within distinct cluster. The CHs are responsible to aggregate the info collected from CMs to cut back the energy utilization. CMs are identical and they can be static or movable. The sink could be a node having high capability positioned in one corner of detecting territory. The duty of working as a CH is switched between various CMs. This switching will stabilize the energy utilization among the CMs. The concentration of nodes within the topographic point is extremely large. For such state of affairs, clustering dependent data forwarding mechanism is offered.

2.6. GREEN-MOHRA (G-MOHRA) IN WSN

The MO [37] data forwarding issue is a policymaking issue where a multiple QoS parameters are considered simultaneously. In most of the cases, these parameters are all time conflicting. Depending on the need of applications the parameters are selected. The decision makers favor decision for forwarding packets with numerous objectives [37] rather than a SOO. The principle burden of present-day data forwarding mechanisms is that most of the protocols yield a single objective solution for selecting best route as opposed to a multi-objective solution those can be investigated for a good deal. The contribution of this chapter is an innovative multi-objective technique identified as Green (Energy Efficient)-MOHRA (G-MOHRA) for WSNs [38]. In this scenario the CM, CH, and the sink nodes are immobile. It utilizes distinct leveled grouping (hierarchy). It provides low cost solution network where the nodes don't have GPS ability. It is a dynamic clustering dependent data forwarding mechanism that utilizes a Weighted Average of numerous Metrics (WAM) (Ref. Section 2.4.1).These metrics are utilized for selecting the CHs. Here, the key objective is to drop the energy utilization of nodes for expanding the lifetime of the network.

2.6.1. EQUATIONS OF ENERGY-EFFICIENCY OF G-MOHRA

Each node is non-rechargeable and has the opening energy of E0. Energy depletion while transferring a packet beginning with ith node to jth node uses a free-space as well as multi-path fading model banking on the distance amongst source and target. The source and target node has radio electronics for energy depletion. Depending upon distance and whether a node is a child or parent node in BHT the energy depletion varies for all packet of size Ps.

When the child node transfers Ps bytes of data, then the energy depletion is specified as: (Ref. eq. 2-14 to 2-18) [42]

$$E_{DISSI}(N_i) = E_{elec} * P_s + E_{amp} * P_s * \left\|d_{ij}\right\|^4 \ \ if \ \left\|d_{ij}\right\| \geq d_0 \tag{2-14}$$

$$E_{DISSI}(N_i) = E_{elec} * P_s + E_{amp} * P_s * \left\|d_{ij}\right\|^2 \ \ if \ \left\|d_{ij}\right\| < d_0 \tag{2-15}$$

where, E_{elec} is electronic-energy centered on coding, distribution, modulating, filtering and amplification. d_{ij} is the distance amongst ith and jth node. When the jth node accepts the packet of size Ps the energy dissipation is specified as:

$$E_{DISSI}(N_j) = E_{elec} * P_s \tag{2-16}$$

The energy cost of all nodes is amended after transferring or reception of packet of size Ps.

$$E_{remain+1}(N_i) = E_{remain}(N_i) - E_{DISSI}(N_i) \tag{2-17}$$

$$E_{remain+1}(N_j) = E_{remain}(N_j) - E_{DISSI}(N_j) \tag{2-18}$$

The procedure of data transferal and energy cost amendment is recurrent till every node is dead.

2.7. MOBILITY AWARE MOHRA (MMOHRA)

Mobile WSN (MWSN) has expanded hugely because of the capacity to interface the environment through the real world. In MWSN, nodes travel spontaneously in an objective region deprived of any exclusive framework [39]. Because of movement, data forwarding has turned out to be more difficult as associations among the nodes in the network change dynamically. The contribution of this chapter is a novel Mobility-Aware MOHRA (MMOHRA) [39]. In this mechanism the CH as well as the sink node are stationary, and mobility is given to few CMs. MMOHRA can persistently assess different routes and chooses the optimal path to send the detected information upto the sink.

2.7.1. EQUATIONS OF MOBILITY-AWARENESS OF MMOHRA

In MMOHRA, movable nodes are well thought-out to be traveling alongside a one-dimensional territory also the pause-time of the nodes are exponentially disseminated. MMOHRA utilizes Random-Way-Point (RWP) model for mobility. In this model interval for the travel phase is governed by endpoint and speed. The end-users don't have control on this. The following section illustrates thru mathematical equations how the mobile state dissemination go forward over time.

Notations

[a1, au] – Area where the sensor node can travel
λ - Exponential distributed pause time
d – Destination Point
r(d) – Random Distribution
Vmax – Upper bounded Speed
K(t) – Instantaneous State of the node
∅(t) – Instantaneous Phase of the node either {Move or Pause}
A(t) – Instantaneous Position belongs to [a1, au]
V(t) – Current Speed belongs to $[-V_{max}, V_{max}]$ in case $\emptyset = \text{move}$
D(t) – Current destination belongs to [a1, au].
P(a, v, d, t) – Cumulative probability at time t in case $\emptyset = \text{move}$
Q(a, t) – Cumulative probability at time t in case $\emptyset = \text{pause}$ at position $A(t) \in [a_1, a]$

When the mobile node move in the region a first they select d according to r(d). Then they select the speed permitting to the distribution $f_V(v|d, a) = 0$ for $v > 0$. $f_V(v|d, a) = 0$ belongs to the interval $[-V_{max}, V_{max}], \forall\, d, a$. The dynamism of the mobile node can be described in terms of Markov-Process in which K(t) is characterized by $\emptyset(t) \in \emptyset = \{\text{move}, \text{pause}\}$. The probability at time (t) of a mobile node is (Ref. Eq. 2-14 – 2-22) [41]

$$P(a, v, d, t) \triangleq \emptyset_r\{\emptyset(t) = move, A(t) \in [a_1, a], D(t) \in [a_1, d], V(t) \in -V_{max}, v)\} \quad (2\text{-}19)$$

$$Q(a, t) \triangleq \emptyset_r\{\emptyset(t) = \text{pause}, A(t) \in [a_1, a] \quad (2\text{-}20)$$

Introducing the densities

$$p(a, v, d, t) = \frac{\partial^3 P(a,v,d,t)}{\partial a\, \partial v\, \partial d} \quad (2\text{-}21)$$

$$q(a, t) = \frac{\partial Q(a,t)}{\partial a} \quad (2\text{-}22)$$

Subsequent pair of equations can be obtained

$$\frac{\partial p(a,v,d,t)}{\partial t} = -v\, \frac{\partial p(a,v,d,t)}{\partial a} + \lambda\, f_V(v|d) r(d) q(a, t) \quad (2\text{-}23)$$

$$\frac{\partial q(a,t)}{\partial t} = \lambda q(a,t) + \int v\, p(a,v,d,t)\, dv \quad (2\text{-}24)$$

Boundary Situation

It depicts the chance of a mobile node hitting the boundary is null

$$p(a_l, v, d, t) = 0\ ;\ p(a_u, v, d, t) = 0\ \forall\ v, d, t \quad (2\text{-}25)$$

$$s(a_l, t) = 0\ ;\ s(a_u, t) = 0\ \forall\ t \quad (2\text{-}26)$$

The initial situation

$$p(a, v, d, 0) = p_0(a, v, d)\ ; q(a, 0) = s_0(a) \quad (2\text{-}27)$$

Which is a appropriate pdf for mobile node's original position, speed, and endpoint

The stages in MMOHRA are:

- **Setup stage –** Used for initializing and updating the forwarding table at every node.
- **Data forwarding stage –** Used when information is transferred from a starting node upto sink. The path is picked centered on the weighted average of various factors.

The setup- and data forwarding stage in MMOHRA is same as that of G-MOHRA.

2.8. ROUTING IN G-MOHRA AND MMOHRA

Both these projected mechanisms upgrade the paths constantly. They pick best path to forward information to the sink and they work in stages such as

- Set-up
- Data-Forwarding

Set-up Stage: The nodes arrange themselves into clusters. The method for CHs determination is non-occasional and it starts on request whenever the topology changes. The calculations of the algorithm for finding the best route rely upon a WAM which is a blend of diverse goals (Ref. Segment 2.4.1). The CH decision depends on a global factor (Ref. Eq 2-14) [38]

Here, $0 \leq \alpha, \beta, \gamma, \delta, \eta \leq 1$ are weights. All CMs can calculate the global factor and they can alter the forwarding table as per recent estimations of the cost. Each and every CMs pass on the upgraded data to nearby nodes for updating their data forwarding table. CMs construct a BHT, and therefore the CM having biggest WA (Ref. Section 2.4.1) turns into the CH aimed at the following round.

$$f(n_{ij}) = \alpha . m_{energy}(n_{ij}) + (1-\alpha) . \left[\beta . m_{overhead}(n_{ij}) + (1-\beta) \left[\gamma . m_{rtime}(n_{ij}) + (1-\gamma) \left[\delta . m_{lqi}(n_{ij}) + (1-\delta) [\eta . m_{hops}(n_{ij})] \right] \right] \right] \quad (2\text{-}28)$$

Data Forwarding Stage: From the point of origin the data is relayed to the parent node within the BHT. The nodes can get the data concerning their parent from the forwarding table. The process of delivering the information from child to parent continues until it reaches to sink.

2.8.1. ALGORITHM FOR INTRA- AND INTER- CLUSTER CONVERSATION IN G-MOHRA AND MMOHRA

The algorithm for Intra-, Inter- Cluster Conversation in G-MOHRA and MMOHRA is clarified in Algorithm 2 [38].

Algorithm 2: Algorithm for Intra-, and Inter-Cluster Conversation in G-MOHRA and MMOHRA

Determining CH for Intra-Cluster Conversation

Input: Graph $G = (N, E)$ having $m_{cost}(n_i)$, $\alpha, \beta, \gamma, \delta, \varepsilon$
Output: Modified $f(n_{ij})$, $Modified\ Table_i$
Begin
Set $Cost_{\ i} \leftarrow 0\ along\ with\ \alpha, \beta, \gamma, \delta, \varepsilon$
Considering every node i ϵ v do
Compute a universal factor $f(n_{ij})$
Modify $Cost_{\ i} \leftarrow\ latest\ price\ of\ f(n_{ij})$
end
Considering entire (i,$Cost_{\ i}$) do
$Modify\ \ Table_{\ i} \leftarrow latest\ Cost_i$
Construct-heap ($Table_i, N$)
end
Updated CH ← i^{th} node
End

Inter-Cluster Conversation

In the subsequent stage, CHs establish conversation among them, and that they select a CH amongst them for directing the accumulated data upto sink. For selecting CH at subsequent stage, the process is same as first stage.

2.9. RESULTS AND DISCUSSIONS

Simulation parameters for G-MOHRA and MMOHRA are given in Table 2-2. The performance of G-MOHRA [21], MMOHRA [22] is compared with SHRP, and DyMORA. Both the projected mechanisms show improvement regarding numerous performance metrics.

Table 2- 2 Simulation parameters of G-MOHRA and MMOHRA [40]

Wireless Physical	
Network interface type	Wireless Physical
Radio propagation model	Two-Ray Ground
Antenna type	Omni-directional Antenna
Channel type	Wireless Channel
Link Layer	
Interface queue	Priority Queue
Buffer size (ifqLen)	50
MAC	802.11
Routing protocol	G-MOHRA, MMOHRA, DyMORA, SHRP
Energy Model	
Initial energy (Joule)	10
Radio Model	TR3000
Idle power (mW)	13.5
Receiving power (mW)	13.5
Transmission power (mW)	24.75
Sleep Power (µW)	15
Node Placement	
Number of nodes	50, 60, 70, 80, 90 and 100
Number of sink	1
Placement of the Sink	Left top corner of the simulation area
Placement of nodes and sink	Nodes are placed randomly in the given area, and the sink is placed away from the target
Node placement	Random
Number of simulation runs	10
Miscellaneous Parameters	
Area(m)	500 * 500
Simulation time (s)	2000
Packet size (bytes)	64

Hello Interval (s)	5
CH Election Interval (s)	20
Packet Interval (s)	0.2

Notations

- PDR - Packet Delivery Ratio
- AEC - Average Energy Consumption
- NRL - Normalized Routing Load
- NW - Network

2.9.1. RESULTS WITH STATIC SCENARIO

PDR

Figure 2-5(a) shows PDR of SHRP, DyMORA, and G-MOHRA. As G-MOHRA being a hybrid protocol, its PDR is enhanced by an element of 10.74 % and 8.45 % than SHRP and DyMORA respectively in numerous situations because of optimal packet forwarding. PDR demonstrates how nodes are utilized effectively to forward info. G-MOHRA enhances PDR as a result of the simplest path is picked effectively and rapidly due to MO arrangement where LQI and rtime is improved simultaneously.

AEC

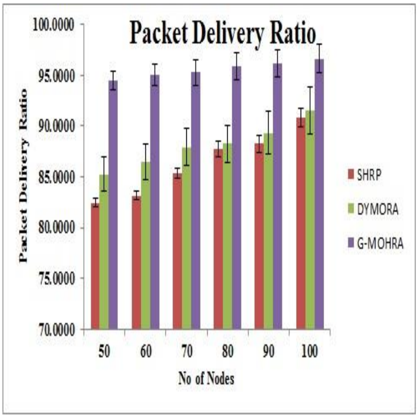
Figure 2-5(b) outlines the AEC. AEC of G-MOHRA is higher than SHRP and lower than DyMORA in numerous situations because of clustering hierarchy. SHRP beats G-MOHRA by a margin of 5.28 %. G-MOHRA has 6.54 % smaller AEC compared with DyMORA. This reduction of energy enhances the life expectancy of the NW also outlines acceptability of G-MOHRA. The outcomes additionally portray that SHRP has brought down AEC than DyMORA.

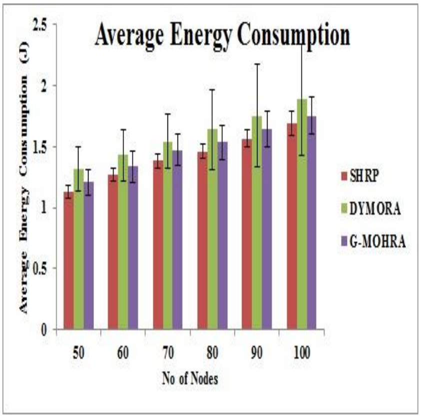
NRL

As G-MOHRA uses a MO data forwarding mechanism, and it uses average of numerous parameters (Ref. Section 2.3.1) for choosing the best way point of origin upto target. NRL is more in G-MOHRA by 4.83 % compared with SHRP and smaller by 18.76 % than DyMORA. The advantage of G-MOHRA is that it deliberates QoS issues against varied layers of WSN. Figure 2-5(c) provides an investigation of NRL.

Jitter

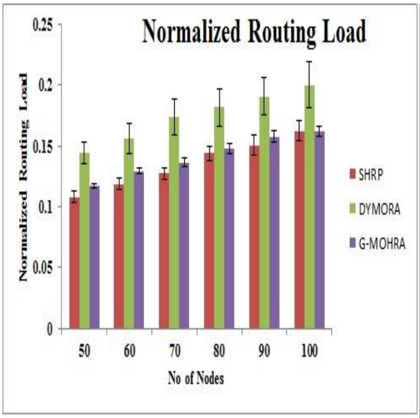
Figure 2-5(d) show the analysis of jitter. As G-MOHRA has more routing overhead than SHRP the jitter is more by a factor of 28.28% than SHRP. It is optimally forwarding the packets from point of origin to target when contrasted with DyMORA. It enhances jitter with a margin equal to 26.43% when contrasted with DyMORA.

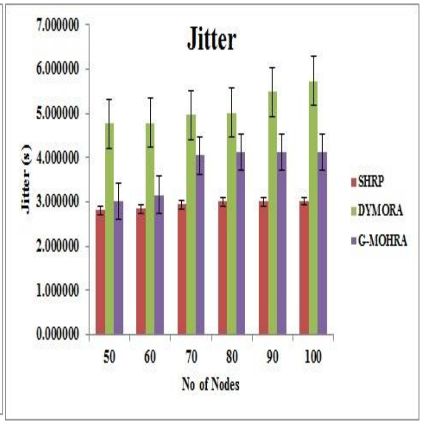




a) PDR _G-MOHRA

b) AEC_G-MOHRA





c) NRL_G-MOHRA

d) Jitter_G-MOHRA

Figure 2- 7 Results with static-homogeneous scenarios.

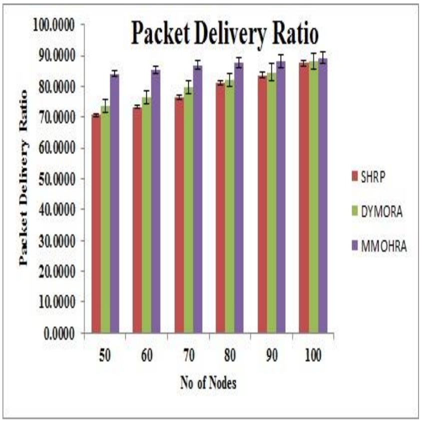
2.9.2. RESULTS WITH MOBILE SCENARIO

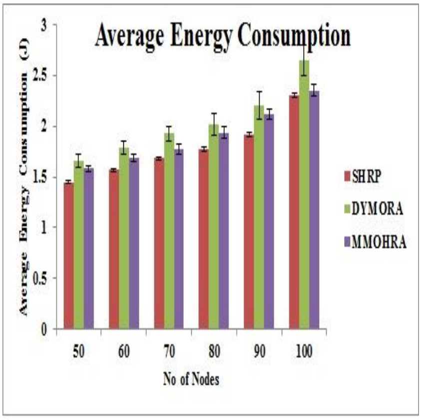
PDR

Figure 2-6(a) outlines the PDR of SHRP, DyMORA, and MMOHRA. Because of the amalgamation of numerous MO elements, greater PDR is anticipated in MMOHRA. The ratio is greater by an factor of 7.5% against DyMORA and with 10.27% against SHRP. This is because of the well-organized data forwarding. This ratio demonstrates that nodes are utilized effectively to forward information packets and in tern it increments life of the network.

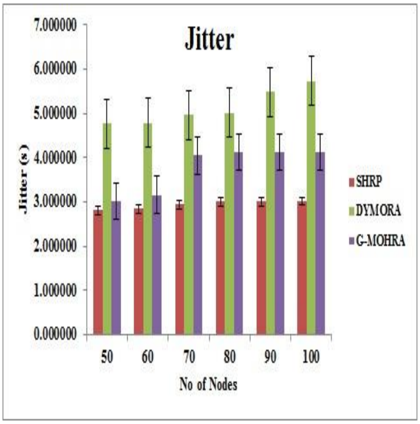
AEC

Figure 2-6(b) delineates the AEC utilization of three MO data forwarding mechanisms. The energy depletion in MMOHRA is reduced against DyMORA and higher against SHRP. MMOHRA outflanks DyMORA by a factor of 6.43%. SHRP has 7.05 % less energy consumption than MMOHRA. This saving of energy compared with DYMORA elongates the lifetime of the network and outlines the adequacy of MMOHRA. The outcomes additionally delineate that SHRP has lesser AEC than DYMORA.





a) PDR_MMOHRA b) AEC_MMOHRA



c) Jitter_MMOHRA

Figure 2- 8 Results with dynamic-homogeneous scenarios.

Jitter

Figure 2-6(c) describes the investigation of jitter. MMOHRA has brought down jitter against SHRP as well as DyMORA. MMOHRA is productive in advancing the data from the point of origin upto end point when contrasted with SHRP and DyMORA. The projected data forwarding mechanism enhances jitter with a component of 31.11% contrasted with DYMORA and it has 13.11% high jitter when compared with SHRP.

2.10. SUMMARY OF THE CHAPTER

The contribution of this chapter is a innovative routing algorithm for static WSN called as G-MOHRA. The notable resolution of G-MOHRA is to choose an ultimate way upto sink in sight of MO measurements to lessen the energy depletion and to elongate the NW lifespan. The act of G-MOHRA is assessed and contrasted with two MO data forwarding mechanisms. G-MOHRA is energy proficient as opposing with SHRP and DyMORA.

Another impact of this chapter is a new movement conscious MOHRA (i. e. MMOHRA for homogeneous NW. The essential objective of this projected mechanism is to extend the lifespan of NW. The implementation of projected mechanism is better contrasted using SHRP and DyMORA in presence of movement of sensor nodes. The proposal beats DyMORA with respect to energy efficiency, PDR, and jitter. Both G-MOHRA and MMOHRA can be extended out by the thought of energy heterogeneity of sensor nodes and sink under static and movability conditions.

2.11. REFERENCES

[1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "Wireless Sensor Networks:A Survey", Computer Networks, Vol. 38 (4), PP. 393–422, 2002.

[2] G. Anastasi, M. Conti, M. Di Francesco, and A. Passarella, "Energy conservation in wireless sensor networks: A survey", Ad-hoc Networks, Vol. 7, PP. 537–568, 2009.

[3] A. Ali, A. Khelil, F. K. Shaikh, and N.Suri, "Efficient Predictive Monitoring of Wireless Sensor Networks", International Journal of Autonomous and Adaptive Communications Systems (IJAACS), Vol. 5(3), PP. 233–254, 2012.

[4] N. Pantazis, S. Nikolidakis, and D. Vergados, "Energy-Efficient Routing Protocols in Wireless Sensor Networks: A Survey", IEEE Journal, Communications Survey and Tutorials, Vol. 15 (2), PP. 551-591, 2013.

[5] J. Al-Karaki, and A. Kamal, "Routing techniques in wireless sensor networks: a survey", IEEE Journal, Wireless Communications, Vol. 11 (6), PP. 6-28, 2004.

[6] Y. Yong-Chang, and W. Gang, "Survey on routing protocols for wireless sensor networks", Application Research of Computers, PP.1616-1621, 2008.

[7] M. A. Rahman, S. Anwar, M. I. Pramanik, and M. F. Rahman, "A Survey on Energy Efficient Routing Techniques in Wireless Sensor Network", IEEE, 15th International Conference on Advanced Communication Technology (ICACT), PP. 200-205, 2013.

[8] B. R. Bellur, and R. G. Ogier, "A Reliable, Efficient Topology Broadcast Protocol For Dynamic Networks", In Proceedings of the IEEE international conference on computer communications (INFOCOM), PP. 178–186, 1999

[9] G. Liu, H. Zhang, F. Lei, and D. Wei, "A New Hybrid Routing Protocol in WSNs", Proceedings of the IEEE International Conference on Cyber Technology in Automation, Control, and Intelligent Systems, Kunming, PP. 175-179, 2011.

[10] S. O¨. zdemir, B. A. Attea, and O ¨ nder A. Khalil, "Multi-Objective Clustered-Based Routing with Coverage Control", Springer Journal of Soft Computing, Vol. 17(9), PP. 1573-1584, 2013.

[11] M. Tabibzadeh, M. Sarram, and F. Adibnia, "Hybrid Routing Protocol for Prolonged Network Lifetime in Large Scale Wireless Sensor Network", IEEE,

International Conference on Information and Multimedia Technology (ICIMT), PP. 179-183, 2009.

[12] S. Ehsan, and B. Hamdaoui, "A survey on energy-efficient routing techniqueswith QoS assurances for wireless multimedia sensor networks", IEEE Journal, Communications Survey and Tutorials, Vol. 14 (2), PP. 265-278, 2012.

[13] N. Magaiaa, N. Hortab, R. Nevesb, P. Pereiraa, and M. Correia, "A multi-objective routing algorithm for Wireless MultimediaSensor Networks", ELSEVIER Journal, Applied Soft Computing, Vol. 30, PP. 104–112. 2015.

[14] W. B. Heinzelman, A. P. Chandrakasan, and H. Balakrishnan, "An Application-Specific Protocol Architecture for Wireless Microsensor Networks", IEEE Transactions on Wireless Communications, 1(4), PP. 660–670, 2002.

[15] M. Bala Krishna, and M. Doja, "Multi-Objective Meta-Heuristic Approach for Energy-Efficient Secure Data Aggregation in Wireless Sensor Networks", Springer Journal, Wireless Personal Communication, Vol. 81, PP, 1:16, 2015.

[16] N. Kulkarni, N. Prasad, and Ramje Prasad, "MOHRA: Multi Objective Hybrid Routing Algorithm for Wireless Sensor Network", Wireless VITAE13, Global Wireless Summit 2013, 2013.

[17] C. Poellabauer, and W. Dargie, "Fundamentals of Wireless Sensor Networks: Theory and Practice Book", John Wiley and Sons Ltd, PP. 163–204, 2010.

[18] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-Efficient Communication Protocol for Wireless Microsensor Networks", in Proceedings of the 33rd Hawaii international conference on system sciences, Vol. 8, 2000.

[19] A. Manjeshwar, and D. P. Agrawal, "APTEEN: A Hybrid Protocol for Efficient Routing and Comprehensive Information Retrieval in Wireless Sensor Networks", Proceedings of 16th International Parallel and Distributed Processing Symposium /International Parallel Processing Symposium - IPDPS(IPPS) , PP. 01-95b, 2002.

[20] S. D. Muruganathan, and A. O. Fapojuwo, "A Hybrid Routing Protocol for Wireless Sensor Networks Based on a Two-Level Clustering Hierarchy with Enhanced Energy Efficiency", IEEE Communications Society, WCNC proceedings, Las Vegas, NV, PP. 2051-2056, 2008.

[21] G. Valentini, C. Abbas, L. Villalba, and L. Astorga, “DyMORA :A Multi-Objective Routing Solution Applied on Wireless Sensor Networks”, IET Communications, Vol. 4(14), PP. 1732–1741, 2010.

[22] N. Sengottaiyan , Rm. Somasundaram, and Balasubramanie, “A Hybrid Routing Protocol for Wireless”, Springer the series Communications in Computer and Information Science, Vol. 70, PP. 183-193, 2010.

[23] V. Safdar, F.Bashir, Z. Hamid, H. Afzal, and J. Y. Pyun “A Hybrid Routing Protocol for Wireless Sensor Networks with Mobile Sinks”, IEEE, 7th International Symposium on Wireless and Pervasive Computing (ISWPC), Dalian, PP. 1-5, 2012.

[24] G. P. Hancke, and C. J. Leuschner, “SEER: A Simple Energy Efficient Routing Protocol for Wireless Sensor Networks”, South African Computer Journal, Vol. 39, PP. 17–24, 2007..

[25] Y. Yu, R. Govindan, and D. Estrin, “Geographical and Energy Aware Routing: A Recursive Data Dissemination Protocol for Wireless Sensor Networks (Technical Report)”, Computer Science Department, UCLA, 2001.

[26] G. Lukachan, and M. Labrador, “SELAR: Scalable Energy-Efficient Location Aided Routing Protocol for Wireless Sensor Networks”, In Proceedings of the 29th annual IEEE international conference on local computer networks, PP. 694–695, 2004.

[27] M. Zimmerling, W. Dargie, and J. M. Reason, “Energy-Efficient Routing In Linear Wireless Sensor Networks”, In the Proceedings of IEEE International Conference on Mobile Adhoc and Sensor Systems (MASS), PP. 1-3, 2007.

[28] R. Anitha, and P. Kamalakkannan, “Enhanced Cluster Based Routing Protocol for Mobile Nodes in Wireless Sensor Network”, Proceedings of the International Conference on Pattern Recognition, Informatics and Mobile Engineering (PRIME), PP. 187-193, 2013.

[29] A. Sivagami, K. Pavai, D. Sridharan, and M. Satya, “Design issues on tree based aggregation algorithms in wireless sensor networks”, International Journal of IT and Knowledge Management, Vol. 1 (2), PP. 449–462, 2008.

[30] L. Choi , J. Jung, B. Cho, and H. Choi, “M-Geocast: robust and energy efficient geometric routing for mobile sensor networks”, Proceedings of IFIP international federation for information processing, Vol. 5287, PP. 304–316, 2008.

[31] L. Nguyen, X. Defago, R. Beuran , and Y. Shinoda, "Energy efficient routing scheme for mobile wireless sensor networks", In Proceedings of IEEE international symposium on wireless communication systems, PP. 568–572, 2008.

[32] T. Chang, K. Wang, and Y. Hsieh, "A color theory based energy efficient routing algorithm for mobile wireless sensor networks", International Journal of Computer Networks and Communications, Vol. 52, PP. 531–541, 2008.

[33] K. Kim, J. Yun, J. Yun, B. Lee, and K. Han, "A location based routing protocol in mobile sensor networks", In Proceedings of the international conference of advanced communication technology (ICACT), PP. 1342–1345, 2009.

[34] S. Choi, J. Kim, J. Lee, and K. Rim, "REDM: robust and energy efficient dynamic routing for a mobile sink in a multihop sensor network", In Second international conference on communication software and networks, PP. 178–182, 2010.

[35] L. Borsani, S. Gugliemi, A. Redondi, and M. Cesana, "Tree based routing protocol for mobile wireless sensor networks", In Proceedings of eighth international conference on wireless on-demand network systems and services, PP. 164--170, (2011).

[36] F. Ren, J. Zhang, T. He, C. Lin, and S. K. Das, "EBRP: Energy Balanced Routing Protocol for Data Gathering in Wireless Sensor Networks", IEEE Transactions on parallel and Distributed Systems, Vol 22(12), 2011.

[37] H. Alwan, and A. Agarwal, "Multi-Objective QoS Routing for Wireless Sensor Networks", IEEE International Conference on Computing, Networking and Communications (ICNC), PP. 1074-1079, 2013.

[38] N. Kulkarni, N. R. Prasad and Ramjee. Prasad, "G-MOHRA: Green Multi-Objective Hybrid Routing Algorithm for Wireless Sensor Networks", International Conference on Advances in Computing, Communications and Informatics (ICACCI), PP. 2185–2190, 2014.

[39] N. Kulkarni, N. R. Prasad and Ramjee Prasad, "MMOHRA: Mobility Aware Multi-Objective Hybrid Routing Algorithm for Wireless Sensor Networks", 4th International Conference on Wireless Communications, Vehicular Technology, Information Theory and Aerospace & Electronic Systems (VITAE), 2014.

[40] N. Kulkarni, N. R. Prasad and Ramjee Prasad, "A Novel Sensor Node Deployment using Low Discrepancy Sequences for WSN", An International

Journal of Wireless Personal Communications, Springer Journal, ISSN 0929-6212, pp. 1-14, DOI 10.1007/s11277-017-5063-9, 2017.

[41] M. Garetto, E. Leonardi, "Analysis of Random Mobility Models with Partial Differential Equations", IEEE Trans. Mobile Computing, vol. 6, no. 11, pp. 1204-1217, Nov. 2007.

[42] R. Kumar, D. Kumar, “Multi-objective fractional artificial bee colony algorithm to energy aware routing protocol in wireless sensor network”, Springer, Wireless Networks, Vol. 22(5), PP. 1461–1474, 2015.

CHAPTER 3. MOBILITY AND HETEROGENEITY AWARE ROUTING IN WIRELESS SENSOR NETWORK

Cluster-dependent Heterogeneous Mobile-WSN (CHMWSN) is turned out to be promising and exciting study in the arena of ICT due to inadequate means. In the most recent decade, the investigators presumed WSN to be gathering of identical and steady nodes. Motion, heterogeneity, and MOO has added different dimensions to the research and it demand for innovative green way out to enrich network lifespan. The chapter examines the effect of energy diversity and movement of nodes on MOHRA. This chapter offers a novel QoS Assured MOHRA (Q-MOHRA) and Heterogeneous MOHRA (H-MOHRA) for Heterogeneous WSN (HWSN). As compared to contemporary solutions the proposed mechanism based on mobility and heterogeneity concept is energy efficient.

3.1. INTRODUCTION

WSN is very crucial technology for structuring IoT. WSN makes use of sensors, transducers, actuators, which are essential things for acknowledgment of IoT frameworks. The prime advantage of WSN is that one can associate these sensors to each other and can infer critical data by ceaselessly detecting environmental or physical data in real time, distantly, and from a greater terrain. WSN is the basic enablers of IoT. WSNs have countless differentiated applications such as watching physical or environmental conditions, battleground monitoring, national and armed forces applications, habitat- health- monitoring, home-, office- automation, etc. Originally most of the researchers believed WSN to be pool of homogeneous nodes where all the nodes had identical initial-energy and fitted with identical capability hardware. In HWSN, nodes have various computing power and detecting range. Unlike homogeneous WSN, placement and topology control are more intricate in HWSN. Still, the HWSN has become public as they prolong the network lifespan deprived of any considerable surge in the cost. In WSN the heterogeneity is of three types. Computational-, Link-, and Energy- heterogeneity. The nodes may have high end processors and memory for accomplishment of very multifaceted task. A node may have high data transportation capacity for over a long distance due to powerful transceiver. Nodes may have dissimilar initial energy. Using heterogeneous nodes on the field lessens reaction time and enhances battery life. HWSN where all the sensor nodes when deployed maintain the location at following instants of time are called as static HWSN. Dynamic HWSN on the contrary, have the nodes move around with time e.g. sensors that are fitted to a car, airplane, truck, bus and so on. The mobility of nodes will force extra burden in routing the packets, as the route stability becomes important condition. The prime objective of this chapter is to attain energy enhancement and to expand lifespan of the NW.

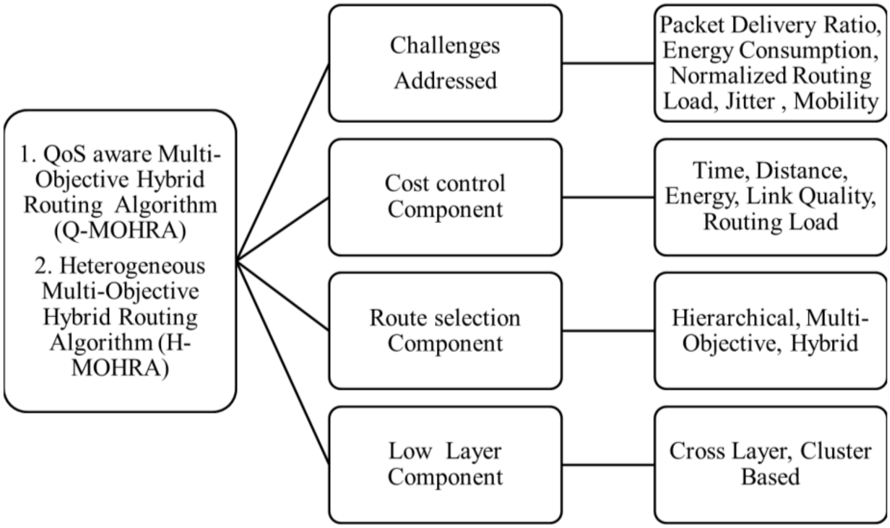


Figure 3- 1 Contribution of chapter 3

Conventional routing techniques utilize single metric (e. g. hop count) and force few upper limits on the metrics for forwarding the packets [4, 5]. This chapter contributes with an innovative MOHRA with QoS assurance for static and dynamic HWSNs.

Figure 3.1 illustrates the chapter 3 contributions with challenges addressed, and cost control-, route selection-, and low layer- components used in the research. The remaining chapters are structured as below. Section 3.2 focuses on the different QoS multi-objective, hybrid routing algorithms with energy heterogeneity under with and without mobility scenario. Section 3.3 explains the assumptions, network and communication model, methodology, and notations used. Section 3.4 gives the details of Q-MOHRA with different phases of communication. Section 3.5 describes H-MOHRA with flowchart and algorithm. Section 3.6 presents the comparative results of Q-MOHRA and H-MOHRA with recent solutions under static and mobile scenarios. Lastly, Section 3.7 gives the comprehensive overview of the work.

3.2. RELATED WORK

Numerous researchers have projected different multi-objective protocols depending on various QoS parameters design issues and applications to enhance the energy efficiency [6]. Nevertheless, not any routing protocol is perfect, that is utilized for various applications and diverse cause.

3.2.1. QOS BASED MULTI-OBJECTIVE HYBRID ROUTING ALGORITHM FOR HWSN

The authors of [7] have projected a structure for routing in WSN. It's MO constraint-based, and accommodative. It's exclusively reliant on native information of every sensor. [7] Outlines a data forwarding mechanism aiming every packet. The direction finding operation rest on, $source_{id}$, one or set of targets, native path restrictions, and forwarding purpose. Native path restrictions put on to the nearby nodes. Native path restrictions can eliminate the problem of energy depletion, risky zones. Packet forwarding purpose is governed by MO to enhance path. The different features of this routing are decreasing hop count, utilizing maximum energy path, decreasing threat on the route.

AACOCM in [8] offers a MO prototype built on bandwidth limitations. It improves path to the target depending on MO function. The MO function concurrently enhances several metrics such as depletion, delay, packet dropping rate, and energy depending on weight. The algorithm can suitably use for many applications by changing the weights. It scales back energy-charge, interval, and dropping rate. It describes three classes of nodes, standard-, hungry-, and uncommon- ants. Here, the movement related to ants from start to end node is nothing but data forwarding tree construction. AACOCM uses optimistic and pessimistic opinion method and rest on a cloud.

MOEA/D [9] is meant to resolve energy management shortcoming. It deals with MO downside by means that of issue related data. It splits MO downside into numerous sub-issues that are improved at the same time by means of native issue details. It relieves inessential searches and severe connections harmfully affecting the act. Operation of the projected mechanism in [9] banks upon erratic core density as well as computation of Euclidian distance between weight vectors. Here, the improvement is subject to node grouping, choice of acceptable CHs as well as the state of nodes.

MQoSR [10] deals with observed nearby node choice method. It is aggregation of topographical- and QoS- routing. MQoSR forms several separate paths. MQoSR works on the basis of consistency, interval, distance to sink, energy, and lifespan. MQoSR splits QoS considerations within connection- and path. Link considerations are used for the subsequent stage where as path considerations permit dropping the NW usage.

In [11] the authors projected MOO method using Evolutionary-Algorithms (EA). EA tries to create the balance between min-lifespan and avg-lifespan of nodes. The authors have projected a unique way that is banking on k-shortest paths" to realize quicker optimization. Attributing to the inadequacy of computing resources, this progression algorithm utilizes a consolidated method. The EA attempts to make the most of the lowest lifespan of nodes in the network. EA reacts with packet-loss relation to enhance the network performance of the network.

The crucial aim of 2LB-MOPSO [12], method is that distinguish everlasting and erratic behavior depending on MO QoS factors such as Detection-Accurateness, False-Discovery-Rate, diagnosis expectancy, PDR. It stabilizes detection correctness and expectancy. 2LB-MOPSO This algorithm pinpoints the faulty nodes banking on comparative data within one-hop distance. To distinguish erratic defects, 2LB-MOPSO exploits time duplication. The researchers have recommended a MOO method to identify erratic faults.

3.2.2. ROUTING ALGORITHMS WITH ENERGY HETEROGENEITY AND MOBILITY IN WIRELESS SENSOR NETWORKS

Researchers have characterized routing protocols used for homo- and hetero-generous networks depending on the kind of nodes used. This part of the thesis reveals outline of routing protocols with energy heterogeneity and mobility in WSNs.

EDDEEC in [13] for HWSNs could be a versatile protocol wherever the CH selection is based upon original-, residual- node's energy and AEC of the network. The protocol utilizes fluctuating possibilities for choosing CH in present iteration. It dispenses energy in the NW effectively to improve lifespan of the network. EDEEC handles the problem that once sequent iterations some super-, and progressive nodes have identical remaining energy comparable to traditional nodes. This issue is because of the fact that the super- and advanced nodes are repeatedly elected as a CH. EDDEEC solves the matter by properly choosing absolute residual energy Tabsolute. Below Tabsolute all super-, advanced- and normal- nodes have a similar chance of becoming CH in the successive round.

Efficient and Dynamic Clustering Scheme (EDCS) [14] utilizes the different energy level for multi-level WSN. In EDCS, CH is selected based on mathematical calculations. For electing CH, EDCS utilizes AEC estimation and previous energy utilization. EDCS uses a gravitational scheme for joining the CM to the CH.

BEENISH [15] classifies sensor nodes into four totally different classes in view of their initial energy. Nodes having better enduring-energy are going to turn into CH. Likelihood of choosing a node within the highest ranking as CH is large within next iterations. This mechanism accomplishes even dissemination of energy and will increases the lifespan of the NW.

Evolutionary based clustered Routing Protocol (ERP) [16] handles routing issue in clustered WSN. It enhances Evolutionary algorithm by using a novel fitness function. ERP uses a mixture of two novel ideas viz. consistency and departure error. The capability function relies upon broadcast distance. The broadcast range is measured as consistency within the cluster and departure error between the clusters In ERP, node that is not part of the cluster becomes a member of group in the event that it fulfills minimum distance criteria.

Energy Efficient Stable Election Protocol (EE-SEP) [17] gives further network-security and energy competency. EE-SEP reflects the nodes in two categories viz. standard and propelled. A CM chooses a CH in light of no of CH necessary, present round-number, and non-CHs in the past round.

Heterogeneous Disjoint Multipath Routing Protocol (HDMRP) [18], a multipath routing protocol, utilizes a special idea called as energy-node-disjointness to expand various ways concerning the sink and the sensor nodes. HDMRP deals with faults within the routing and makes the network more rigid as against internal failure. Here, disjointness implies there aren't any coupled nodes.

Energy Dissipation Forecast and Clustering Management (EDFCM) [19] relies upon a strategy designated as "one-stage energy utilization prediction". EDFCM alters grouping mechanism used in LEACH together with its descendants. EDFCM developed for HWSNs, distributes sensor nodes in the target region with some nodes used for management purpose. EDFCM extends the network life by accurately choosing number of clusters to balance energy in subsequent rounds.

Energy Efficient Heterogeneous Clustered scheme (EEHC) [20] utilizes efficient heterogeneous multi-leveled clustering mechanism. EECH considers the balance energy, and weighted probability of every node for deciding the electoral merit as CH. EECH upgrades resource utilization and process of CH election.

3.3. METHODODOLOGY

In most conventional routing protocols the route of the data packets depends on SOF (e.g. only hop-count), and sometimes the protocols utilize settings over some threshold value [21]. In such protocols, only few sensor nodes are associated in conveying information commencing the target area up to sink and remaining nodes are useless. Because of this scheme, the energy associated with these nodes is promptly exhausted. The nodes will fall short of energy, and will be dead causing either network partition or connection failure. The chapter proposes Multi-Objective Routing (MOR). MOR is an example from decision science which supports in making decisions about a route. It assists in arranging, forming, and solving the problems based on numerous measures. Occasionally, mentioned MO is incompatible with one another. Following MOR algorithms are projected to discover the way from point of origin to target built on WAM (Ref Section 2.4.1) to expand lifespan of WSN.

- QoS-aware MOHRA(Q-MOHRA) [26]
- Heterogeneous MOHRA (H-MOHRA) [25]

3.4. ASSUMPTIONS, NETWORK MODEL

This section describes the different notations assumptions, and methodology used in Q-MOHRA, H-MOHRA. In this section, we introduce the details regarding implementation of QoS aware and Heterogeneous MOHRA algorithms, which considers the mobility and heterogeneity with reference to energy of sensor nodes [25, 26]. The nodes are configured with different initial energy. Further investigation is carried out by adding mobility to them. The details of the node and network assumptions along with network model and flow of algorithm is discussed in sub-sections.

3.4.1. NODE ASSUMPTIONS, NETWORK ASSUMPTIONS

Node and Network Assumption

All the assumption employed by Q-MOHRA and H-MOHRA are same as mentioned in section 2.3.1 from chapter-2 except

- Only few nodes are mobile.
- Heterogeneity of nodes is with reference to initial energy

Basic Notations

- G = (N, E) is a graph of N vertices and E edges. Here G models WSN as a graph.
- N= $\{n_1 \ldots\ldots n_2\}$ is set of all vertices including Cluster Member, Cluster Head, and Sink.
- $E \in \{(n_i, n_j) \in N \times N \mid i \neq j\}$ is the collection of edges which includes different links between the vertices v_i, v_j.
- CM - Cluster Member
- CH - Cluster Head
- m_{cost} - supplementary response of every element n_{ij}
- $\alpha, \beta, \gamma, \delta, \varepsilon$ - weight
- Table – Routing-Table of every node
- S = Set of all sensor nodes.
- NeighboringNodes - Neighbors identified
- $f(n_{ij})$- A universal parameter

3.4.2. NETWORK MODEL FOR Q-MOHRA AND H-MOHRA

The NW model for the H-MOHRA [25] and Q-MOHRA [26] is appeared in Figure 3-2. It is an expansion of Figure 2-2 (Ref. Section 2.3.2). Figure 3- 2 characterizes

WSN as a graph G. It comprises of a gathering of nodes with totally diverse energy ranking. The NW model is taken into account as a connecting graph G (N, E) of various clusters {C1, C2, C3, - - - Cn} of WSNs having gathering of heterogeneous nodes. Every region integrates a CH and no of nodes that are delineate by a group of vertices 'N' and wireless linking edges 'E'. The 'N' nodes (n_1---n_2) within the NW are at random disseminated and arranged into 'n' clusters employing a multi-hop clustering. Limited nodes 'V' are set up with larger energy (20J) than the conventional nodes 'n' (10J). Q-MOHRA is meant for static heterogeneous WSN and H-MOHRA is meant for Movement aware WSN. In H-MOHRA node mobility is taken into account and also the movement is given to only fraction of total no of nodes set up in the target region. The procedure of development of BHT and furthermore the alternative correspondence details among CHs and CMs are clarified exceptionally well in 2.7.2.

3.5. Q-MOHRA IN WSN

Sensor n/w applications require elongated lifespan, energy competence. Hence the prerequisite of WSN is to guarantee Quality-of-Service (QoS) apart from node placement, energy competence and small price tag etc. This perhaps can be realized thru appropriate routing techniques for data transferal. Owing to poor energy competence, customary routing algorithms are not appropriate for current WSN usages. It is especially anticipated to incorporate an energy competent path-detection and data conveying methods to handover data amid sensor nodes as well as BS. Node -placement, -heterogeneity, -linkage, -extent, and QoS etc. are few concerns in routing. In QoS-aware routing algorithms, the crucial strategic objectives are to warrant enhanced QoS parameters such as jitter, energy proficiency, packet transfer ratio, routing load etc. in most of the WSN usages. In this section, Q-MOHRA, a strategy that supports WAM as well as MOHRA algorithmic rule is projected for heterogeneous WSN where all the nodes are immobile. Its activities are divided into two phases [26].

- Built zone liaison
- Data Forwarding

Built zone liaison

The process begins with establishing relations with the other nodes within the zone. Every node contains a forwarding table that has info concerning to the nearby nodes. As a part of table each and every node has below inventory noted as zone data (Ref. Table 3-1).

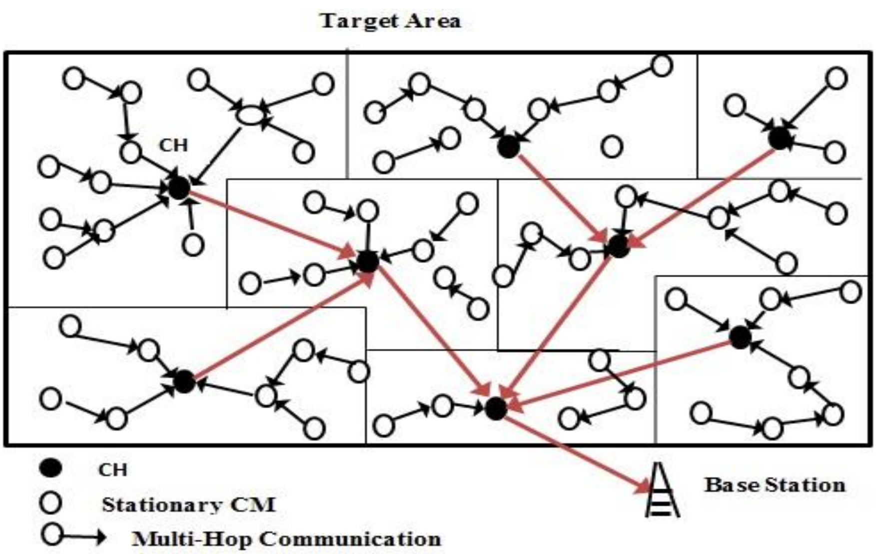
Table 3- 1 Fields in data forwarding table

ID	Leftover-energy	Link-status	Operating-cost	Response-period	hops

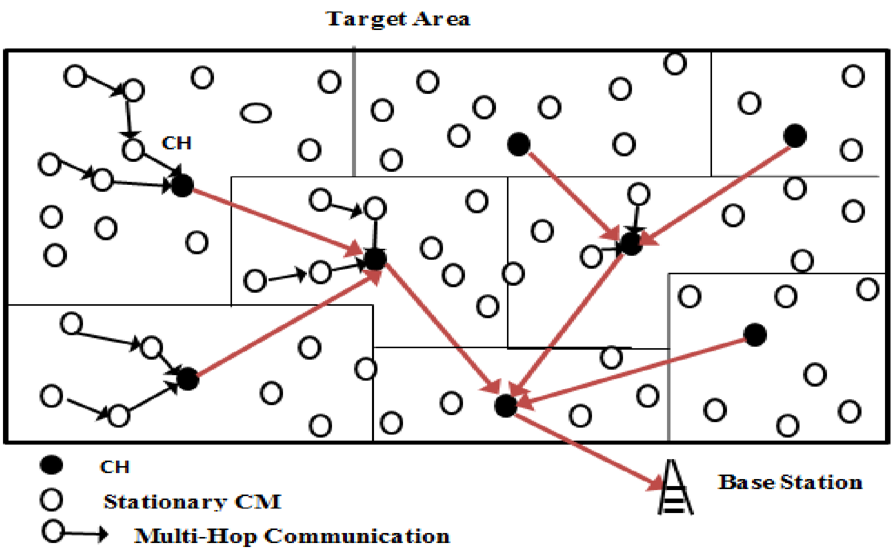
The process of building zone liaison is illustrated hereafter. After booting, a node within the NW starts greeting nearby nodes with a hello-msg so as to build/store zone info. If nearby nodes which are directly connected can respond to this hello-msg. The reply message can contain the data relating to all the fields mentioned within the above table. On receiving the positive acknowledgement from the recipient the sender node can commit to establish a zone relationship with the neighbor. The sending node will endure accumulating this info in the forwarding table for each nearby node. This phase is repetitive either every so often or on the occasion of changes in the NW.

Data Forwarding

The improved path calculation upto sink is relies on the values within the forwarding table. Every node will figure out average of a number of factors as accumulated within the forwarding table in step 1. Depending on the computed cost for every neighbor that is found with WAM approach as well as a universal function [23] (Ref equation 2-14 from section 2.5.1 in chapter 2), the CH for the zone are determined. All the nodes will follow the same process to build their zone info. The nodes can arrange themselves to create a BHT (logical arrangement) supporting the cost computed. At second stage, all the CH will from BHT. In BHT, Each child can send the data to its parent until the data gets transmitted to the sink.



(a) Network model_Q-MOHRA



(b) Communication Model_Q-MOHRA

Figure 3- 2 Model_Q-MOHRA

Figure 3-2 (a) and 3-2 (b) respectively gives information about the NW and communication model considered for the projected algorithms.

3.6. H-MOHRA IN WSN

In WSN, the fundamental research happened to be with identical, immobile nodes which can't be substituted. Nodes detect happenings of concern, and particular energy competent routing algorithm is utilized for conveying the data to stationary sink. Nevertheless, mobility is a vital characteristic of nodes in WSN. Mobility is concerned mostly with subsection of the nodes also it is further varying subject with application. In H-MOHRA the influence of mobility of nodes on behavior of WSN has been comprehensively discovered. The crucial objective of H-MOHRA is to exploit WSN under mobility of few nodes. Movement of node is utmost typical and all together the most exciting type of mobility, which can alter network topology radically unless and until the system can dynamically change around.

In WSNs, grouping of sensor nodes is a technique employed to extend the lifespan and scalability of network [24]. In many implementations, the analysts accepted all nodes to be same. To extend lifespan, and to enhance steadiness, WSNs may use heterogeneous node. The node heterogeneity is about processing capability of CPU, channel ability or regarding preliminary energy level of the nodes. Few nodes may have higher processing capability than a conventional one. Few links in the network may have higher capacity. Nodes may differ in initial energy. Heterogeneity regarding initial energy of node is considered in H-MOHRA development.

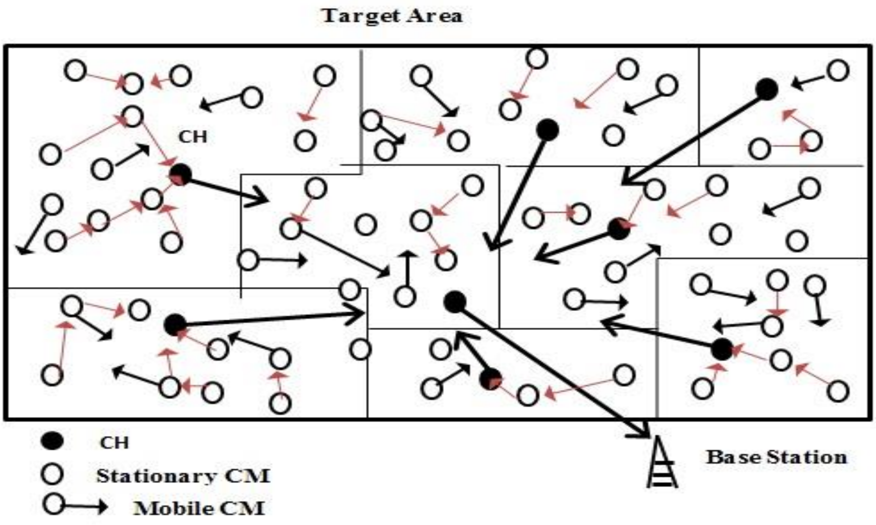
Several researchers suggested numerous protocols for forwarding packets and most of them are centered on best route selection-, initial network establishment-, and communication criteria. In most protocols, the packets are dispatched considering QoS parameters such as minimum delay, hop count, possible energy consumption and maximum throughput, link quality, [3].

At primary level the objective region is partitioned within smaller groups called as clusters. CMs within the cluster will elect head. All the members and head coordinate to form Binary-Heap-Tree (BHT). The method is repetitive for the chosen CHs at the secondary level. The CH designation in light of the WAM is already explained in section 2.3.2 in chapter 2. The node having significant average will get to be head of that group. At upper level within the ladder the procedure is repeated among the CHs. The part of CH is to aggregate the information from numerous sensor nodes and to remove the duplicate information if any. CH will transfer the accumulated information to sink. Responsibility as a head is rotated among the CMs in the successive rounds. H- MOHRA uses clustering and hierarchical technique. Figure 3-3 (a) and 3-3 (b) respectively gives information about the NW and communication model considered for the projected algorithms.

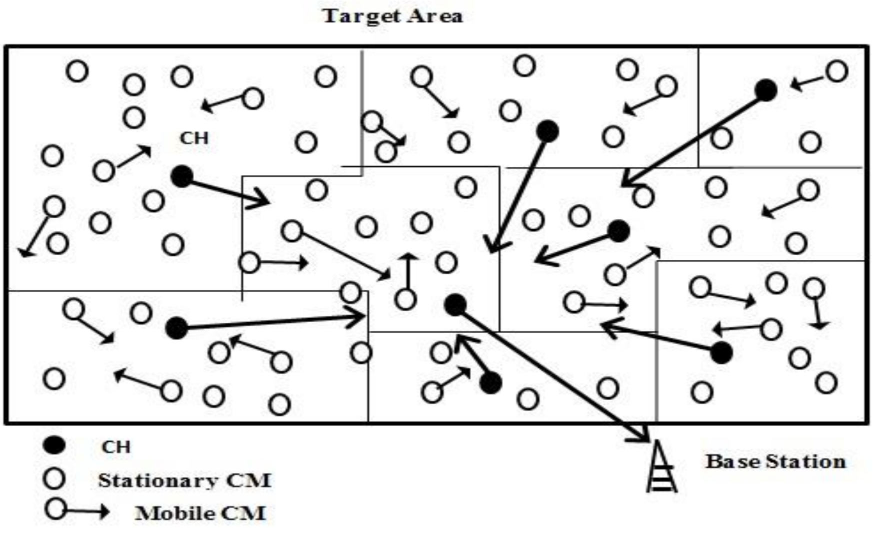
3.7. FLOWCHART FOR Q-MOHRA AND H-MOHRA

Both these projected mechanism operates [25, 26] in three phases: Cluster construction, CH appointment, Data forwarding.

The cluster construction stage relies upon the Hello message which is broadcasted by every one of the member of the cluster and the reply from the adjacent nodes. Both the mechanisms concentrates on the calculation of the WAM based on numerous parameters expressed before. The CH election decided upon a cost function [23] (Ref equation 2-14 from section 2.5.1 in chapter 2). CMs will evaluate the cost function for all the neighbors among the network. CMs advertise the



(a) Network model_ H-MOHRA



(a) Communication Model_ H-MOHRA

Figure 3- 3 Model_ H-MOHRA

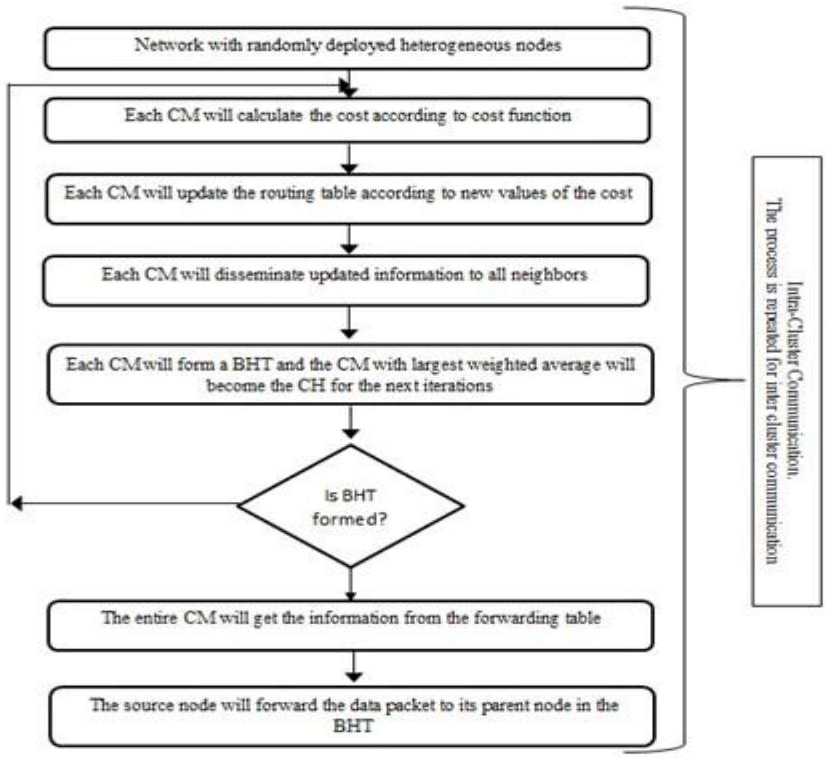


Figure 3-4 Flowchart of Q-MOHRA & H-MOHRA for intra-cluster communication

updated information from the routing table to every one of their adjacent node. The adjacent node will update their routing table based on the current information they hold and the updated information received from the broadcasting node. CMs shape a BHT and whichever node has higher value is selected for formation and updating of the cluster in the successive round. The flow chart in Figure 3-4 depicts the intra-cluster correspondence. The data forwarding node sends an information packet to its predecessor node. The predecessor node will forward the information to its predecessor from BHT. This process is repetitive till the information is delivered to the sink.

3.8. ALGORITHM OF Q-MOHRA AND H-MOHRA

Algorithm 1 exhibits working of Q-MOHRA and H-MOHRA for cluster construction and CH appointment [25].

Algorithm 1 Working of Q-MOHRA and H-MOHRA

Input: *Graph* $G = (V, E)$ *using* $m_{cost}(n_i)$, $\alpha, \beta, \gamma, \delta, \varepsilon$
Output: $Updated\ Table_i, Updated\ f(n_{ij})$

Procedure of Cluster Formation

Begin
Set the $Cost_{\ i} \leftarrow 0\ and\ \alpha, \beta, \gamma, \delta, \varepsilon$
for every node i ϵ v *perform*
    Compute a universal-parameter $f(n_{ij})$
    Overhaul $new\ Cost_{\ i} \leftarrow\ parameters\ of\ \ f(n_{ij})$
end for
for every node (i, $new\ Cost_{\ i}$*) perform*
    $Modify\ Table_{\ i} \leftarrow Updated\ Cost_i$
end for
for $\forall\ N_s \in S$
    Advertise_Hello_msg (nodeID, $updated\ Cost_{\ i}$*)*
End for
for $\forall\ N_s \in S$
begin
    Advertised_Msg_Recv (nodeID, $updated\ Cost_{\ i}$*)*
    ID = Search_node_ID. Neighboring_Nodes (nodeID)
    if (ID∉ Neighboring_Nodes)
    update_ Neighboring_Nodes (nodeID, $updated\ Cost_i$*)*
        heapify ($Table_i, Ns$*)*
    endif
end

Appointment of Cluster-head for Internal Communication (Within the group) and the process is rehashed for External (outside the group) Communication [25]

for $\forall\ N_s \in S$
begin
    Largest_Avg_Cost_node=Neighboring_Nodes.get_ Largest_Avg_Cost()
    CH_Msg_Broadcast (nodeID)
end
for $\forall\ N_s \in S$
begin
    CH_Msg_ Rec (nodeID)
    Insert_ CH (ID, nodehasLargestAvgCost)
    Transmit_ Connect_Msg_ CH (nodeID, LargestEnery)
end
for $\forall\ N_s \in S$
begin
    Rec_ Connect_Msg_ CH (nodeID)
End

3.9. RESULTS AND DISCUSSIONS

The scenario is verified by NS-2.34 simulator. The purpose is to analyze and compare QoS parameters viz. AEC, Jitter, NRL and PDR in Q-MOHRA, H-MOHRA, SHRP, and DyMORA. Simulation parameters mentioned in Table 3- 1 is utilized to confirm the performance of Q-MOHRA and H-MOHRA.

Table 3- 2 Simulation Parameters Q-MOHRA and H-MOHRA

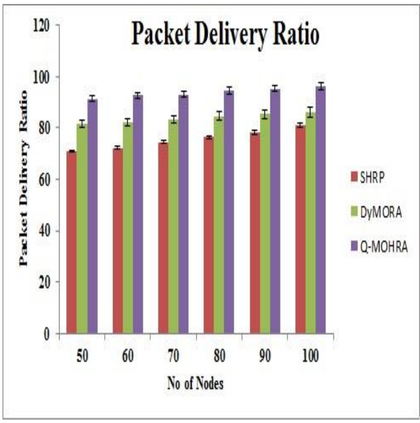
Wireless Physical	
Network interface type	Wireless Physical
Radio propagation model	Two-Ray Ground
Antenna type	Omni-directional Antenna
Channel type	Wireless Channel
Link Layer	
Interface queue	Priority Queue
Buffer size (ifqLen)	50
MAC	802.11
Routing protocol	Q-MOHRA, H-MOHRA, DyMORA, SHRP
Energy Model	
Initial energy (Joule)	10 (20% nodes have Initial energy=20J for creating heterogeneous environment)
Radio Model	TR3000
Idle power (mW)	13.5
Receiving power (mW)	13.5
Transmission power (mW)	24.75
Sleep Power (µW)	15
Node Placement	
Number of nodes	50, 60, 70, 80, 90 and 100
Number of sink	1
Placement of the Sink	One of the corner of the simulation area
Placement of nodes and sink	Nodes are placed randomly in the target area
Node placement	Random
Number of simulation runs	10
Miscellaneous Parameters	
Area(m)	500 * 500
Simulation time (s)	2000

Node Mobility	0.1 m/s (Only in case of H-MOHRA)
Packet size (bytes)	64
Hello Interval (s)	5
CH Election Interval (s)	20
Packet Interval (s)	0.2

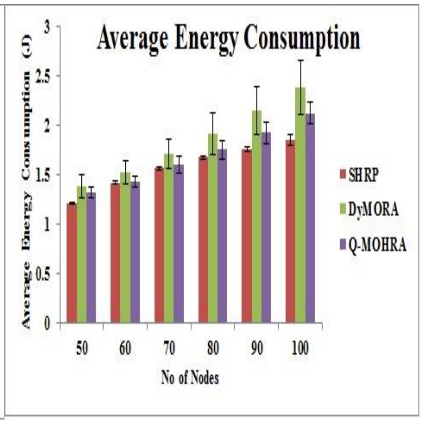
3.9.1. RESULTS WITH NODE HETEROGENEITY WITHOUT MOBILITY: Q-MOHRA

Packet Delivery Ratio

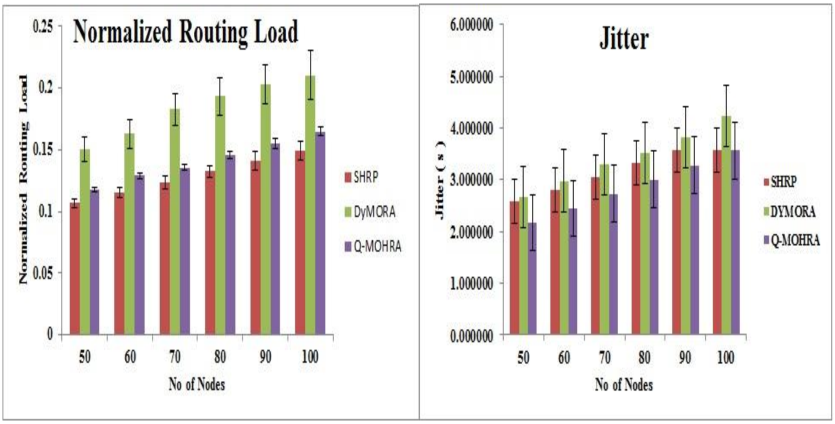
PDR provides the association amongst the the gathering of data collected from sink as well as data generated by sending nodes. By varying the no of nodes from fifty to a hundred underneath equal info generation rate, PDR in Q-MOHRA increases from 91.42 % to 96.29 %. Compared with SHRP and DyMORA the PDR is greater by 11.86% and 24.31 % relating to DyMORA and SHRP. Figure 3-5(a) demonstrates comparative analysis of PDR. Q-MOHRA encompasses a greater PDR as a result of MO mechanism used for enhancing the route. From the figure the inference can be drawn that with less no of nodes within the same simulation space the connectivity among the nodes is poor, therefore the PDR is less in all the compared protocols.



(a) PDR_Q-MOHRA.



(b) AEC_Q-MOHRA.



(d) NRL_Q-MOHRA. (d) Jitter__Q-MOHRA.

Figure 3- 5 Results of static-heterogeneous scenario.

Average Energy Consumption

It is the degree of relation amongst amounts of energy depletion of every node to the aggregate amount of nodes. Figure 3-5(b) demonstrates that AEC in Q-MOHRA is reduced with orientation of DyMORA and SHRP in numerous conditions because of gathering in a hierarchical manner. SHRP is superior to Q-MOHRA by an element of 7.04 %. Performance of Q-MOHRA is good relating to DyMORA by 8.27 % regarding AEC. This energy saving within the network increases lifespan of network and underlines the usefulness of Q-MOHRA.

NRL

It is relation of an aggregated series of packets forwarded per information packet. Q-MOHRA exhibits considerably less routing-load compared with DyMORA as shown in Figure 3-5 (c). Q-MOHRA needs less routing-packet by an element of 23.07 % less than DyMORA and 10.39 % higher than SHRP. The major contribution of Q-MOHRAs NRL is from route establishment stage where it takes care of MO from totally different layers from the layered architecture of WSN by utilizing WAM (Ref. section 2.3.1). SHRP requires less routing-packets to take care of transmission of data packets of the simulated network.

Jitter

Figure 3- 5(d) exhibit the assessment of jitter. Q-MOHRA brought down jitter compared with SHRP and DyMORA. Jitter is oscillations of packet latency over the period of time. The proposal is effective in directing the info between point of origin towards sink when differentiated with SHRP and DyMORA. Projected mechanism enhances jitter by a part of 16.25% and 8.99% when discriminated with DyMORA and SHRP separately.

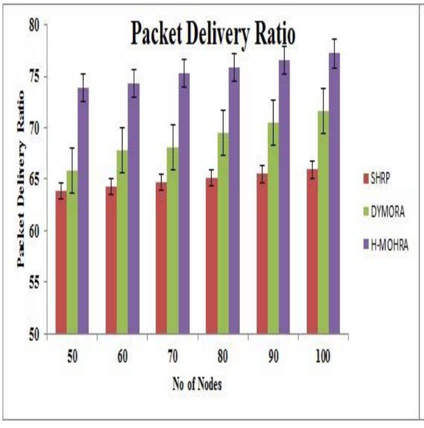
3.9.2. RESULTS WITH NODE HETEROGENEITY WITH MOBILITY: H-MOHRA

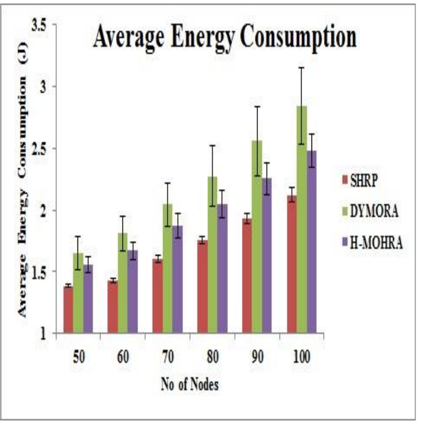
Packet Delivery Ratio (PDR)

Figure 3-6 (a) shows the PDR of three MO approaches. Using the approach of combination of multiple parameters, as proposed in H-MOHRA, It has greater PDR associated with SHRP by an element of 16.32% and an element of 9.55 % over DyMORA in numerous situations because of effective routing of data packets. In H-MOHRA, criteria used to select the appropriate route up to the sink are relying on optimization of multiple parameters such as LQI and reaction time, etc. Higher PDR confirms the energy efficiency of H-MOHRA.

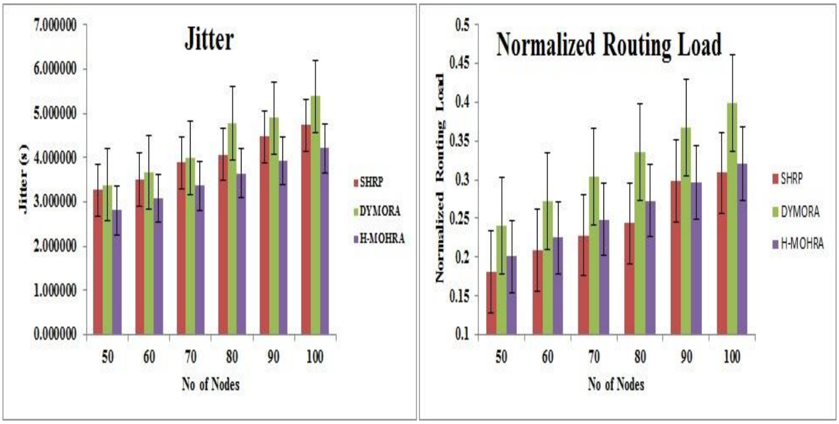
Average Energy Consumption

As illustrated in Figure 3-6(b), AEC of H-MOHRA is not as much as SHRP and DyMORA. The reason behind this is hierarchical clustering. In H-MOHRA AEC is less by 16.37 % and 9.7 % compared with SHRP and DyMORA respectively. The outcome additionally describes that DyMORA has lesser AEC than SHRP for the operational environment described in section 3.6.





(a) PDR_H-MOHRA. (b) AEC_H-MOHRA.



(c) Jitter_H-MOHRA. (d) NRL_H-MOHRA.

Figure 3- 6 Results of dynamic-heterogeneous scenario.

Jitter

Figure 3- 6(d) illustrate the comparison of jitter. H-MOHRA is additionally effective in directing the info from point of origin towards sink when contrasted with SHRP and DyMORA. The projected protocol enhances jitter with a component of 19.39% and 12.12% when contrasted with DyMORA and SHRP individually.

Normalized Routing Load (NRL)

H-MOHRA uses a MOHRA, and it tackles QoS restrictions as of various layers of WSN, data forwarding load is high in H-MOHRA by 6.5 % associated with SHRP also 18.46 % lesser when associated with DyMORA. Figure 3-6(g) provides a correlation of NRL amongst all the three MO techniques.

3.10. SUMMARY OF THE CHAPTER

This chapter recommends an imaginative QoS guaranteed MOHRA algorithmic rule known as Q-MOHRA. The principle objective of this projected mechanism is to guarantee QoS whereas choosing an ideal way till sink in light of MO conditions. The execution of Q-MOHRA is assessed through exhaustive reenactment and compared with SHRP and DyMORA. The factors, for example, AEC, PDR, Jitter, as well as NRL are utilized for assessment. The execution of Q-MOHRA got the better of SHRP and DyMORA. It enhances the PDR with 24.31% when contrasted with SHRP also 11.86 % when contrasted with DyMORA. Q-MOHRA is energy effective as opposing with SHRP and DyMORA.

Movement- and diversity- of nodes have forced different investigation difficulties also interest for different energy competent way outs with a specific end goal to expand network lifespan. In this chapter, H-MOHRA for MWSN utilizes various leveled clustering. H-MOHRA roads the information packets on their way to the sink using a cost function in light of numerous measurements such as Overhead, response Time, LQI, and HOP no etc. In this chapter the influence of energy diversity and effect of node movement on H-MOHRA assessed. The implementation outcome demonstrates the adequacy of H-MOHRA contrasted with SHRP and DyMORA. H-MOHRA cut backs the AEC by 16.37% associated with SHRP also 9.7% when associated with DyMORA. H-MOHRA leaves behind SHRP as well as DyMORA when associated by means of PDR by 16.32 % and 9.55 % in that order.

3.11. REFERENCES

[1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, “Wireless Sensor Networks: A Survey”, Computer Networks, 38(4), PP. 393–422, 2002.

[2] J. Al-Karaki and A. Kamal, “Routing techniques in wireless sensor networks: a survey”, IEEE Journal, Wireless Communications, 11(6), PP . 6-28, 2004.

[3] N. Pantazis, S. Nikolidakis and D. Vergados, “Energy-Efficient Routing Protocols in Wireless Sensor Networks: A Survey”, IEEE Journal, Communications Survey and Tutorials, 15(2), PP. 551-591, 2013.

[4] S. Ehsan, and B. Hamdaoui, “A survey on energy-efficient routing techniqueswith QoS assurances for wireless multimedia sensor networks”, IEEE Journal, Communications Survey and Tutorials, 14(2), PP.. 265-278, 2012.

[5] N. Magaiaa, N. Hortab, R. Nevesb, P. Pereiraa, and M. Correia, “A multi-objective routing algorithm for Wireless MultimediaSensor Networks”, ELSEVIER Journal, Applied Soft Computing, Vol. 30 PP. 104–112, 2015.

[6] M. Bala Krishna, and M. Doja, “Multi-Objective Meta-Heuristic Approach for Energy-Efficient Secure Data Aggregation in Wireless Sensor Networks”, Springer Journal , Wireless Personal Communication, Vol. 81, PP 1:16, 2015.

[7] D.Mahjoub and H.El-Rewini, “Adaptive Constraint-Based Multi-Objective Routing for Wireless Sensor Networks”, In Proceedings of IEEE International Conference on Pervasive Services, Istanbul, PP. 72–75, 2007.

[8] X. Wei and L. Zhi, “The multi-objective routing optimization of WSNs based on an improved ant colony algorithm”, 6th International Conference on

Wireless Communications Networking and Mobile Computing (WiCOM), PP. 1-4, 2010.

[9] S. Özdemir, B. Attea, and Ö. Khalil, "Multi-Objective Evolutionary Algorithm Based on Decomposition for Energy Efficient Coverage in Wireless Sensor Networks", Springer Journal , Wireless Personal Communication, Vol. 71, PP. 195–215, 2013.

[10] H. Alwan, and A. Agrawal, "Multi-Objective Qos Routing for Wireless Sensor Network", International Conference on Computing, Networking and Communications (ICNC), San Diego, CA, PP. 1074-1079, 2013

[11] A. Rahat, R. Everson, and J. Fieldsend, "Multi-Objective Routing Optimisation for Battery-Powered Wireless Sensor Mesh Networks", Proceedings of the 2014 conference on Genetic and evolutionary computation (GECCO), ACM New York, NY, USA, PP. 1175-1182, 2014.

[12] A. Mahapatro, and A. Panda, "Choice of Detection Parameters on Fault Detection in Wireless Sensor Networks: A Multiobjective Optimization Approach", Springer Journal , Wireless Personal Communication, Vol. 78, PP, 649–669, 2014

[13] N. Javaid, T. N. Qureshi, A.H. Khan, A. Iqbal, E. Akhtar, and M. Ishfaq, "EDDEEC: Enhanced Developed Distributed Energy-Efficient Clustering for HeterogeneousWireless Sensor Networks", Procedia Computer Science, Vol. 19, PP. 914 – 919, 2013.

[14] Z. HONG, L. YU, and G. ZHANG, "Efficient and Dynamic Clustering Scheme for Heterogeneous Multi-level Wireless Sensor Networks", Acta Automatica Sinica, Vol. 39(4), PP. 454−460, 2013.

[15] T. N. Qureshi, N. Javaid, A.H. Khan, A. Iqbal, E. Akhtar, and M. Ishfaq, "BEENISH: Balanced Energy Efficient Network Integrated Super Heterogeneous Protocol for Wireless Sensor Networks", International Workshop on Body Area Sensor Networks (BASNet), Procedia Computer Science, Vol. 19, PP. 920 – 925, 2013.

[16] B. A. Attea, and E. A. Khalil , "A new evolutionary based routing protocol for clustered heterogeneous wireless sensor networks", ELSEVIER, Applied Soft Computing Journal, Vol. 12, PP. 1950–1957, 2012.

[17] T. Venu Madhav, and N. V. S. N. Sarma, "Energy Efficient Cluster Routing Protocolfor Heterogeneous Wireless Sensor Networks", Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, CNC, LNICST, Vol. 108, PP. 452–455, 2012.

[18] A. Hadjidj, A. Bouabdallah, and Y. Challal "HDMRP: An Efficient Fault-Tolerant Multipath Routing Protocol for Heterogeneous Wireless Sensor Networks", Institute for Computer Sciences, Social Informatics and Telecommunications Engineering LNICST 74, PP. 469–482, 2011.

[19] H. Zhou, Y. Wu, Y. Hu and Guangzhong Xie, "A novel stable selection and reliable transmission protocol for clustered heterogeneous wireless sensor networks", Computer Communications, Vol. 33, PP. 1843–1849, 2010.

[20] D. Kumar, T. C. Aseri, and R. B. Patel "EEHC: Energy efficient heterogeneous clustered scheme for wireless sensor networks", Computer Communications, Vol. 32, PP. 662–667, 2009.

[21] N. Kulkarni, N. Prasad, and R. Prasad, "MOHRA: Multi Objective Hybrid Routing Algorithm for Wireless Sensor Network", IEEE, Wireless VITAE, Global Wireless Summit 2013, Atlantic City, State of New Jersey, USA, June 24-27, 2013.

[22] N. Kulkarni, N. Prasad, and R. Prasad, "MMOHRA: Mobility Aware Multi-Objective Hybrid Routing Algorithm for Wireless Sensor Networks", IEEE, Wireless VITAE, 2014.

[23] N. Kulkarni, N. R. Prasad and R. Prasad, "G-MOHRA: Green Multi-Objective Hybrid Routing Algorithm for Wireless Sensor Networks", International Conference on Advances in Computing, Communications and Informatics (ICACCI), PP. 2185 – 2190, 2014.

[24] O. Boyinbode, L. Hanh, A. Mbogho, M. Takizawa, and R. Poliah, "A Survey on Clustering Algorithms for Wireless Sensor Networks", IEEE, 13th International Conference on Network-Based Information Systems, PP. 358-364, 2010.

[25] Nandkumar Kulkarni, Neeli Prasad, Ramjee Prasad, "H-MOHRA: Heterogeneous Multi-Objective Hybrid Routing Algorithm for Mobile Wireless Sensor Networks", 1st IEEE Global Conference on Wireless Computing & Networking (GCWCN), Lonavala, India, PP. 249 – 253, 2014 (Best Paper Award).

[26] Nandkumar Kulkarni, Neeli Prasad, Ramjee Prasad, "Q-MOHRA: QoS Assured Multi-Objective Hybrid Routing Algorithm for HWSN", IEEE International Conference on Wireless Communications, Vehicular Technology, Information Theory and Aerospace & Electronics Systems (VITAE), Hyderabad, India, 2015.

CHAPTER 4. DEPLOYMENT OF SENSOR NODE USING QUASI SEQUENCES

In WSN, one of the most significant and open problem is where to place nodes to fulfill certain performance criteria's such as land coverage, population distribution, subject to total no of sensors to be deployed. Node deployment could be one in all the dominant improvement method for realizing the projected aims. Node deployment backs numerous major network services such as topology control, routing, and boundary revealing. The position of nodes dramatically affects the practicability and the throughput of WSN. Node deployment decides how well the detecting field is observed or tracked by sensors. This chapter emphasizes different node deployment techniques, features different issues, and recognizes the diverse objectives. An innovative node placement technique depending on quasi arrangements is proposed in this chapter so as to enhance the lifespan of sensor NW also to tackle the coverage problem. The goal of this chapter is to check however the node positioning influences distinctive QoS bounds, for instance, PDR, AEC, Delay, etc. with MOHRA in WSN. The simulation outcomes obtained in this chapter support the recommendation. At the end the chapter comments on the future outlook.

4.1. INTRODUCTION

In modern ages, Wireless Sensor Networks (WSNs) comprises of enormous amount of sensor nodes, closely positioned over an area. Sensor nodes can work together for assessing the state of their surroundings. The detected information is then transformed into digital signals and processed to the get the facts about happenings around. Due to the fact that the sensor nodes should be very tiny, must have extremely low power consumption, should operate in an unattended manner, should be cheap, and be adaptive to the surroundings, puts lot of constraints on the use of senor nodes. Sensor Nodes are used for many multi-disciplinary applications not limited to security surveillance, wild-habitat monitoring, observing surroundings (i.e. Light, temperature, sound, and vibration), intrusion detection on the border, Intelligent Transport System (ITS), Wireless Body Area Network (WBAN) for healthcare monitoring, atomic power stations, home- office- automation, and Medical-Image-Processing etc. [1-6, 11-13].

In WSN, deployment of nodes is a key problem as it has direct impact on coverage and connectivity [14-16]. Sensor Coverage is related to placing the activate sensors to cover the target area and connectivity studies how the sensed data reaches to sink node. Many researchers in this domain have suggested numerous deployment schemes. Objective of all techniques is to maximize the network lifespan, improve the coverage and connectivity by placing minimum number of nodes [5-7]. Nodes can be placed either arbitrarily or they can have fixed placement [8-10]. Arbitrary deployment is useful in huge scale WSNs and in hostile surroundings, because it is simple and less expensive strategy. However, arbitrary placement of nodes is not effective all the time as it might generate coverage holes (not able to access certain areas in the target field). On the other hand fixed placement is very complicated in huge scale WSNs, in harsh environments. The cost and time required for placing the nodes is also very high. By providing mobility to the sensor nodes, the network coverage and the coverage-holes problem can be eliminated. Nevertheless, mobility of sensor nodes brings together different challenges in terms of energy consumption and route stability.

This chapter offers a Quasii-Random-Deployment (QRD) method built on structures with small inconsistency to reduce shortcomings in fixed as well as arbitrary organization [28]. The nodes are positioned quasi-randomly within the region of examination using Halton-, Faure- and Sobol- sequences. The chapter investigates performance of QRD using MOHRA. The simulation outcome demonstrates that MOHRA has better performance when used with QRD compared with random deployment.

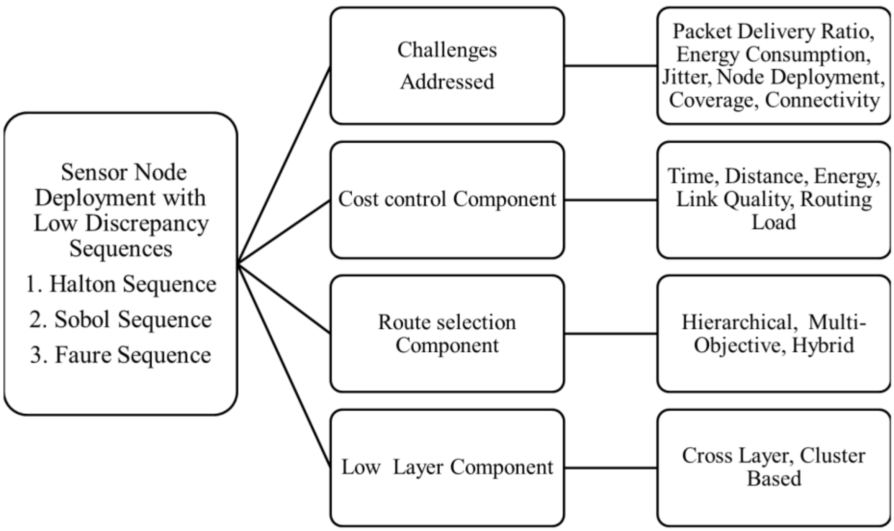


Figure 4- 1 Contribution of chapter 4

Figure 4.1 explains the chapter 4 contributions with challenges addressed, and cost control-, route selection-, and low layer- components used in the research. The leftover of the chapter is structured as takes after. Section 4.2 labels the different sensor node deployment strategies used by different researchers. Section 4.3 describes node deployment schemes proposed in this thesis. Section 4.4 portrays the presumptions, the framework and communication model, procedure. Section 4.5 gives the insights about simulation parameters and result analysis of quasi-random deployment. Lastly, Section 4.6 gives the summary of the work discussed in the chapter.

4.2. RELATED WORK

The authors of [17] proposed CIVA to take advantage of the extent engineered on each paired also predictive model. It utilizes the MO resistant algorithmic rule that practices the Voronoi chart; also it proposes a higher stability among exposure as well as the energy depletion. This algorithmic rule attempts to boost lifespan as well as scope in MWSN. It accomplishes this with adjustment in positions, detecting radius of traveling nodes. This projected algorithm makes the nodes to snooze in order to cut back the energy depletion throughout detecting activity.

Researchers in [18] illustrate completely different challenges and it classifies various open analysis issues within the positioning of nodes within the distinctive use-case. The study additionally gives information on however cutting-edge technologies resembling Bluetooth, ZigBee, also EnOcean, etc. influence node positioning.

The authors of [19], matter of shaping best uneven structural node concentrations as long as positioning concerned with nodes is examined. A bound price for decreasing typical assessment fault-Likelihood is computed. The analysis additionally emphasizes upon equalization on range possibility also the lowest attainable fault-Likelihood.

The investigators of [20] have estimated a collective framework tactic for arbitrarily placed nodes demanding a focus on reasonably associated range to settle Optimal-Deployment (OD) issue. The investigators utilized thought of group extent to assess incomplete-scope. The group extent preparations are additionally helpful in computing the scope of clustered WSN devising an arbitrary positioning.

The authors in [21] have expressed the node positioning assignment by MOO. Exclusive desire of this assignment is to place nodes in such a way to fulfill scope, TEC of the network, and associativity. The analysis makes use of a standard MO approach called MOEA/D-DE. The investigators improved mechanism in consideration by incorporating a fuzzy-Pareto control idea called MOEA/DFD.

The strategic MO configuration gives additional extensibility in picking out the reference to fulfill concern goals

A novel polygonal shape node deployment with secure scope and also connectivity is projected in [22]. The researchers utilized topography management strategy to scale back energy usage. The topography regulation algorithm is taken into account for announcement. The analysis exhibited WSN as if a graph of unit disc wherever all nodes represented sort of a disk. The affiliation in the UDG is estimated by taking the amount of live sensors those are engaged in sending the information to sink.

In [23] a novel PDF is suggested by the investigators to beat the matter of energy loopholes also to prolong the lifespan of the NW. The effort endorses and derives vital features of PDF. PDF is utilized to prototyping the NW specification and to improve algorithmic rule for effective positioning of nodes. The prime goal of suggested approach and conjointly the specifications employed is to stabilize the energy among all nodes to enhance lifespan of the NW. The PDF encompasses a non-uniform distribution of sensor nodes in such a way that greater price of PDF suggests that the nodes are nearer to sink and vice a versa.

The article [24] has offered an uneven; position dependent decided in advance node deployment policy. The offered scheme manages the energy depletion issue. The positioning scheme is appropriate for usages wherever correct placement of nodes is needed. To start with nodes are placed within intended places to make sure connectivity as well as scope. Within the subsequent stage, nodes are located at the ordered points. Precedence within diverse places is specified with the end goal that even when a node fails the maximum precedence regions are packed first. At last the nodes are positioned close to the sink for the purpose of energy equalization.

In article [25] an assessment of various approaches for MO nodes deployment is the main topic enclosed and the information regarding the varied intents for sensor placement is accessible. The analysis is carried out in view of scope, range, durability, energy competency, capacity harmonizing, node count, and reliability. Investigation focuses upon several harmonizing approaches including Pareto-Frontier-solutions. In addition, investigation deliberates the characteristics of the diverse tactics for MO node placement.

4.3. NODE DEPLOYMENT IN WIRELESS SENSOR NETWORK

4.3.1. QUASI-RANDOM DEPLOYMENT (QRD)

From the time when computer era began, Monte-Carlo strategies have been utilized for determining the outcome of the integrand function. These strategies utilize

Pseudo-Random-Sequence (PRS). Since then, a variety of modus operandi has been developed to boost the precision of those strategies. Another modus operandi is to substitute the PRS with a fixed sequence which has higher consistency. Consistency of a sequence is dogged by its inconsistency (error).

In arithmetic, Quasi-Random-Sequence (QRS), also known as Low-Discrepancy-Sequence (LDS), is an arrangement of points by means of the property that, for all values of N, its sub-sequence a_1, ..., a_N encompasses a low inconsistency. The "quasi" name is employed to symbolize that value of LDS are neither random nor pseudorandom, but they have certain belongings of random-variables. The dictionary connotation of term ‘quasi’ is being partly or almost. The QRS is additionally known as squat-discrepancy-sequence. If by “random” somebody means “points distributed all over the place deprived of a clear outline and not clustered together” then in such circumstances QRS is useful.

In QRS the inconsistency on N points with d-dimension is of the order of $(\log N)^d N^{-1}$ for huge N in contrast to the PRS which has inconsistency of the order of $(\log \log N)^{1/2} N^{-1/2}$. In QRS the points generated fill the target space more efficiently. Fixed (grid) points are appropriate in small dimension sequence, but in higher dimension they are not beneficial. Additive increase of points is not possible in grid. As an alternative a specified d dimensional grid can be fine-tuned by adding points by a factor of 2^d. The inconsistency of a grid is of the order of O (1).

QRS are deterministic substitute to PRS meant for usage in Monte-Carlo approaches because of their nature. PRS generator with an interval of [0 to 1] may yield output such that every trial has a likelihood of producing a point with equivalent subintervals. In this case it may happen that the output for ‘n’ trials may fall in the first halve of the interval and the output of ‘n+1’ trial may fall within the other halve with probability of 0.5 i.e. these points may cluster in one region. In QRS the output is compelled by low-discrepancy. The generated points are profoundly correlated i.e. the succeeding point "is acquainted with" the position of the preceding points. The points generated with QRS spread out in a better way in the targeted region. Such an arrangement is to a great degree valuable in computational issues where points are computed on a grid, however it isn't known ahead of time how fine the grid must be to acquire precise outcomes. QRS permits finishing anytime where convergence is perceived.

Advantages of QRS over PRS when used for sensor node placement in WSN

1. QRS explore a target region more proficiently than PRS. The target region is filled homogeneously.
2. With the use of QRS in WSN, the network coverage increases.
3. QRS are highly correlated, so connectivity among the sensor nodes is good.

4. QRS have a self-avoiding property that avoids clumping of sensor node

To cut back the disadvantages of fixed and arbitrary deployment and to mix benefits of both the techniques, the thesis recommends an innovative sensor node placement strategy referred to as QRD [26]. The QRD is based on QRS from mathematics. QRS has belongingness of fixed and arbitrary arrangements. The chapter explores the realization of three QRS [26] namely Halton, Sobol, and Faure and used for node placement.

4.3.2. HALTON SEQUENCE (HS)

In statistics, HS is used to spawn coordinates in a given space for numerical techniques, for example, Monte Carlo. In spite of the fact that this sequence is deterministic, they are of small error. In spite of the fact that, this sequence gives impression of being random, actually it is QRS and it sums up the one-dimensional van der Corput sequence.

- The procedure for obtaining HS is as follows: In a specified base HS [26] is acquired by means of turning around the numbers of certain arrangement of whole number. For example in an exceedingly binary numeral scheme, think about 1D scenario. Here D and B indicate dimension and base of the number system respectively. For one dimensional sequence D=1 and the base of the binary number system is 2. Map the base B between the interval [0, 1] with the goal that the integer $\sum_{\mathrm{k}=0}^{\mathrm{t}} a_k b^k$ is plotted into the point$\sum_{\mathrm{k}=0}^{\mathrm{t}} a_k b^{-k-1}$.

- If one would like to find the sixth component of HS then N=06
- Convert the decimal number into binary i.e. (06)10 = (110)2
- Flip all the bits from the binary equivalent. So (110)2 will become (011)2.
- Map (011)2 in the interval [0, 1].
- So the mapping becomes 0.011
- Translate this binary number back to decimal. i. e. (0.011)2 = 0*2-1 + 1*2-2 + 1*2-3 = 3⁄8.
- So the grouping above is the same as (0.1)2, (0.01)2, (0.11)2, (0.001)2, (0.101)2, (0.011)2, (0.111)2, (0.0001)2, ...
- When this 6th component is mapped on x and y axis in a 2D plane then the coordinate in 2D facet becomes (X coordinate, Y coordinate) = (3/8, 3/8) (ref. Figure 4-2). Similar to this, the other points can also be mapped.
- The above sequence is founded on 2. In the same way the HS can also be founded on 3, 5, 7 (prime numbers) ....and so on.

The Figure 4–2 illustrates the placement pattern of the sensor nodes in two dimensions with HS.

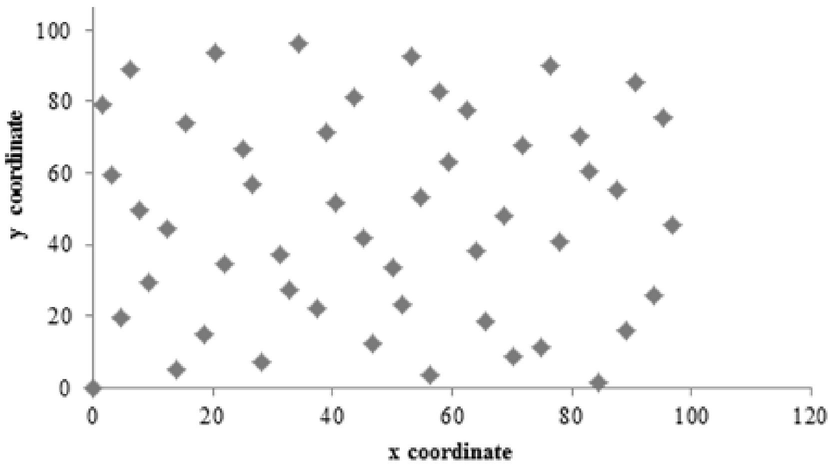


Figure 4- 2 Placement pattern using Halton sequence [28]

HS is more suited for small dimensions. It faces correlation problems at higher prime numbers.

4.3.3. SOBOL SEQUENCE (SS)

SS [26] is an example of QRS with the little discrepancy. SS has the identical base (base 2) for all dimensions to frame better indistinguishable dividing wall concerning interval [0, 1]. SS reorganizes vector elements within every facet. In SS reorganization is more complex. To build SS, a group of direction numbers $\{v_i\}$ given by Eq 4-1.

$$v_i = \frac{m_i}{2^i} \tag{4-1}$$

Where the m_i is odd positive integers less than 2^i, and v_i is picked with the goal that they fulfill recurrence-relation by the coefficients of a basic polynomial [27]. There is some opportunity in the choice of starting direction numbers. Subsequently, it is conceivable to get different arrangements of the SS for a particular dimension. A poor choice of starting direction numbers can significantly reduce the ability of SS when utilized for calculation. Possibly the easy way of selecting the starting direction numbers is to set the l-th leftmost bit to 1, and all the left over bits to be zero, i.e. $m_{k,j} = 1$ for all k and j. The Figure 4– 3 exhibits the arrangement of the sensor nodes with SS.

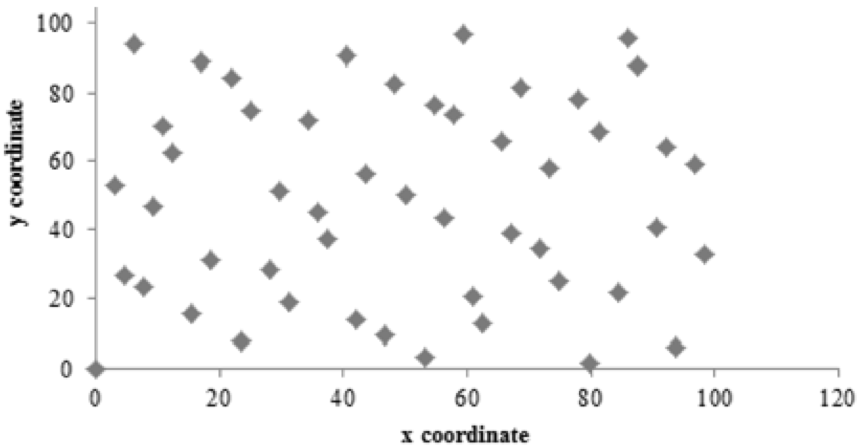


Figure 4- 3 Placement pattern using Sobol sequence [28]

4.3.4. FAURE SEQUENCE (FS)

The FS [26] resembles the HS; it utilizes only one base (one prime number) for finding the coordinates for all measurements. The base of FS is the smallest prime that is bigger than or equivalent to the quantity of measurements (or 2 for 1D). For example if D=100, then HS (in dimension 100) utilizes the 100th prime number that is 541, while the FS utilizes smallest prime no after 100, that is 101 as a base, which is substantially smaller than 541. This is how FS uses a technique for "filling in the holes" in high-dimension quickly. FS avoids correlation problem in high dimension that happened with HS. The FS generation algorithm is a merger of a van der Corput sequence generation algorithm. For the first dimension sequence generation, FS uses identical equation as used in van der Corput sequence generation (Refer Eq. 4-2) but with a reordering of the a_j (Ref. Eq. 4-3). This is done with a recursive equation, from dimension (d -1) to the new dimension d.

In general for base b if $n = \sum_{j=0}^{m} a_j(n)\, b^j$

$$van\ der\ Corput\ base\ b\ (n) = \sum_{j=0}^{m} a_j(n)\, b^{-j-1} \tag{4-2}$$

$$a_i^d(n) = \sum_{j \geq i}^{m} \frac{j!}{i!(j-i)!} a_j^{d-1}(n) \bmod b \tag{4-3}$$

The Figure 4–4 demonstrates the placement of the sensor node with FS.

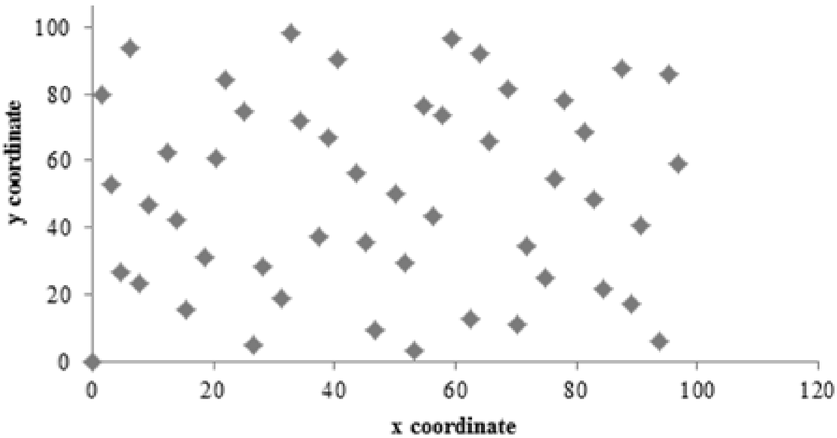


Figure 4- 4 Placement pattern using Faure sequence [28]

4.4. ASSUMPTIONS, NETWORK MODEL FOR WSN

4.4.1. NODE AND NETWORK ASSUMPTIONS

Node Assumptions

- Each and every node is homogeneous regarding initial energy.
- Every node has a separate identity (ID)
- The sink, CHs, also nodes are considered as either stationary / moveable.

Network Assumptions

- The complete NW is distributed mad about smaller groups.
- Each group has a CH. CMs use multihop announcement within the group.
- For communication within the cluster unidirectional-, and inter-cluster communication bidirectional links are used.

4.4.2. NETWORK MODEL

Figure 4-5 demonstrates the WSN as a connected graph G [28]. In graph G nodes represent the vertices and the connections between the nodes represent the edges. In the graph G= (N, E) where N= {n_1.....$n_{2\ldots}$} is collection of sensor nodes, and E ∈ {(n_i, n_j) ∈ N x N | i ≠ j} is a collection of links amongst n_i and n_j. G is shown as a group of little group. In sensing region nodes are placed quasi-randomly. The sink node is placed in one corner of the target region. The CH governs the entire communication within the cluster. It collects the data from the entire CM. The intra-cluster and inter-cluster communication happens at various levels in the hierarchy

(Ref section 2.3.2 for details). The communication among CM-CH and CH-CH is multihop.

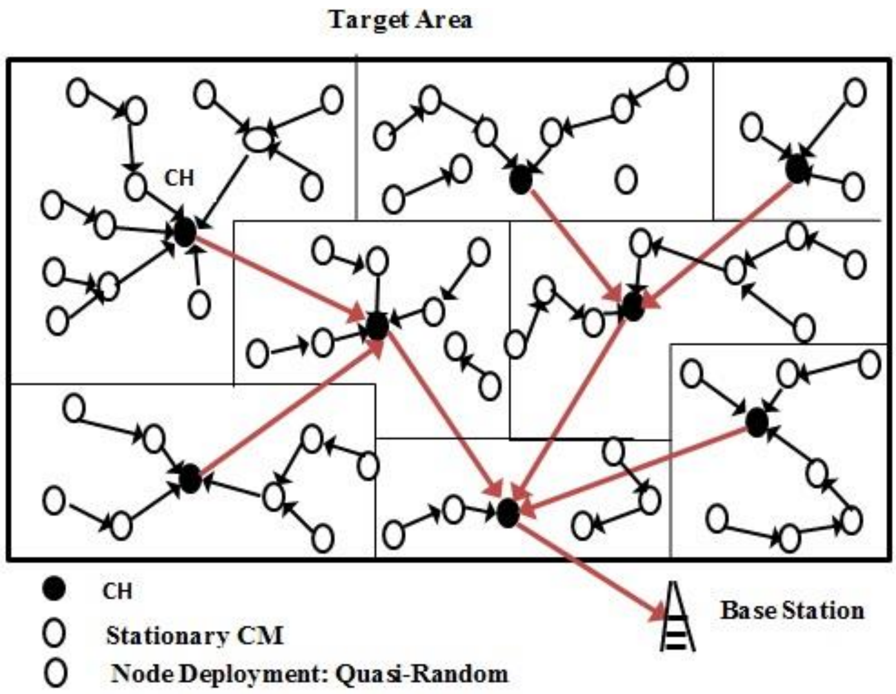


Figure 4- 5 Network model for QRD.

4.4.3. METHODOLOGY

The simulation is carried out in NS-2 for various sensor node placements. QRD strategy is used for placement of the nodes in the sensing area. The performance of MOHRA is analyzed for different QRD strategies and it is equated with the contemporary solutions. Different QoS parameters are energy competency, scope, range will be resolved by means of QRD scheme.

Table 4- 1 Simulation parameters meant for QRD [28]

Wireless Physical	
Network interface type	Wireless Physical
Radio propagation model	Two-Ray Ground
Antenna type	Omni-directional Antenna
Channel type	Wireless Channel

Link Layer	
Interface queue	Priority Queue
Buffer size (ifqLen)	50
MAC	802.11
Routing protocol	MOHRA
Energy Model	
Initial energy (Joule)	10
Radio Model	TR3000
Idle power (mW)	13.5
Receiving power (mW)	13.5
Transmission power (mW)	24.75
Sleep Power (μW)	15
Node Placement	
Number of nodes	50, 60, 70, 80, 90 and 100
Number of sink	1
Placement of the Sink	One of the corner of the simulation area
Node placement	Quasi Random Deployment using Halton-, Sobol-, Faure- Sequence.
Number of simulation runs	10
Miscellaneous Parameters	
Area(m)	500 * 500
Simulation time (s)	2000
Packet size (bytes)	64
Hello Interval (s)	5
CH Election Interval (s)	20
Packet Interval (s)	0.2

4.5. SIMULATION AND RESULT ANALYSIS

Simulation bounds are given in Table 4-1. The performance of MOHRA with arbitrary placement of sensor nodes is compared with various QRD. The quasi-sequences are generated with Halton-, Sobol-, and Faure- low discrepancy sequences from mathematics.

4.5.1. RESULTS WITH RANDOM AND QUASI-RANDOM DEPLOYMENT

AEC

The AEC with different placement strategies is as shown in Figure 4-6. When the nodes are placed arbitrarily in the sensing region, the AEC of MOHRA has increased by 13.21% as compared with the placement of nodes by means of SS. When the nodes are placed by means of FS the amount of AEC reduces by 6.89 %. The AEC of MOHRA is reduced by 2.63 % when the nodes are positioned by means of HS sequence. In nutshell, the AEC in case of QRD is reduced whenever related with arbitrary positioning. The reason for this is due to the fact that QRS fill the target area more uniformly compared with random deployment. This also depicts that with QRD the sensor nodes track the sensing field well and the coverage is good. The AEC in case when the nodes are positioned with SS is less compared with deployment using Faure-quasi-random and Halton quasi-random sequences.

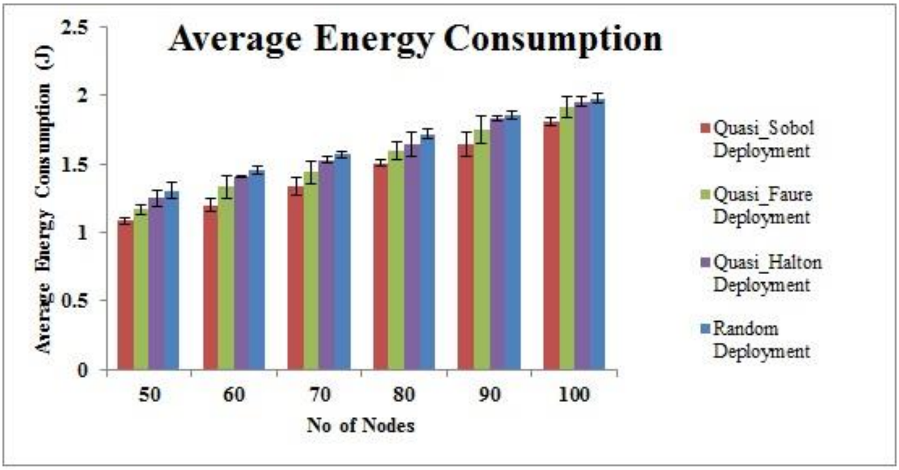


Figure 4- 6 Comparison of AEC.

PDR

Figure 4- 7 illustrates PDR of MOHRA for arbitrary and QRD. When nodes are placed by means of SS the amount of PDR increases by 6.55 % equated with arbitrary positioning of nodes. PDR of MOHRA is increased by 5.3 % when the nodes are organized using FS. PDR is improved by a factor of 3.07 % when HS is used for node placement compared with arbitrary placement. By reason of the MOO approach and proper distribution of node, the PDR in case of QRD is higher when compared with random deployment. The results also illustrate that with QRD the sensor nodes connectivity is good and the nodes track the sensing field well so that sensed data can reach to sink node. The PDR in case when the nodes are organized with SS sequence is higher equated with positioning using FS and HS.

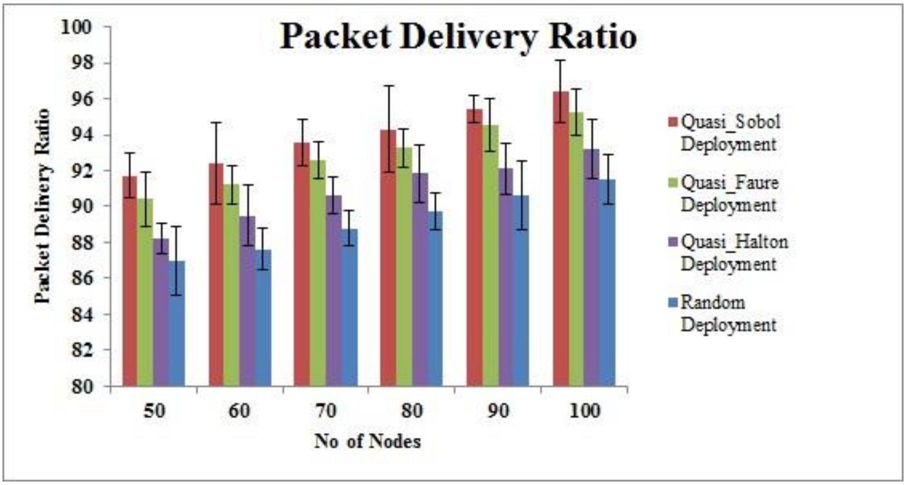


Figure 4- 7 Comparison of PDR.

Jitter

Jitter with totally different placement methods is as shown in Figure 4-8. Once the nodes are placed arbitrarily within the objective region, the jitter of MOHRA has reduced by 31.18% as compared with the placement of sensor nodes by means of Sobol-quasi-random sequence. When the sensor nodes are placed using Faure-quasi-random sequence the amount of jitter reduces by 35.74 %. The jitter of MOHRA is reduced by 19% when the nodes are organized using Halton quasi-random sequence. Jitter in QRD is smaller compared with arbitrary placement of sensor nodes. The reason is multi-hop communication is used for relaying the data from sensing area up to the sink. Another reason is due to well distribution of sensor nodes compared with random deployment, good connectivity among the sensor nodes. This also portrays that one can use QRD for real time applications compared with arbitrary deployment. Jitter in case when the nodes are arranged with Faure-quasi-random sequence is less compared with deployment using Sobol-quasi-random and Halton quasi-random sequences.

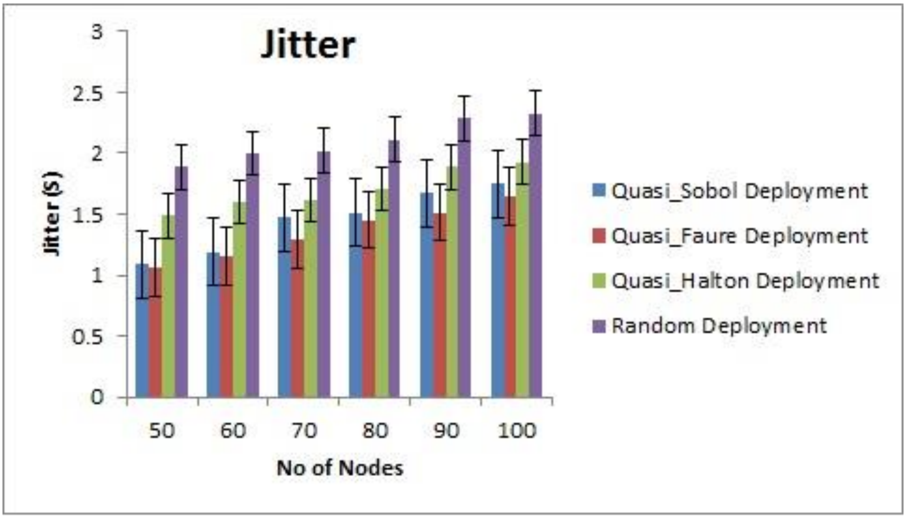


Figure 4- 8 Comparison of Jitter.

4.6. SUMMARY OF THE CHAPTER

This chapter reasonably discusses the crucial pros and cons of current tactics for node deployment. The contribution of this chapter is an innovative placement strategy known as QRD. The functioning of MOHRA is verified with different QRD strategies. MOHRA functions well in terms of PDR, Jitter, and AEC equated with its counterparts. The suggested QRD approaches utilizing FS, SS, and HS decrease the AEC within the NW, in doing so it increases the network lifetime. With QRD, the increased PDR means reliable transmission and it enhances the throughput.

4.7. REFERENCES

[1] V. Bhateja, A. Krishn, H. Patel, and A. Sahu, “Medical Image Fusion in Wavelet and Ridgelet Domains: A Comparative Evaluation”, International Journal of Rough Sets and Data Analysis (IJRSDA), Vol 2(2), PP. 78-91, 2015.

[2] M. Cinque, A. Coronato, and A. Testa, “Dependable Services for Mobile Health Monitoring Systems”, International Journal of Ambient Computing and Intelligence (IJACI), Vol. 4(1), PP. 1-15, 2012.

[3] S. Kumar, and N. Nagarajan, “Integrated Network Topological Control and Key Management for Securing Wireless Sensor Networks”, International

Journal of Ambient Computing and Intelligence (IJACI), Vol. 5(4), PP. 12-24, 2013.

[4] P. K. Nizar Banu, and S. Andrews, "Performance Analysis of Hard and Soft Clustering Approaches For Gene Expression Data", International Journal of Rough Sets and Data Analysis (IJRSDA), Vol. 2(1), PP. 58-69, 2015.

[5] N. Pantazis, S. Nikolidakis, and D. Vergados, "Energy-Efficient Routing Protocols in Wireless Sensor Networks: A Survey", Journal of IEEE Communications Surveys and Tutorials, Vol. 15(2), PP. 551-591, 2013.

[6] S. Yessad, L. Bouallouche-Medjkoune, and D. Aïssani, "A Cross-Layer Routing Protocol for Balancing Energy Consumption in Wireless Sensor Networks", Springer Journal of Wireless Personal Communications, Vol. 81(3), PP. 1303-1320, 2014.

[7] G. Sara, and D. Sridharan, "Routing in mobile wireless sensor network: A survey", Springer Journal of Telecommunication Systems, Vol. 1(57), PP. 51-79, 2014.

[8] N. Kulkarni, R. Prasad, H. Cornean, and N. Gupta, "Performance Evaluation of AODV, DSDV & DSR for Quasi Random Deployment of Sensor Nodes in Wireless Sensor Networks", IEEE International Conference on Devices and Communications (ICDeCom-11), PP. 1-5, 2011.

[9] X. Xing, D. Xie, Z. Sun, "An approximate optimal coverage set algorithm in wireless sensor networks", IEEE Seventh International Conference on Advanced Computational Intelligence (ICACI), PP. 300 – 305, 2015.

[10] G. Horvat, D. Zagar, and D. Vinko, "Influence of node deployment parameters on QoS in large-scale WSN", IEEE, 3rd Mediterranean Conference on Embedded Computing (MECO), PP. 202-205, 2014.

[11] L. M. Oliveira, and J. J. Rodrigues, "Wireless sensor networks: a survey on environmental monitoring", Journal Communication, Vol. 6(2), PP. 143–151, 2011.

[12] M. P. Durisic, Z. Tafa, G. Dimic, V. Milutinovic, "A survey of military applications of wireless sensor networks". In IEEE Mediterranean conference on embedded computing (MECO),PP. 196–199, 2012.

[13] G. Liu, R. Tan, C. M. Zhou, S. González, H. Cao, Y. Zhang, and ST.Vuong "Enabling low bit-rate and reliable video surveillance over practical wireless sensor network", Journal Supercomputing, Vol.65(1), PP. 287–300, 2013.

[14] Z. Honghai, and C. H. Jennifer, “Maintaining sensing coverage and connectivity in large sensor networks”, Handbook on Theoretical and Algorithmic Aspects of Sensor, AdHocWireless and Peer-to-Peer Networks, AuerbachPublications, 2005.

[15] A. Ghosh, S. K. Das, “Coverage and connectivity issues in wireless sensor networks”, in: R. Shorey (Ed.), Mobile, Wireless, and Sensor Networks: Technology, Applications, and Future Directions, John Wiley & Sons, PP.221–256, 2006.

[16] W. Y. Poe and J. B. Schmitt, "Node Deployment in Large Wireless Sensor Networks: Coverage, Energy Consumption, and Worst-case Delay", Proc. ACM, AINTEC, PP. 1-8, 2009.

[17] M. Abo-Zahhad, N. Sabor, S. Sasaki, and S. M. Ahmed , “A centralized immune-Voronoi deployment algorithm for coverage maximization and energy conservation in mobile WSNs”, Elsevier, Journal of Information Fusion, Vol. 30, PP. 36–51, 2016.

[18] P. Rawat, K. D. Singh, H. Chaouchi and J. M. Bonnin, "Wireless sensor networks: A survey on recent developments and potential synergies", J. Supercomput., 68(1), PP. 1-48, 2014.

[19] V. Kapnadak, E. J. Coyle, “Optimal Nonuniform Deployment of Sensors for Distributed Detection in Wireless Sensor Networks”. ACM Transaction Sensor Network, Vol. 10, PP. 1-27, 2014.

[20] C. Sevgia, A. Koçyiğitb, “Optimal deployment in randomly deployed heterogeneous WSNs: A connected coverage approach”, Journal of Network and Computer Applications, Vol.46, PP.182-197,2014.

[21] S. Sengupta, S. Das, M. D. Nasir, and B. K. Panigrahi," Multi-objective Node Deployment in WSNs: In Search of an Optimal Trade-off Among Coverage, Lifetime, Energy Consumption and Connectivity”, Engineering Applications of Artificial Intelligence, Vol. 26, PP. 405-416, 2012.

[22] R. Ramalakshmi, and S. Radhakrishnan, “Coverage and Connectivity Guaranteed Deterministic Deployment Pattern for WSN”, Computer Networks & Communications (NetCom), Vol. 13, PP. 341-347, 2013.

[23] S. Halder, A. Ghosal, A. Chaudhuri and S. DasBit, "A Probability Density Function for Energy-Balanced Lifetime-Enhancing Node Deployment in WSN", Proc. of 11th Int'l Conf. on Computational Science and its Application, LNCS, Vol. 6018, PP. 472-487, 2011.

[24] S. Halder, A. Ghosal and S. DasBit, "A Pre-determined Node Deployment Strategy to Prolong Network Lifetime in Wireless Sensor Network, " Computer Communications, 34(11), PP. 1294-1306, 2011.

[25] M. Marks, "A survey of Multi-Objective Deployment in Wireless Sensor Network", Journal of Telecommunication and Information Technology, Vol. (3), PP. 36-41, 2010.

[26] C. Lemieux, “Quasi- Monte Carlo Constructions”, in Book Monte Carlo and Quasi-Monte Carlo Sampling, Springer series in Statistics, PP. 139-197, 2009

[27] J. E. Gentle, “Random Number Generation and Monte Carlo Methods”, Springer-Verlag, New York, Inc., PP. 161, 1998.

[28] Nandkumar Kulkarni, Neeli Rashmi Prasad, and Ramjee Prasad, “A Novel Sensor Node Deployment using Low Discrepancy Sequences for WSN”, An International Journal of Wireless Personal Communications, Springer Journal, ISSN 0929-6212, pp. 1-14, DOI 10.1007/s11277-017-5063-9, 2017.

CHAPTER 5. BUSINESS MODEL PERSPECTIVE OF MOHRA: USE CASE OF CONVERGENCE OF VANET AND CLOUD

With the recent advances within the arena of ICT and computing, the researchers have envisioned that Vehicular Ad-hoc Network (VANET) could be the basis of many new use-cases in the field of Internet of Things (IoT). The express growth of vehicular traffic and bottleneck on the highways began hindering the safe and efficient movement of traffic. The soaring rate of vehicle mishaps and casualties in most of the countries has made the researchers to exploit the new technologies, e.g. Wireless Sensor Networks (WSNs), to reduce these upsetting and disgraceful statistics. VANET is a highly mobile, self-organizing, Ad Hoc sensor network comprising of countless sensor nodes. This chapter sets the platform and describes the use case of WSN in IoT. A novel idea for the convergence of VANET and Cloud is presented in this chapter, which has broad scope in IoT applications. This chapter also covers taxonomy of Vehicular Cloud Computing (VCC) to give scope to VANET and Cloud researcher.

5.1. OVERVIEW

5.1.1. INTRODUCTION TO VANET

Alerting the drivers about the road situations and improving road safety is a subject of deep interest and research. Today, more and more people are affording to buy cars as the car manufacturers are manufacturing more and more sophisticated cars at a reduced prize. Although human error is the predominant cause of collisions, creators of technologies used in vehicles have an obvious vested interest in helping to lower the distressing statistics. In USA, Walker deaths ascended by 3.1 percent in 2014 as indicated by the Nationwide Road traffic Security Management. In the same year, 726 cyclists and 4,884 walkers lost their lives in motor accident. Also, this harm to pure spectators does exclude the developing demise rate of drivers and their travelers themselves [1].

USA information demonstrate that diverted driving represented 10 percent of all bang victims, massacring 3,179 individuals in 2014 while sleepy driving represented 2.6 percent of all crash fatalities, executing 846 individuals in 2014. As indicated by the European Commission Transport Statistics [2] in 2014, additional 25,000 individuals strike out on the streets, i.e. comparable to medium town. On roads in Europe, for each death there are an expected four permanent paralyzed cases. For example, harm to the cerebrum or spine, eight genuine wounds and 50 negligible injuries. The road carnage is hardly limited to the United States or Europe. The International Organization for Road Accident Prevention [3] noted a few years ago that 1.3 million street expirations happen every year, and more than 50 million individuals are extremely harmed. There are 3,500 demises a day or 150 per hour, and almost three individuals get killed out in a minute.

Accidents have been accepted as serious problems, and a significant challenge to the modern society [4, 5]. Current evolvement in Information and Communication Technology (ICT), networks those are suitable for safety applications that communicate through wireless networks are envisioned. The prime goal of such network is to avert roadside accidents and passenger safety. For the last few years, one such network that has received more attention by most of the researchers in the field of ICT is VANET [6]. VANET is another innovation that incorporates wireless networks into moving vehicles using a Dedicated Short Range Communication (DSRC). DSRC fundamentally depends on the IEEE 802.11a standard and revised by 802.11p [7]. Comparison of latest standards for DSRC is available in Table 5- 1

Table 5- 1 DSRC Standards in JAPAN, Europe, and the US [8]

Features	Japan (ARIB)	Europe (CEN)	USA (ASTM)
Communication	For On Board Unit - Half Duplex and For Road Side Unit - Full Duplex	Half -Duplex	Half -Duplex
Radio Frequency	5.8 GHz	5.8 GHz	5.9 GHz
Bandwidth	80 MHz	20 MHz	75 MHz
Channels	Down-link and Up-link: 7	4	7
Channel Separation	5 MHz	5 MHz	10 MHz
Data Transmission Rate	Down / Up-link 1 or 4 MBits/s	Down / Up-link 500Kbits/s and 250 KBits/s	Down / Up-link 3-27 MBits/s
Coverage	30 m	15-20 m	1000 m
Modulation	Amplitude Shift Keying, Phase Shift Keying	For Road Side Unit - Amplitude Shift Keying, For On Board Unit Phase Shift Keying	OFDM

- ARIB: Association of Radio Industries and Businesses
- CEN: European Committee for Standardization
- ASTM: American Society for Testing and Materials
- OFDM: Orthogonal Frequency Division Multiplexing

With VANET, vehicles on the road can communicate with other vehicles directly forming Vehicle-to-Vehicle correspondence (V2V). The vehicles can speak with immovable equipment next to the road, stated to as Road Side Unit (RSU) creating

Vehicle-to-Infrastructure communication (V2I) [9]. Once deployed, the advantages of Vehicle-to-Everything (V2X) are extensive, alerting drivers to road hazards, the approach of emergency vehicles, pedestrians or cyclists, changing lights, traffic jams and more. The technology can control car systems like brakes and power to help reduce possible adverse outcomes while this new area for car technology underscores a certain time when cars can talk to each other and road sensors.

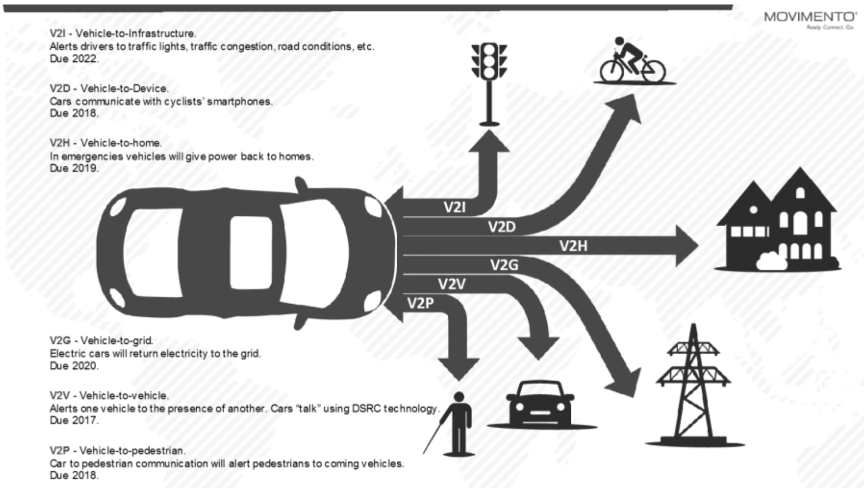


Figure 5- 1 V2X terminology, use case, and deployment timeline

The only problem with V2X is that it's emerging as a perplexing stew of acronyms such as V2V, V2I, V2D, V2H, V2G and V2P that require some explanation and the technology, while important, is not yet available. But the significance of this technology is undeniable so getting proficient in understanding V2X is valuable in tracking future vehicle features that will link cars to the world around them and make driving safer in the process (Ref. Figure 5-1).

V2X, a new way of communication between the user, cars, and infrastructure, permits to envision numerous applications focusing on VANET. Table 5-2 lists recent or on-going industrial and university vehicular projects across the globe. The classification of VANET applications will help the researchers and academia in this domain. Summary of Recent or On-Going Industrial and University Vehicular

Table 5- 2 Projects across the globe [10]

PROJECT NAMES	**PURPOSE**	**ZONE**	**PARTICIPANT**	**LINK**
COMeSafety	To support realization and deployment of cooperative communication-based active safety systems	EU	BMW, Daimler, Fiat, Renault & Volvo	www.comesafety2.org
COSMO	To demonstrate range of V2V &V2I services in realistic conditions	EU	Volvo, Fiat	www.cosmo-project.eu
Drive C2X	Equipped with radio hardware based on 802.11p & UMTS for data exchange with other vehicles or roadside infrastructure	EU	Daimler, Audi, BMW, Fiat, Ford, Honda, Opel, PSA, Renault & Volvo, Bosh, Continental, Delphi, Denso, Hitachi, NEC & Renesas, Traffic engineers: PTV (Planung Transport Verkehr) ERTICO ITS, EICT	www.drive-c2x.eu/overview
EuroFot	To assist driver in detecting hazards & avoiding accidents	EU	Ford, MAN, Volvo Cars, Volvo Trucks, VW & Audi, Renault, Fiat, [BMW, Daimler, Bosh, Continental, Delphi & Harman Alcor, ERTICO, ADAS, EICT	www.eurofot-ip.eu
FOT-Net	To assess efficiency, quality, robustness and acceptance of ICT solutions	EU	Daimler AG, Ford, Nissan, Orange, Continental, Vufo GmbH, VTT (coordinator), ERTICO-ITS Europe, Chalmers University of Technology, IKA, CTAG, University of Leeds,	www.fot-net.eu
Intersafe-2	To develop & demonstrate a cooperative Intersection Safety System (CISS) that can reduce injury and fatal accidents at intersections.	EU	BMW, VW	www.intersafe-2.com
OVERSEE	To ensure security, reliability, secure communications & strong mutual isolation of simultaneously running applications	EU	VW, Industrial Partners (encrypt GmbH Embedded Security TRIALOG OpenTechEDV Research GmbH) Academic Partners (Technische Universität Berlin Fraunhofer Universidad Politécnica de Valencia	www.oversee-project.com
Pre-Drive C2X		EU	Volvo, Daimler	
TeleFOT	most important project CVIS managed by European ITS organization ERTICO	EU	BMW, Daimler, Renault, Volvo, Fiat, Magneti, Bosh, Navteq, Tele Atlas, Telecom Italy, Vodafone	www.telefot.eu
Safety Pilot Test		USA	GM, Ford, Toyota, Honda, VW, Daimler, Hyundai, Nissan, In-Vehicle: AutoTalks, Cohda, Denso, Delphi, Visteon, DGE, ITRI, Savari, Arada, Roadside:	

			Arada, Kapsch, ITRI, Cohda/Cisco Aftermarket Safety Devices: Kapsch	
CVIS	To focus on developing key elements needed to test and prove the viability of V2V &V2I systems	EU	Fiat, Daimler, Renault, Volvo, Bosch, Siemens, Vodafone, Autoroutes du Sud de la France, BAE Systems, CIT, Department of Transport, Efkon, ERTICO, FEHRL, INRIA, Intempora, Navteq	http://www.cvisproject.org/
iTETRIS	To develop an evaluation platform for large-scale, long-term simulations of cooperative traffic management applications.	EU	Hitachi,Thales, CBT, Innovalia, PEEK, Eurecom	www.ict-itetris.eu; http://www.eurecom.fr/en/publication/2785/download/rs-publi-2785.pdf
EVITA	To protect onboard components against tampering and sensitive data against compromise.	EU	BMW, Bosh, Continental, Siemens, Fraunhofer SITISI, escrypt, EURECOM, Infineon, MIRA, Trialog, Fujitsu	www.evita-project.org
SAFESPOT	"Smart Vehicles on Smart Roads".	EU	Fiat, Daimler, Renault, Volvo, Bosh, Siemens, Magneti, Continental, ANAS, Cofiroute, Mizar, Piaggio, IBEO, Kapsch, Lacroix, Navteq, PTV, G-Free, Télé Atlas, PEEK, ERTICO, CNRS,	http://www.safespot-eu.org/
SEVECOM	To give a full definition and usage of security prerequisites for vehicular communications.	EU	Fiat, Daimler, TRIALOG Budapest University of Technology and Economics EPFL - Ecole Polytechnique Fédérale de Lausanne Katholieke Universiteit Leuven Ulm University, Bosch	www.sevecom.org
AKTIV	To prevent accidents using intelligent traffic management systems and mobile communications technologies for connected vehicles	DEU	Opel, AUDI, BMW, Daimler AG, MAN, Volkswagen, Ford, Continental, Bosch, Siemens, Ericsson, Ibéo, Allianz, TeleAtlas, TRANSVER, Vodafone	http://www.aktiv-online.org/english/projects.html
SCORE	To quantify benefits of the system, identify stakeholders, validate or evolve standards and applications, develop qualification tests to ensure interoperability, and calculate deployment costs	FRA	Renault, PSA, Cofiroute, Néavia, Senda, Viveris, Orange, Intempora, EURECOM	http://www.pole-moveo.org/pdf-projets-das/Scoref-A.pdf
SARTRE	To develop and test vehicles that can autonomously drive in long convoys or road trains	UE	led by Volvo, Tecnalia, Indiana, IKA, SP Technical Research Institute of Sweden	http://www.sartre-project.eu/en/Sidor/default.aspx

5.1.2. CHARACTERISTICS OF VANET

VANETs have numerous properties that distinguish it from other Ad Hoc wireless network. Vehicles (Nodes) in VANETs are highly mobile. Due to high mobility, the probability of partitioning the network is very high [7, 11]. End-to- End connectivity is not guaranteed. VANETs have dynamic topology, but the movement of the vehicles is predictable, and they are not completely random. The vehicles are restricted to the roads on which they are traveling. This restriction has the advantage of selecting the finest path beginning with point origin to target. This predictable behavior of the vehicles also has an advantage during the link selection. In VANETs, the bandwidth issue also intensified due to crossings, traffic bottlenecks, and the existence of buildings beside the roads, particularly in an urban environment [12].

5.2. CLOUD COMPUTING

With the quick improvement in handling, and stockpiling mechanism and the accomplishment of the Internet, Cloud Computing (CC) has turned into a focal range of research in the worldwide business. The National Institute of Standards and Technology (NIST), characterizes cloud-computing as:

"CC is a model for empowering helpful, on-request NW admittance to a common group of designable computing assets (e.g., systems, master-device, stockpiling, usages, and administrations) which are quickly charged and discharged using negligible administration exertion or specialist co-op communication"[13].

Today, computing resources have become inexpensive. The resources are more powerful and universally available for computing than ever before. This technological inclination has allowed infrastructure providers to let out assets (e.g., CPU and repository) to service providers. The service providers rent and relinquish the resources on-demand basis through the Internet to serve the end users. The infrastructure suppliers oversee cloud platforms and rent assets as per a utilization based valuing model.

The advances in CC have had a remarkable effect on the ICT commerce throughout the most recent decade. Many organizations produce a significant amount of sensitive data. Storage of that data on local server or machine results into the maximization of storage cost and maintenance cost. Most of the business organizations have changed their business models, and they have opted to store such vast data on a cloud to earn profit from this new paradigm. Organizations, for example, Google, Amazon and Microsoft have begun giving heartier, dependable and cost-productive cloud stages. CC offers several impressive features which have attracted the business listed below.

5.2.1. ADVANTAGES OF CLOUD COMPUTING

Highly scalable

A specialist can quickly grow its support to an enormous extent as the infrastructure suppliers by making unlimited assets easily available from data-centers.

Easy access

Any computing devices like mobile, laptop, desktop, etc., which have internet capability, can easily avail services facilitated in the cloud.

No investment

CC utilizes a compensation-as-you-go cost model. A specialist organization does not have to put resources into the framework. The service provider just leases assets from the infrastructure providers as indicated by its needs [14, 15].

Reduction in the operating cost

The service provider can acquire and relinquish resources on a demand basis and need not provision resources in advance for the peak load. This strategy will reduce the operating cost significantly when the service request from the end user is little.

Reducing business threats and maintenance expenditures

A specialist swings its business risk, (for example, equipment breakdown) to infrastructure suppliers by subcontracting the cloud services. Additionally, a specialist can chop down support and the staff preparing costs.

5.2.2. CLOUD COMPUTING ARCHITECTURE

The design of layered architecture in the cloud is like the plan of layers in the OSI model. The Cloud model defines four Layers that describe how applications running on network-aware user devices may communicate with the cloud. As appeared in Figure 5-2, hardware (H/W)-, infrastructure-, platform layer-, and application are the four layers.

Layer 1 is the H/W layer that is accountable for handling the assets. These incorporate H/W such as servers, routers, and S/W, power, and A/C systems. The H/W is part of data-centers. A data-center is an accumulation of numerous servers. These servers are usually mounted in shelves. Servers are interlocked through S/W, router or different fabrics. Common issues at H/W layer incorporate configuration of the physical hardware, fault tolerance, traffic administration, energy conservation, resource organization.

Layer 2 is the Infrastructure Layer (IL) or Virtualization Layer (VL). The infrastructure layer partitions the physical resource using virtualization techniques and it produces a group of stockpile-, and computing- assets. The dynamic resource allocation is the primary task of the infrastructure layer.

Layer 3 is Platform Layer (PL) that is put up on top of the IL. The PL involves OS and application framework. The role of the PL is to diminish the load of setting up applications right into virtual machine (VM) compartments.

Layer 4 is Application Layer (AL). AL is the topmost layer in the hierarchy, and it comprises of actual cloud applications. Cloud applications have a programmed scaling highlight to accomplish better execution, accessibility and lower working expense when contrasted with conventional applications.

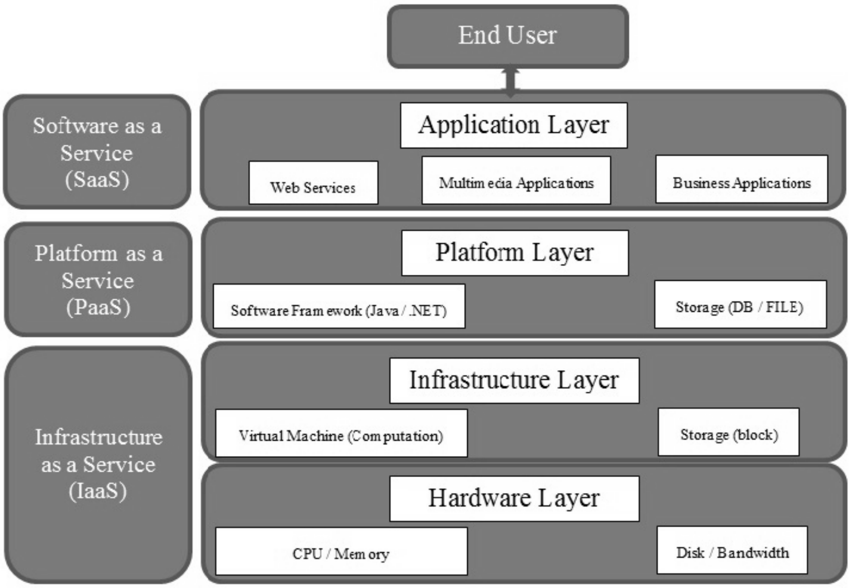


Figure 5- 2 Cloud computing architecture

5.3. VEHICULAR CLOUD COMPUTING

The CC model has enabled the utilization of surplus computing power. Recently Olariu [9] presented the idea of Vehicular Cloud (VC) in front of the world. The definition of VC is as follows

“Computing-, Sensing-, Communication-, and physical asset of a independent vehicles can be harmonized and whose access can be distributed among the certified users.”

The idea in VC is the gigantic number of vehicles on highways, street ways and parking lots can provide public services. Each vehicle on the road or in the parking lot will be treated as useful, under- utilized computational resources and each vehicle is acting as a node in the cloud. The vehicle owners of parked vehicles in the parking lot and the owners of the cars stuck in the traffic jam can contribute to the computing power of parking garage or city traffic data centers. In these cases, the vehicles can help the local authorities in improving parking conditions or traffic conditions on the roads by sending correct messages in a timely fashion (see Figure 5-4). The new VC can help in resolving serious and unexpected problems by utilizing the computing power of self-organized autonomous nodes (vehicles) dynamically [16].

Figure 5- 3 Convergence of vehicle and cloud computing

IEEE has amended the basic Wi-Fi IEEE 802.11 norms to include WAVE to bolster the requirement of ITS usage. The new standard is called 802.11p. A spectrum band of 75 MHz is allocated in the range of 5850 MHz to 5925 MHz. This allocated spectrum can be utilized for priority road safety applications, V2V-, and V2I Communication [16, 17, 18]. This new technique of communication amongst cars and infrastructure allowed envisioning a lot of diverse applications centering vehicle and the user. Recent or ongoing innovative projects and applications on VCC are listed in Table 5-3.

Table 5- 3 Taxonomy of vehicular cloud computing [10]

	Vehicle to ReaL (V2RL)	**Vehicle to Vehicle (V2V)**	**Vehicle to Infrastructure (V2I)**	**Vehicle to User (V2U)**
Basic Blocks	Emergency Vehicle Detection Basic Crash Warning Sign Detection Road Condition Warning Emergency Breaking Safely Distance Detection Lane Change Warning Overtaking Vehicle Warning	Propagation of Warning Detection Propagation of Lane Change Propagation of traffic light status Warning Blind Spots Propagation of Speed Limit Propagation of Distance Co-Ordination Information of Turn and Direction	Pedestrian Detection Propagation Information Wireless Dangerous Zone Detection Detection Traffic Light Communication with Pedestrian Detection Bicycle	Personalized Navigation Call via Smartphone Share Events Connect with Home Connection with social content Tourism
Projects / Applications	Honda: Traffic Congestion Minimizer Pioneer: ’Cyber Navi’ or ‘AVIC-ZH99HUD.' BMW: Head-Up Display Intel: Augmented Reality and In-vehicle Infotainment System PSA PeugeotCitroën: ’Peugeot connect Apps.'	Intelligent Truck Parking Application Vision of Internet of Cars An independent traffic cautioning system with Car-to-X communication Volvo Car: SARTRE Audi: ’Travolution project.' Swarco Volkswagen: ’C3World, connected car in	Nokia: Connected Car Fund W3C launched work on Web Automotive Toyota: ’Toyota Friend.' Alcatel-Lucent and Toyota: LTE connected car Mercedes: ’Fleet tweet.' Ford: ’Facebook and Ford SYNC Hackathon.' Microsoft and West Cost	

	BMW: ’XL Journey Mate Mini’Land Rover:’Concept Discovery Vision’SystemX: Localization in Augmented RealityGoogle: Driverless Car Volvo: Magnet project Ford: ’Blueprint for Mobility.'	a connected world.' Denso Corporation: FieldOperational Test SmartWay US Department of Transportation: Connected Vehicle Safety Pilot Program Compass4D SCORE@F in France	Custom: 'Project Detroit.' Mercedes: Mbrace2 Bosch and University of St.Gallen: IoTS Lab Toyota: ’Windows to the world.' General Motor: Windows of opportunity.' Audi: Future Urban Personal MobilityBMW: Connected Drive Concept Car Mercedes: ’DICE’ (Dynamic IntuitiveControl Experience) Valeo Project	

5.4. CONVERGENCE OF VANET AND CLOUD

The idea in VANET is the gigantic number of vehicles on highways, street ways and parking lots can provide public services. With VANET, vehicles on the road can have dialogue with other vehicles directly forming V2V dialogue. The vehicles can have dialogue with RSUs also, creating V2I architecture [19, 20]. Vehicular-, VANETs utilizing -, and Hybrid- clouds can be three key designs of VANET cloud. In Vehicular Cloud (VC) the infrastructure (correspondence, stockpiling, and process) can be rented to make the income. IaaS-, Storage-, Services- are practical for such arrangement. In VANETs using Clouds, users can utilize cloud benefits during transport by linking to the customary clouds. In Hybrid Cloud, the VC can intermingle with the conventional cloud for facility altercation. In this section, to leverage cloud computing functionalities a new architecture is proposed for convergence of VANET and cloud. This model prolongs the conventional cloud infrastructure which consists of servers, workstations, etc., to the edge of vehicles [21].

5.4.1. DATA COMPRESSION

VANET could be the foundation of numerous new applications in the field of IoT. In future, VANETs are expected to carry the gigantic information. To access information on any occasion, by anyone at any place, Cloud Computing (CC) is the solution. The cloud specialist co-ops cloud assets and rent them as per a use estimating cost model [22, 23]. In STorage as a Service (STaaS), to benefit the end user regarding price storage, the overhead should be as minimum as possible. Data compression techniques can be used to reduce the storage cost on the cloud. This reduction improves transmission efficiency with saving in the channel bandwidth requirement. Data compression becomes particularly important in the transmission of multimedia such as text, audio, and video. There are numerous data compression algorithms available for lossy and lossless compression. If the data is compressed with lossy data compression techniques, then the entire data cannot be recovered, so it is beneficial to use a lossless technique to recover the original data. This section discusses some latest compression methods. These methods are most interesting since they are efficient and can compete with the modern compression methods developed over the past numerous years. Different lossless data compression algorithms discussed is Brotli, Deflate, Zopfli, LZMA/ LZMA2, BZip2. Comparative analyses of these techniques which will help the researchers in this field are summarized below.

The Brotli algorithm [24] is an amalgamation of the modified LZ77 algorithm, Huffman coding, and 2nd order context modeling. It is a general-purpose lossless compression algorithm that compresses data using a very high compression ratio. It is equivalent to the best presently available general-purpose compression techniques. The performance of the Brotli compression algorithm is comparable with deflate on speed but, Brotli has a higher compression ratio (nearly 10-15% more than Deflate). Brotli is free under the Apache License, Version 2.0. Brotli is faster in compression than Zopfli, and it provides 20–26 % higher compression ratio. Brotli has a whole new data format. Brotli is as fast as the Deflate implementation but, it compresses slightly more than LZMA and bzip2. The higher compression ratio is achieved due to 2nd order modeling, re-cycling of entropy codes, the larger window size for the past data and joint distribution codes.The high compression ratio of Brotli allows smaller storage overhead and faster page loads. The smaller output size will help vehicles and cell phone users in reducing battery usage and data transfer costs. The disadvantage of Brotli is that it is not supported by existing systems (e.g. many browsers).

Deflate [25] is a blend of the Huffman coding and LZ77 algorithm [14]. It is an example of a lossless compression algorithm. The Huffman trees for every block are not dependent on previous or subsequent blocks. The LZ77 algorithm may use a reference to a duplicated string occurring in a previous block. The efficiency of Deflate is comparable with the best general-purpose compression techniques available in the market. Deflate compression algorithm works well even for a randomly long input sequence at the cost of intermediate storage. The advantage of Deflate algorithm is that it is autonomous concerning CPU type, OS, file system, and character set. It is freely available and can be implemented readily.

Lempel–Ziv–Markov (LZMA) [26] chain algorithm is a dictionary based lossless data compression algorithm. It uses a complex dictionary data structures, and a dynamic programming algorithm for encoding one bit at a time.7-Zip is an open-source utility to compress files. 7-Zip uses its own 7z archive format with a .7z file extension. LZMA is a comparatively new algorithm, making its debut as part of the 7z format to compress files. LZMA maintains decompression speed similar to other commonly used compression algorithms. LZMA uses a dictionary compression scheme similar to LZ77. The compressed output is then encoded with a range encoder, using a complex probability prediction model of each bit. Proceeding to LZMA, most encoder models were purely byte-based. The novel idea in LZMA is its generic bit-based model. LZMA gives a better compression ratio because it avoids mixing unrelated bits together in the same context. LZMA has higher compression ratio than bzip2. It has a variable compression dictionary size. LZMA2 is like a container that holds both the uncompressed and LZMA-compressed data. It also provisions multi-threaded compression and decompression. It can compress data that is not compressible with other compression algorithms.

Zopfli [27] compression algorithm is significantly slower regarding compression speed, but it is a most size efficient deflate variant. Zopfli compression algorithm's data format is compatible with data formats of Deflate, gzip and zlib. Zopfli can produce raw Deflate data stream or compressed data in gzip or zlib formats. Google released the zopfli algorithm under the Apache License, Version 2.0. Zopfli Compression Algorithm and was created by Lode Vandevenne and Jyrki Alakuijala, based on an algorithm by Jyrki Alakuijala [28]. Due to its considerably slow speed during compression, it makes zopfli less suitable for on-the-fly compression. It is mainly suitable where static compression is required. Zopfli compression method is based on iterative entropy modeling and an express route procedure to find a low bit cost route through the entire graph. The Zopfli algorithm can be used to compress Portable Network Graphics (PNG) files as PNG uses a DEFLATE compression layer.

BZip2 [29] is open source, patent free high-quality data compression algorithm. BZip2 has a compression gain of typically 10% to 15% over the available techniques. BZip2 helps in recovering media errors. The commands to use Bzip2 are similar to GNU Gzip. It is portable and runs well on 32 bit as well as 64-bit machine with Unix or win32 machines. As compared to Brotli, Deflate and Zopfli BZip2 is very slow in compression and decompression.

The comparison of different compression techniques is illustrated in.

Table 5- 4 Comparison of compression techniques

Compression Technique	CPU Time / Compression & Decompression Time	Compression Ratio	Throughput	Buffer	Lossless / Lossy	Complexity	Window Size
Brotli	High	High	Moderate	High	Loss-less	High	22
Deflate	Moderate	High	High	Moderate	Loss-less	Low	15
Zopfli	More	High	Moderate	High	Loss-less	Moderate	15
LZMA / LZMA2	More	Moderate	Low	Moderate	Loss-less	Moderate	22
LZHMA	More	Moderate	Low	Moderate	Loss-less	Moderate	22
BZIP2	More	Low	Low	Low	Loss-less	Low	22

For the comparison of different compression techniques following metrics are used.

CPU Time

It is the total time for which a central processing unit (CPU) was used for Compression/ Decompression.

Data Compression Ratio

It is a ratio between the uncompressed file size and compressed file size:

Throughput

It is a measure of how many units of information a system can process in a given amount of time.

Buffer

The total amount of memory used for compression / decompression.

Window size

It is the maximum volume of data received in bytes as well as buffered

Lossless compression

It is a type of data compression algorithms using which the data can be perfectly restored from the compressed data.

5.4.2. ASSUMPTIONS AND SYSTEM MODEL

Figure 5-5 shows the proposed model of convergence of VANET and Cloud. Here, all vehicles that are part of Intelligent Transport System (ITS) are equipped with OnBoard Units (OBUs).

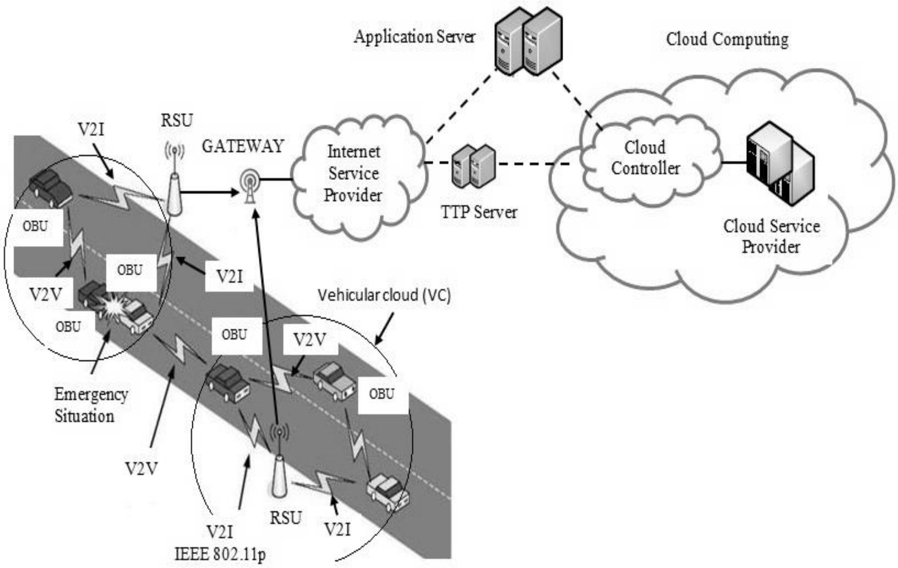


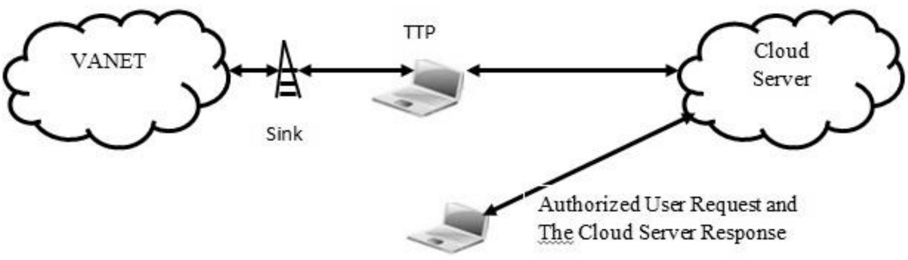
Figure 5- 4 Convergence of VANET and cloud

Using wireless communication OBUs are capable of communicating with OBUs of another vehicle termed as Vehicle-to-Vehicle Communication (V2V). OBUs can also communicate with RSUs called as Vehicle-to-Infrastructure communication (V2I) [30, 31, 32, 33]. The RSUs are remote static gateways fixed on transport network that backs data interchange with OBUs. RSUs acts like gateways for vehicles to the cloud services. High speed wired internet connection could be used for the data transfer from RSUs to the cloud. All the vehicles are internet enabled. The vehicles can form a static Vehicular Cloud (VC) for sharing their computing resources. Vehicles parked in the parking lot of a big organization or vehicles stuck in the traffic jam on the highway can form VC. On the other hand, the dynamic cloud can be built on demand. Vehicles using Clouds [34] can connect the vehicles to the traditional clouds. Vehicles with internet access can offer Network as a

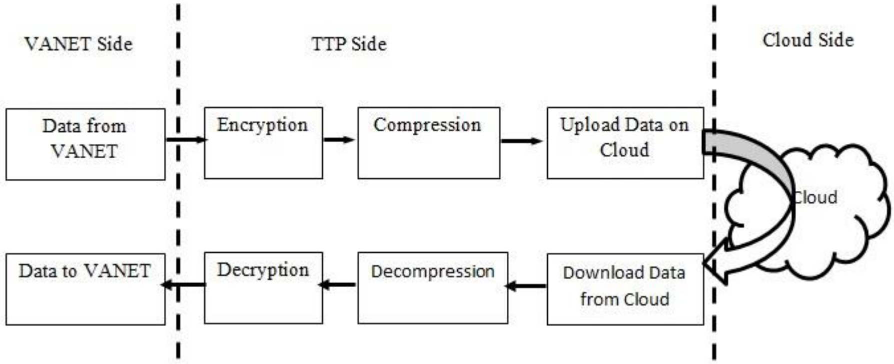
Service (NaaS) for other vehicles on the road if they need the net access. Some vehicles are equipped with higher onboard storage capacity. If one of the vehicles requires storage space for the execution of its applications then the vehicle having larger storage capacity can provide STaaS [35].

5.4.3. BLOCK SCHEMATIC OF COMMUNICATION BETWEEN VANET AND CLOUD

The block schematic of communication between VANET and cloud is illustrated in Figure 5-6. Figure 5-6 (a) gives information about the data storage model, and Figure 5-6 (b) depicts the overall communication process between VANET and cloud. The EC order, i.e. compression followed by encryption, is applied on VANET data. A Standard encryption algorithm secures the VANET data. A lossless compression algorithm compresses the resultant encrypted data. With such encryption and compression system, the data owner can outsource his data. Dynamic data will get stored on the cloud server in encrypted and compressed format. The file is first divided into a block and after that, each block will be encrypted and compressed. The data owner can do each block level operation. An certified user will get the newest version of data when they request for it. Trusted Third Party (TTP) is to create a faith amongst data owner & Cloud Service Provider (CSP). The detailed explanation about the block schematic is given below



(a) Data storage model



(b) System with encryption and compression

Figure 5- 5 communication between VANET and cloud

5.4.4. ENCRYPTION PHASE

At the encryption phase, the VANET information is encoded utilizing the Data Encryption Standard Algorithm. The encrypted data can be read only by authorized parties. It protects the confidentiality of messages, and the message content will be denied to the interceptor. Encryption is carried out by the Trusted Third Party (TTP) server. The encryption with compression system is implemented on the Amazon Elastic Compute Cloud (Amazon EC2). For a data owner, the TTP and cloud server instances of the server are created on Amazon EC2. Windows free tier instances are used for implementation. In an implementation large Amazon EC2 instance is used to run Cloud server. 64-bit windows 2008 server is used to create an instance on Amazon cloud. One similar type of instance is used for TTP. Data owner & authorized user can so login through any device.

5.4.5. COMPRESSION PHASE

This phase is used in VANET applications to minimize the storage overhead. For compressing VANET data, the Deflate algorithm is used. The compression ratio is more with the Deflate algorithm than with the Huffman encoding and LZ77 algorithm. It reduces the storage overhead on a cloud. Compression is carried out on the TTP server. Figure 5-7 shows the flowchart of encryption and Compression.

Description of the Deflate Algorithm State Transition:

1. The state transition illustration of the Deflate Procedure is revealed in Figure 5-8.

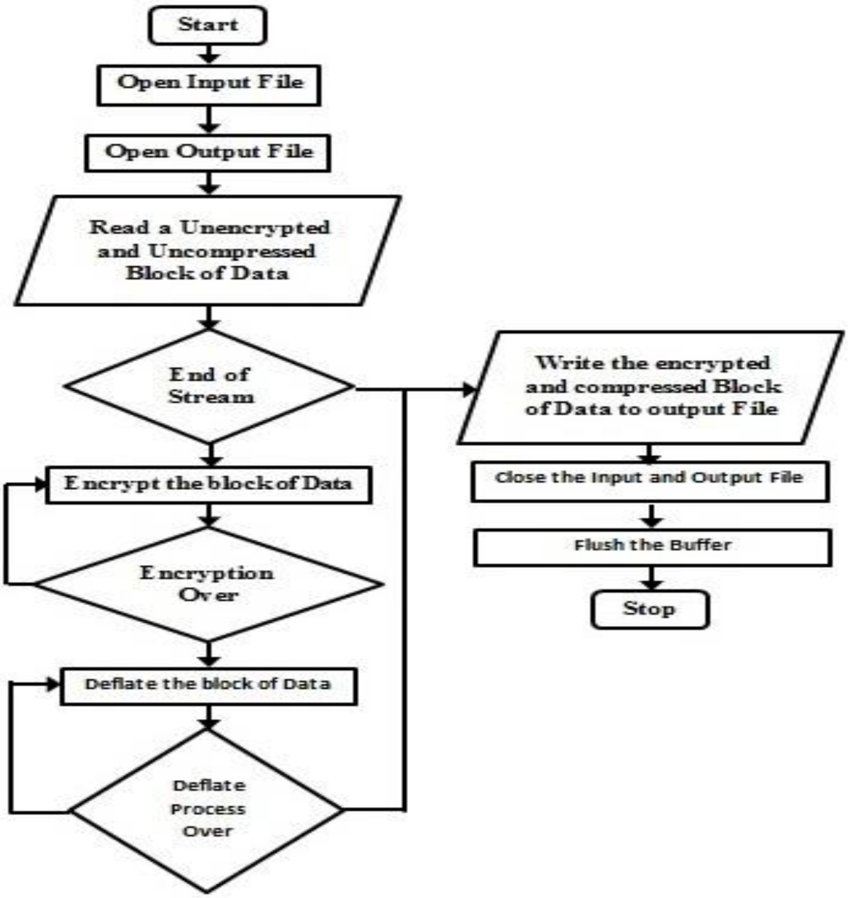


Figure 5- 6 Encryption and compression of VANET data

If a header is available then the Deflate algorithm starts with the INIT_STATE. Otherwise it starts with BUSY_STATE.

2. A dictionary may be set only in INIT_STATE. Then the deflate algorithm goes in the SETDICT_STATE, and one can change the state as mentioned.

3. Irrespective of whether a dictionary is set or not, the algorithm goes into BUSY_STATE.

4. The algorithm is in FINISHING_STATE when flush is called; however the process of writing the new data into the output file is not over. It just indicates the end of the input stream.

5. The Deflate algorithm is only in FINISHED_STATE when everything is flushed into the output file.

6. At any other time, the Deflate algorithm is in the CLOSED_STATE.

5.4.5.1 Advantages of Deflate Compression Algorithm

1. Reduction in memory requirement
2. Reduction in power consumption
3. Compression is very Fast

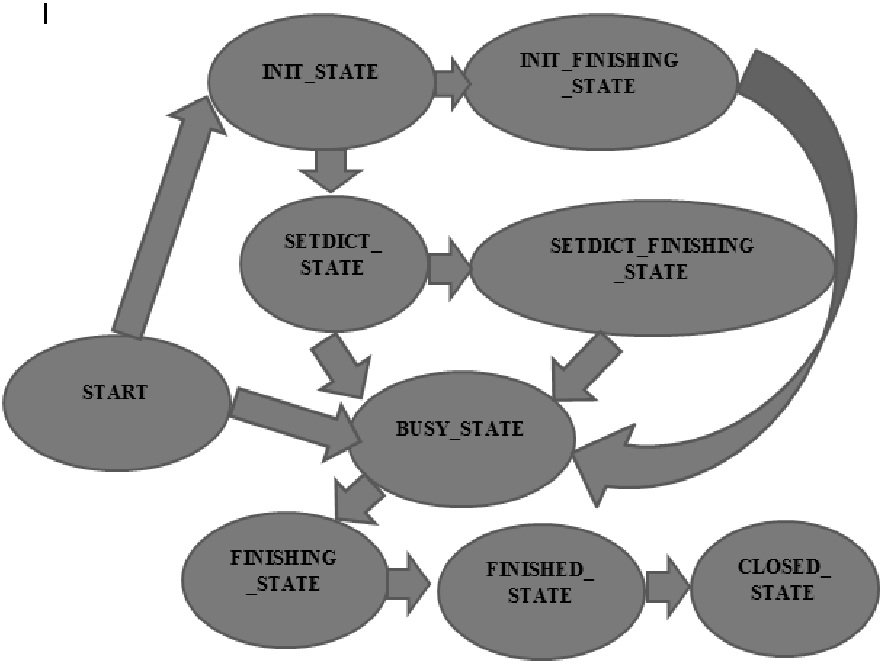


Figure 5- 7 State transition diagram of Deflate algorithm

5.4.6. CLOUD

Amazon EC2 cloud instance is used to store the encrypted and compressed data.

5.4.7. DECOMPRESSION PHASE

This phase is used in VANET applications to use the compressed file. Inflate is the decompression technique that takes a Deflate bit stream for decompression and appropriately yields the original full-size data or file.

5.4.8. DECRYPTION PHASE

In this phase, the uncompressed data that is in an encrypted format is converted back to the initial form. The vehicles can make use of V2I infrastructure for accessing an external cloud on the move by using the net connection. The vehicles can store relevant data on the TTP server, and then information can be uploaded to the cloud in the encrypted and compressed format.

5.4.9. STEPS FOR UPLOADING A FILE ON CLOUD

Let F be the original unencrypted and uncompressed File to be uploaded to the Cloud. The file is divided into n blocks as shown in Eq. (1).

$$F= \{b_1, b_2, b_3, ------, b_n\} \quad (5\text{-}1)$$

i.e. $F = \{b_i\}$ where $1<=i<=n$

The entry of each block is made in Block Status Table (BST). BST is a small data structure used to access and reconstruction of blocks those are outsourced to the Cloud Service Provider (CSP). As shown in Table 5-5, BST contain three fields namely serial number (SN), Block Number (BN) and Key Version (KV). BST Entries

SN	BN	KV

SN is used to number each block. It gives the physical location of the block in the file. BN is a counter used for logical numbering of each block. Key Version (KV) designates the version of the key utilized to encrypt the blocks in the data file. BST stores a set of records that contain SN, BN and KN for each block as shown in Eq. (5-2).

$$BST=\{\{SN_1,BN_1,KV_1\},\{ SN_2, BN_2,KV_2\},\ldots,\{ SN_n, BN_n,KV_n\}\} \quad (5\text{-}2)$$

When a data file is created initially counter (ctr) and KV is set to 1.

When a block-level modification is performed then, ctr is increased by 1 and KV of the modified/new block is set to ctr.

Let F' be the encrypted file generated by encrypting each block (b'_j) as shown in equation

$$F' = \{b_1', b_2', b_3' \ldots, b_n'\} \tag{5-3}$$

Where each block b'_j is encrypted using a Data Encryption Key (DEK) (Ref Eq-5-3)

$$b'_j = E_{DEK}(BN_j \,||\, b'_j), \tag{5-4}$$

and DEK = $h\,(K_{ctr})$.

Here, Kctr is a hash key which depends on the counter value.

Deflate algorithm is used to compress the encrypted file F'. Let us assume ECF as the Encrypted Compressed File as shown in Eq. (5-5).

$$ECF = C_{DCA}(F') \tag{5-5}$$

Where, DCA is a Deflate Compression Algorithm.

ECF is uploaded on a VC.

Let $Size_{Ori}$ is the size of unencrypted and uncompressed file and $Size_{Disc}$ is the size of encrypted compressed file. The storage overhead on the cloud can be calculated using the equation

$$Storage_{Overhead} = (\frac{Size_{Ori.} - Size_{Disc})}{Size_{Ori}} * 100 \tag{5-6}$$

5.5. SIMULATION AND RESULT ANALYSIS

The proposed system is simulated on Amazon Elastic Compute Cloud (Amazon EC2). Trusted Third Party (TTP) and Cloud Server (CS) instances have been created on Amazon EC2. Windows free tier instances are used for implementation. Large Amazon EC2 instance is used to run Cloud server. Amazon cloud instance has configuration as Windows 2008sever, 64-bit base system & Instance ID: windows_server_2008- R2_SPI-English-64bit-Base_2015.05.1. One similar type of instance is used for TTP. Data owner & authorized user can login to any machine.

A file of size 10 Mb containing the VANET data is encrypted on the TTP server using encryption algorithm. This encryption is necessary for security reason so that only authorized parties can read it. After encryption, the size of the encrypted file has increased by a factor of 0.06%. The encrypted file size is 10.704 Mb. The encrypted file is given as an input to the compression block to reduce the storage overhead. After compression, the original file is compressed by a factor of 22 %. Figure 5-9 gives a comparison between original file, uncompressed encrypted file and compressed encrypted file.

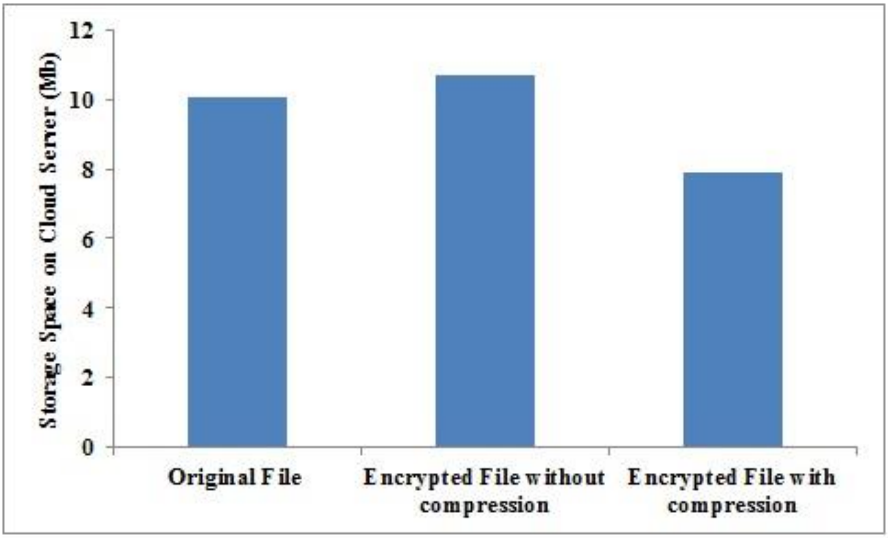


Figure 5- 8 Comparison of storage space requirement

5.6. BUSINESS MODEL

CC has risen as another exemplar for accommodating and providing assistance on the web. In the recent years, CC has fascinated many business owners as it removes the need for resource reservations in advance. It allows business enterprises to start with small resources when the service demand is low and increase additional resources only when there is an ascent sought. Figure 5-9 depicts the business prototype. In the layered architecture of CC every lower layer can be implemented as a service, and they are clustered into three kinds [15].

- **Software as a Service (SaaS)** – To serve requests on-demand over the web. E.g. of SaaS services are analytical, browsing, interactive, transaction, etc.
- **Platform as a Service (PaaS)** – To deliver assets like OS, DataBase Management System (DBMS), and Software development framework.
- **Infrastructure as a Service (IaaS)** – On-demand catering of infrastructural assets, typically VMs. Multiple types of virtualization occur in this layer.

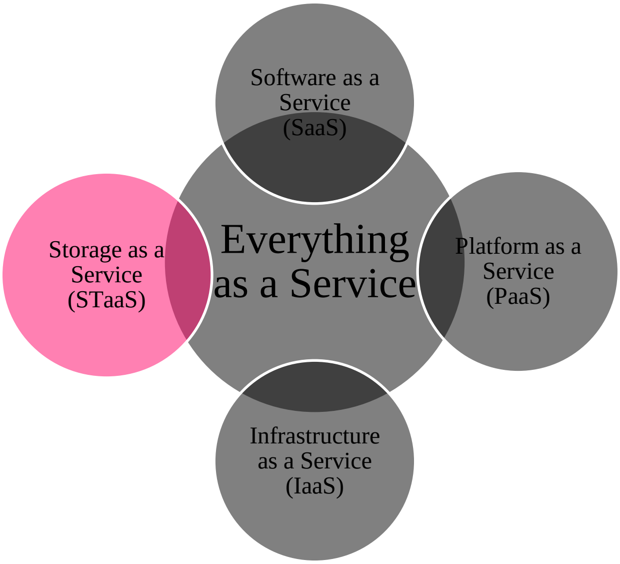


Figure 5- 9 Business model in Cloud

It is perfectly all right that the PaaS supplier runs their cloud on top of an IaaS provider's cloud. But, today, IaaS and PaaS suppliers are frequently share the same enterprise. That is the reason PaaS and IaaS service caterers are often called the infrastructure- or cloud- providers. In this thesis STaaS service is proposed. Figure 5-9 depicts the STaaS added into the Business Model (BM).

5.7. BUSINESS MODEL (BM) OF CONVERGENCE OF VANET AND CLOUD

A Business Modeling is a technique within which an organization "builds, supplies and catch value" [36]. It is also the "plan of how an organization will do business" [37]. Thus, a BM gives information about product or service an organization offers. It provides information about manufacturing process, supply-chain, and the vendors if any. It also gives insight of how the organization earns profit. The BM may also be used for bonding technology and economy [38]. Moreover, [39] see a BM as a collection of four key components clients, product, process, and returns. According to [36, 40, 41] the BM of an organization can be split within different modules for abstracting a BM. [36] generated a tool called as the BM Canvas (BMC) for generating a fresh BM or in investigating a present BM. IBM canvas is the most widespread BM investigation and design tool.

The BM canvas has the following nine components:
1. Key-Partners - The key associates, vendors, means, Activities
2. Key-Activities – Find the key activities to supply the value propositions.

3. Key-Resources - Strategic resources desirable to generate value for the client
4. Value-Propositions - The values provided to its customers by the organization
5. Customer-Relationships - The types of customer associations does the organization create and maintain
6. Channels-Reachability of the organization to its customers
7. Customer-Segments - The organization create value for whom and goal
8. Cost-Structure - costs of the BM
9. Revenue-Streams - The tactic to generate revenue in the customer segments

These nine components are foot-prints for creating a BM. Each component is further divided into elements called as types [42]. E.g. For Value-Propositions the type could be low cost, low Latency, High throughput etc. Developing a BM has defined progressive steps such as organize, comprehend, design, implement and accomplish [36]. In organize phase the people involved in designing have to classify and collect all the resources required for BM project and decide the language, grammar for designing and recitation of the BM [36, 43]. In the comprehend phase, the design team after brainstorming sessions on selected resources will pick the best resources required and implement for building the BM. This activity is the design and implementation steps of the BM development phase [36]. In the accomplish phase, the BM is fine-tuned according to fluctuations in client or market situations [43]. The business model for the proposed use-case is shown in Figure 5-10.

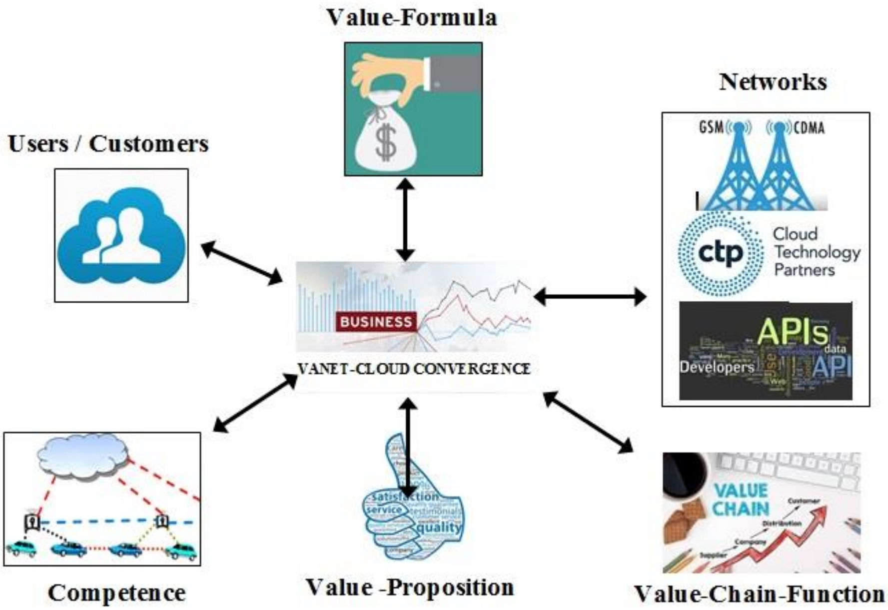


Figure 5- 10 Business model for convergence of VANET and Cloud

The early analysis question in chapter 1 (Ref. Section 1.2) within research hypothesis and methodology section set up was that Which BM building blocks and types the foremost necessary once evolving BM for VANET-Cloud convergence a use-case of IoT? A BM of a organization can be investigated by breaking it down into nine building blocks, and their associated varieties ((osterwalder)). The BM canvas using nine building-blocks for VANET-Cloud convergence is shown in Table 5-5. The analysis results show that to provide the required value proposition the partnership among the different facility suppliers foremost necessary building blocks for the business models. The nine most vital building blocks for every BM are:

- **Key Partners (KP):** The Mobile- and Cloud- Infrastructure / Service suppliers, interface developers are the foremost vital key partners for the proposed use-case as these service-providers firms provide various forms of means that together with APIs, infrastructure-, and sales- support, NW analytics etc.

- **Key Activities (KA):** Package development, recognizing potential Customers, Providing Infrastructure and sales were discovered to be the foremost important types within this building block. The outcomes during this block are very analogous to those of the key resources building block that indicates an association between each of them.

- **Key Resources (KR) :** Humans are key assets for these platforms. . they're at the most important resources for the writing packages for the development of the APIs and for enabling, maintaining, providing selling, and commerce the services on cloud. they're conjointly needed for making the IT infrastructure.

- **Value Propositions (VP):** The organization can resolve client's difficulties and fulfill client needs with VP. Enhancing the system accessibility, availability, decreasing the storage overhead on cloud, reducing the latency, operational price, Enhancing the security and scalability are the key building blocks of VP. This block of the BM provides establishments to look at the performance of their strategies, and act positively.

- **Customer Relationships (CR):** CR is/should be maintained with each CS from the current/future business perspective. CR can be either very close or counseling type. A close CR can be maintained with the CS by providing quality product/service, by building trust, by providing trials, free software, and by controling the costs.

- **Channels (CH):** VPs are offered to the targeted CS through numerous means that known as CH. Direct sale or indirect sale (through KP's) are the key sales CH. The VP can be provided to the CS through voice communication, dispensing, and thru deals. Conferences, Online-Trade, promotion through print and digital media, mouth-publicity, use of social media are the important channels for approaching to the CS. Reaching about to customers through KPs is one among the key one of the key method.

- **Customer Segments (CS):** CS means that, with the assistance of product and services the organization would really like to supply VP to the targeted audience. Within the projected use-case owners of the vehicles, end users connected to cloud is that the targeted CS.

- **Cost Structure (CoS):** The BM components concerned could incur price and one ought to take into account them whereas considering the pricing structure. CoS may embed salaries of the staff (developers, sales, and other), infrastructure development cost, API development cost, Research & Development price etc.

- **Revenue Streams (RS)**: Once the VP is delivered with success to the customers then the organization gets revenue of various types. Annual fee charged per device or per usage, by commerce the connecting gadgets, implementing policies to increasing the accessibility of the network /services and by promotional offerings (free trial, free package, and reducing the value per device/usage) could generate the revenue for the organization.

The BM can also be represented using six building-blocks. This represntation for VANET-Cloud convergence is shown in Figure 5-11. The six most vital building blocks for are:

- **Value Chain Function:** All vehicles should be capable of communicating with one another and also the Infrastructure Unit or RSUs. Vehicles can act like relaying nodes in WSN. They'll forward the info received from neighboring vehicles through RSU or the Infrastructure Units (Cellular, Wi-MAX, DSB base station) of publically or privately owned mobile-Service-providers up to the cloud. This mechanism will enhance the storage and computing capability of the cloud to which the resources of the participating vehicles will get connected. Launching vehicles could be a prime function in this BM. Within the planned use-case, the VANET data is routed up to the gateway using multi-hop communication. The routing protocol used is MOHRA. Every user should purchase storage- space on the cloud inorder to store their private data. So selling storage space is an added necessary function. For connecting to hardware and for communicating with nearby vehicles API is required, developing API is an added function for this case study.
- **Value Formula:** Considering the no of vehicles on road this BM will have huge impact on the turnover. Whereas scheming the profit/loss from the business the technical value, salaries of the staff (developers, sales, and other), infrastructure development cost, API development value, Research & Development value etc. should be quoted. The revenues are often attained by

Table 5- 5 Comparison of compression techniques

The Business Model Canvas for Convergence of VANET and Cloud				
Key Partners • Mobile Service Providers • Cloud Infrastructure Providers • Third-party API Developers • Hardware Suppliers • Service Partners Owners of Vehicles	***Key Activities*** • Software Developer • Launching Customers • Sales of Storage Space on Cloud / Service • Cloud- IT Infrastructure Operation • Setting up Distant Access of Facilities • Offer Cloud Connector • Offer API ***Key Resources***	***Value Proposition*** • Increased System Accessibility • Decreased Storage Overhead • Reduced Latency • Reduced Cost • Security • Scalability • Administration Becomes Simpler because of Central • Device Management • Connect any Device • with open API	***Customer Relationships*** • Providing Quality Service • Regulating Annual Fee • Building Trust to Allow Service Provider Access • Free 3rd party developer accounts • Supplying Free Trial, and Free Software ***Channels*** • Online sales?	***Customer Segments*** • Transport Department • Network Users • Owner of the Vehicles

	• Cloud Technology Designers • API Designers • Cloud Infrastructure • ISP • Marketing People • IT Frame Work • Cloud Connector IPR	Newness	• Secure internet for service delivery • Publicity through Print and Digital Media • Mouth Publicity (users) • Web shop Social Media	

Cost Structure	***Revenue Streams***
• **Mobile Service Providers** • **Interface Developers Cost** • **Cloud Infrastructure Providers Cost** • **Sales costs** • **R&D Costs**	• Annual Fee per user • Increased Accessibility of Cloud Solution and Service • Sales of Connection Gadgets • Promotional Offering (Free Trial , Free Software, and Reducing cost / user to increase the customer base)

Figure 5- 11 Business Model Canvas Using Six Building Blocks

- charging annual fee per device or per usage, by selling the connecting gadgets, implementing policies to increasing the accessibility of the network /services and by promotional offerings (free trial, free software-package, and reducing the price per device/usage).
- **Value Proposition:** The planned use-case study talks regarding using cloud services the info are often uploaded and downloaded through VANET at any time. Thus accessibility is enhanced. The use-case proposes compression of the info before uploading on cloud to cut back storage overhead. To upload and download compressed info time needed is less. Thus it reduces latency. The info is encrypted before uploading on to the cloud so privacy of the info is

maintained. The TTP within the cloud can offer further security and also the newness of the info is additionally taken care of.

- **Competences:** Cloud technology designers and developers are needed. The human resource for developing API for communicating with the hardware is needed. Human resource for sales and promoting the hardware, cloud connector are needed. Considering the novelties within the convergence human resource is required for filing IPRs. For maintaining and administration of the converged VANET and CLOUD network human resource is needed.
- **Networks:** For incubation of this idea of convergence of VANET and Cloud so as to cut back storage overhead Mobile service suppliers, Cloud Infrastructure suppliers, net service suppliers, Hardware suppliers, Vehicle manufacturers, API developers should shake hands.
- **User and Customers:** This BM is going to serve all vehicle owners and also the cloud assessors, mobile service suppliers, cloud infrastructure suppliers, net service suppliers, hardware suppliers, vehicle manufacturers, and API developers.

5.8. SUMMARY OF THE CHAPTER AND FUTURE SCOPE

VCC, cloud-based vehicle architecture, would increase quality, safety, and security, as well as reduce cost and complexity. The competitive advantage of an automotive company would become its ability to enrich the user experience through software innovation. The VANET would enable the integration of automotive, software, networking, and telecommunications industries, which would lead to an evolutionary transformation of the automotive industry and the world

VANET diverges from other types of networks regarding safety, mobility, network dynamics, a way of communication, etc. Utilizing all the VANET resources optimally is a challenging task due to the above constraints. A novel idea for the convergence of VANET and Cloud is presented in this chapter. The prime goal of the proposal is to reduce storage overhead on the cloud server. The proposed scheme is implemented on the real cloud, and storage cost is calculated. The proposed system has lesser space requirements on the cloud. Taxonomy of VCC is also the significant contribution of this chapter to give scope to VANET and Cloud researchers.

VCC is an innovative and exciting area and needs attention from the research community and academia. Moreover, the following challenges require further examination in future studies:

Network Interruption

Vehicles spontaneously join and leave the vehicular cloud as they move. This movement leads to disconnection of the network which is a major challenge for VCC. Such dynamically changing environment may result in the unavailability of cloud resources and result in failure to collaborate. This drawback of VCC has encouraged investigators to discover scalable procedures and framework that are stout enough for the various path disruptions affected by vehicle movement to manage the connectivity.

Routing Protocol

Forthcoming VANET routing protocols should support the coexistence and Interoperability of heterogeneous wireless technologies with changing requirements. Researchers must address the handover issues in the design of such protocols.

QoS

To develop feasible protocols suitable for all VANET applications providing guaranteed cloud services to the users is a challenge. Precise QoS measurements for VANET still should be endorsed upon given the wide varieties of performance metrics (comprising traditional QoS metrics, for example, end-to-end delay, jitter, and accessible data transfer capacity) being utilized by the VANET community. Future research in VCC should focus on improving QoS parameters in case current vehicle paths become inaccessible due to alterations in velocity, position, or distance between vehicular.

Benchmarking of protocol in VCC

Benchmarking of various VCC protocols and the simulation environment should be proposed.

Security

Since VCC encourages sharing resources, the most critical safety issue would be a threat targeting the cloud platform itself. An adversary may launch an attack or, it may try to inject malware into the platform to use up the platform's resources. An intrusion detection system or system integrity checking can help mitigate the problem. Privacy is also important in VNC because the contents each vehicle generates tend to disclose personal information. Numerous VANET security challenges still need to be tended in the regions of genuineness, driver secrecy, and ease of use. In future, the research in VCC should focus on developing need lightweight, scalable authentication frameworks for shielding vehicular nodes from indoor-, or outdoor- aggressors.

Broadcasting

Broadcasting keeps on being a substantial research area of passion by VANET analysts in light of the fact that a critical number of messages transmitted in VANETs are broadcast messages. Novel mechanisms are required to limit communication storms that emerge because of packet flooding (6)

Scalability: The number of vehicles on the road is increasing day by day, so scalability is a critical factor in designing various protocols in VCC.

5.9. REFERENCES

[1] D. Levin, “Why this could be the deadliest driving year in nearly a decade”, [Online] http://fortune.com/2015/09/15/auto-fatalities-increase/, 2015.

[2] European Commission, “Mobility and Transport Statistics–accidents data”, [Online] http://ec.europa.eu/transport/road_safety /specialist/ statistics/ index_en.htm, 2016.

[3] O. Olarte, “Human Error Accounts for 90% of Road Accidents”, [Online] http://www.alertdriving.com/home/fleet-alert-magazine/international/ human-error-accounts-90-road-accidents, International News, 2011.

[4] S. Al-Sultan, M. M. Al-Dhoori, A. Al-Bayatti and H. Zedan, “A comprehensive survey on vehicular Ad-Hoc network”, Elsevier Journal of Network and Computer Applications, Vol. 37, PP. 380-392, 2014.

[5] Y. Toor and P. Muhlethaler etc., “Vehicle Ad Hoc Networks: Applications and Related Technical Issues”, IEEE Communications Surveys and Tutorials, 3 rd Quarter, 10(3), PP.74-88, 2008.

[6] M. Whaiduzzaman, M. Sookhak, A. Gani, and R. Buyya, “A survey on vehicular cloud computing”, in Elsevier Journal of Network and Computer Applications, Vol 40, PP. 325–344, 2014.

[7] D. Jiang, L. Delgrossi, “IEEE 802.11p: Towards an International Standard for Wireless Access in Vehicular Environments”, IEEE, Vehicular Technology Conference (VTC) spring, Singapore, PP. 2036 - 2040, May 11-14, 2008.

[8] S. Zeadally, R. Hunt, Y. Chen, A. Irwin, and A. Hassan, “Vehicular Ad hoc NETworks (VANETS): Status, Results, and Challenges”, Springer, Telecommunication Systems, Vol. 50(4), PP. 217-241, August 2012.

[9] S. Olariu, T. Hristov, and G. Yan, “The next paradigm shift: from vehicular networks to vehicular clouds”, in Basagni MC S, Giordano S, Stojmenovic I, editors. Mobile ad hoc networking: cutting edge directions. 2nd ed. NJ, USA: John Wiley & Sons, Inc., Hoboken; 2013.

[10] M. Lebre, F. LeMouel, E. Menard, J. D. Schneider, and R. Denis, “VANET Applications: Hot Use Cases”, Research Report, PP.36, 2014.

[11] L. Zhang, Y. Liu, Z. Wang, J. Guo, and Y. Huo, “Mobility and QoS oriented 802.11p MAC scheme for vehicle-to-infrastructure communications”, in 6th International ICST Conference on Communications and Networking in China (CHINACOM), PP. 669-674, 2011.

[12] B. Sharef, R. A. Alsaqoura, and M. Ismail, “Vehicular communication ad hoc routing protocols: A survey”, in Elsevier Journal of Network and Computer Applications, Vol. 40, PP. 363–396, 2014.

[13] P. Mell, and T. Grance, “The NIST Definition of Cloud Computing”, Maryland, US: The National Institute of Standards and Technology, 2011.

[14] M. Armbrust, A. Fox, R. Griffith, A.D. Joseph, R. Katz, A. Konwinski, G. Lee, D. Patterson, A. Rabkin, I. Stoica and M. Zaharia, “A view of cloud computing,” Communication ACM, Vol. 53(4), PP. 50-58, 2010.

[15] R. Hussain, J. Son, H. Eun, S. Kim, and H. Oh, "Rethinking Vehicular Communications: Merging VANET with Cloud Computing", in IEEE International Conference on Cloud Computing Technology and Science (CloudCom), PP. 606-609, 2012.

[16] N. Bouchemal, R. Naja, and S. Tohme, “Traffic Modeling and Performance Evaluation in Vehicle to Infrastructure 802.11p Network”, in Ad Hoc Networks Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering Vol. 129, PP. 82-99, 2014.

[17] S. Andrews, “Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) Communications and Cooperative Driving”, in Handbook of Intelligent Vehicles, PP. 1121-1144, 2012.

[18] V. Harigovindan, A. Babu, and L. Jacob, “Ensuring fair access in IEEE 802.11p-based vehicle-to-infrastructure networks”, in Journal on Wireless Communications and Networking, PP. 168, 2012.

[19] J. Seward, “bzip2 and libbzip2, version 1.0.5 A program and library for data compression”, Available [Online] http://www.bzip.org.

[20] V. Harigovindan, A. Babu, and L. Jacob, “Ensuring fair access in IEEE 802.11p-based vehicle-to-infrastructure networks”, in EURASIP Journal on Wireless Communications and Networking, PP. 168, 2012.

[21] S. Bitam, A. Mellouk, and S. Zeadally, “VANET –CLOUD: A Generic Cloud Computing Model for Vehicular Ad Hoc Networks”, in IEEE Wireless Communication, Vol. 22(1), PP. 96-102, 2015.

[22] M. Armbrust, A. Fox, R. Griffith, A.D. Joseph, R. Katz, A. Konwinski, G. Lee, D. Patterson, A. Rabkin, I. Stoica and M. Zaharia, “A view of cloud computing,” Communication ACM, Vol. 53(4), PP. 50-58, 2010.

[23] R. Hussain, J. Son, H. Eun, S. Kim, and H. Oh, "Rethinking Vehicular Communications: Merging VANET with Cloud Computing", in IEEE International Conference on Cloud Computing Technology and Science (CloudCom), PP. 606-609, 2012.

[24] Z. Szabadka, “Google Open Source Blog”, [Online] http://google-opensource.blogspot.in/2015/09/introducing-brotli-new-compression.html, 2015.

[25] O. S. Smyrna Grace, T. Nalini, and A. Pravin Kumar, “Secure and Compressed Secret Writing using DES and DEFLATE algorithm”, in IJCSI International Journal of Computer Science, Vol. 9(2), PP. 423-428, 2012.

[26] J. Alakuijala, and L. Vandevenne, “Data compression using Zopfli”, Available [Online] https://zopfli.googlecode.com/files/ Data_compression_using _Zopfli .pdf

[27] D. Salomon, “Data Compression: The Complete Reference 4th Edition”, Published by Springer, 2006.

[28] J. Alakuijala, L. Vandevenne, “Data compression using Zopfli”, Online Available at https://zopfli.googlecode.com/files/Data_compression_using_ Zopfli.pdf.

[29] D. Singh, V. Bibhu, A. Anand, K. Maity, and B. Joshi “Study of Various Data Compression Tools”, International Journal of Computer Science and Mobile Applications, Vol. 2(12), PP. 8-15, 2014.

[30] N. Bouchemal, R. Naja, and S. Tohme, “Traffic Modeling and Performance Evaluation in Vehicle to Infrastructure 802.11p Network”, in Ad Hoc Networks Lecture Notes of the Institute for Computer Sciences, Social-

Informatics and Telecommunications Engineering, Vol. 129, PP. 82-99, 2014.

[31] J. Miller "Vehicle-to-Vehicle-to-Infrastructure (V2V2I) Intelligent Transportation System Architecture", in IEEE Intelligent Vehicles Symposium Eindhoven University of Technology Eindhoven, the Netherlands, 2008.

[32] M. Kakkasageri, and S. Manvi, "Information management in vehicular ad hoc networks: A review", in Elsevier Journal of Network and Computer Applications, Vol. 39, PP. 334–350, 2014.

[33] A. Dua, N. Kumar, and S. Bawa, "A systematic review on routing protocols for Vehicular Adhoc Networks", in Elsevier Journal of Vehicular Communications, Vol. 1, PP. 33-52, 2014.

[34] S. Al-Sultan, M. Al-Doori, A. Al-Bayatti, and H. Zedan, "A comprehensive survey on vehicular Ad Hoc network", in Elsevier Journal of Network and Computer Applications Vol. 37, PP. 380–392, 2014.

[35] L. Gu, D. Zeng, and S. Guo, "Vehicular cloud computing: A survey", in IEEE Globecom Workshops (GC Wkshps), PP. 403–407, 2013

CHAPTER 6. CONCLUSIONS AND FUTURE OUTLOOK

This chapter concludes the thesis and puts forth different research directions which are based on performance assessment of the offered techniques and algorithms. Energy Efficiency, packet delivery, and delay concerns associated with Wireless Sensor Network (WSN) are analyzed in this thesis. Significant problems in the sensor node placement, coverage, and connectivity in WSN are identified during this research work which is mentioned, and future solutions are proposed. The major contributions are a novel Multi-objective Hybrid Routing Algorithm (MOHRA) designed for hierarchical, cluster-based networks, Mobility aware Multi-objective Hybrid Routing Algorithm (MMOHRA) for mobile sensor nodes, Green (Energy Efficient)-Multi-Objective Hybrid Routing Algorithm (G-MOHRA) for providing Pareto-optimal solutions, QoS Assured Multi-Objective Hybrid Routing Algorithm (Q-MOHRA) is designed for Heterogeneous WSN, Evolutionary Mobility aware multi-objective hybrid Routing Protocol for heterogeneous mobile wireless sensor networks (EMRP). A novel idea for the convergence of VANET and Cloud in IoT is presented in this thesis. The innovative approaches are implemented and simulation outcomes have been presented in this thesis. Throughout the thesis, either the evidence of thought, simulation results or the implementation results are offered to authenticate the outcomes.

6.1. SUMMARY OF CONTRIBUTIONS

This chapter concludes the research work that has been presented in this thesis. This part of the thesis highlights the major contributions and results, and summaries directions for the future work. Due to the enduring spread of WSNs in many diverse applications, it becomes progressively more important to the communication algorithms, mainly routing algorithms to confine themselves not only with the energy efficiency (green) objective but also consider packet delay, packet delivery, control overhead, and empower the vision of IoT. This thesis contributes to the different pillars of IoT which are WSN, Cloud Computing and Vehicular Ad-hoc Network (VANET). This thesis addresses the energy consumption, delay and packet delivery issues in WSN. The major contribution of the thesis is the problem of designing WSN routing methods that are energy efficient.

The first chapter of the thesis provides a comprehensive study and analysis of several WSN routing protocols. This chapter of the thesis describes the pillars of IoT and the importance of routing in processing and communication jargon of IoT. The chapter talks about the drawbacks of the conventional routing algorithms and describes the need for hybrid routing algorithm with real life examples. In this chapter, the outline of the state of the art hybrid routing algorithms is presented. The chapter also examines the distinct hybrid routing algorithms in view of various QoS metrics, for example, power usage, Aggregation, Scalability, Delay, security. The requirement of the hybrid routing and the challenges are understood through this chapter. This chapter also talks about the design of novel green, MOHRA that is one of the major contributions of the thesis. This chapter gives information about the need for multi-objective routing. The chapter describes the motivation and problem statement of the thesis by understanding the state-of-the-art routing scenarios. The chapter gives perception on the methodology used for finalizing the research, and to understand the drift of research and different improvement stages of research. The chapter also labels the novelty and contribution of research that helps to understand the evolution of research and problem addressed.

The significant contribution of the second chapter is that it addresses the MOHRA for homogeneous WSN. This chapter explored analytical and simulation model. The chapter provides a comparative evaluation of MOHRA with the cutting edge arrangements. The evaluation delivered approaches to improve the rendition of MOHRA regarding energy, packet delivery, and jitter. Then the rendition of MOHRA is evaluated for both with and without the mobility of sensor nodes scenario. The proposed algorithm progresses the energy competency, packet delivery, also jitter.

The third chapter majorly describes the classification of routing protocols for heterogeneous WSN. This chapter provides a comprehensive survey of different MOHRA for heterogeneous network. The discussion gives the major pros and cons of existing approaches, which provided insight to develop new hybrid routing algorithm. The chapter contributed with a novel H-MOHRA for mobile heterogeneous WSN. The second contribution of this chapter is Q-MOHRA algorithm for heterogeneous WSN without mobility. The simulation of H-MOHRA and Q-MOHRA has better performance their counterparts. H-MOHARA and Q-MOHRA have better performance regarding energy consumption, packet delivery, jitter, and routing overhead for WSN having mobility and without mobility respectively.

The first part of the fourth chapter categorized the different approaches for arranging nodes in WSNs. This chapter surveyed number of available approaches to deploy sensor nodes in the target area emphasizing their strong points and limitations. The study put forward the impact of node location on the operations and execution of WSN. Further, the deployment strategy in WSN has a direct impact on scope and range of the NW. The second part of the chapter contributed a novel deployment strategy to optimize the performance of WSN. The research in this chapter proposed quasi-random deployment strategy for the sensor nodes. The chapter analyzed the issues, identified the various objectives and enumerated the different. The next section is dedicated to static strategies for node positioning.

Fifth chapter explains and simulates a case study of a converged Internet of Things (IoT) based on a VANET and cloud. The chapter introduces VANET and gives a summary of the various industrial and university on-going projects across the globe. This chapter highlights the characteristics of VANET. The chapter describes cloud computing, cloud architecture, business model. Vehicular Cloud Computing (VCC) and Taxonomy of VCC is one of the major contributions of this chapter. This chapter describes the various data compression techniques used in the internet and summarizes compression techniques based on compression & decompression time, compression ratio, throughput, buffer, and complexity, etc. A novel scheme of convergence of VANET and cloud to reduce storage overhead is a major contribution to this chapter. A business model of converged VANET and cloud is presented.

In conclusion, the work and proposed algorithm put forward in this thesis endorses the research hypothesis through the proposal of a MOHRA for WSNs is energy, delay and throughput efficient, and supports mobility.

6.2. FUTURE SCOPE

There is always a scope to improve it and enhance the work for better applicability. The addressed research problem on routing of WSN will be enhanced in following ways,

- **Routing Protocol:** Routing protocols should support the coexistence and Interoperability of heterogeneous wireless technologies with changing requirements. Researchers must address the handover issues in the design of such protocols for mobile WSN.
- **Benchmarking of protocol:** Benchmarking of various WSN routing protocols and the simulation environment should be tackled.
- **Broadcasting:** Broadcasting keeps on being a substantial investigation region of VANET community in light of the fact that critical messages in VANET are always flooded. Novel algorithms are required to limit broadcast storms that emerge due to flooding.
- **Scalability:** The size and cost of sensors are decreasing day by day. A Large number of unattended, throwaway sensor is used in the target area. So scalability is a critical factor in designing various routing protocols in WSN.
- **3-D deployment:** In most of the published work the researchers have considered 2-D placement of the nodes. Issues of 3-D node placement need attention.
- **Network Interruption:** Vehicles spontaneously join and leave the vehicular cloud as they move. This movement leads to disconnection of the network which is a major challenge for VCC. This drawback of VCC has prompted researchers to find scalable algorithms and framework

APPENDICES

Appendix A. List of publications

The contributions have been or are in the process of being, validated through peer-review publication in journal, conference proceedings, and in book chapters are listed below:

A. Book Chapter

1. **Nandkumar Kulkarni**, Neeli Rashmi Prasad, Tao Lin, Mahbubul Alam, Ramjee Prasad, **"Convergence of Secure Vehicular Ad-Hoc Network and Cloud in Internet of Things",** River Publications, Role of ICT for Multi-Disciplinary Applications in 2030, Edited by Leo P. Ligthart, and Ramjee Prasad, ISBN: 9788793379480, 2016.

B. Journal Publications:

1. **Nandkumar Kulkarni**, Neeli Rashmi Prasad, & Ramjee Prasad, "**An Evolutionary Mobility Aware Multi-Objective Hybrid Routing Algorithm for Heterogeneous Wireless Sensor Networks**", International Journal of Rough Sets and Data Analysis (IJRSDA), Volume 4, Issue 3, Article 2, Special Issue Submission: Internet of Things, Next Generation Networks, Data Mining and Cloud Computing, 2016.

2. **Nandkumar Kulkarni,** Neeli Prasad, Ramjee Prasad, **"Q-MOHRA: QoS Assured Multi-Objective Hybrid Routing Algorithm for Heterogeneous WSN"**, An International Journal of Wireless Personal Communications, Springer Journal, ISSN 0929-6212, pp. 1-12, DOI 10.1007/s11277-017-5064-8, 2017.

3. **Nandkumar Kulkarni,** Neeli Rashmi Prasad, and Ramjee Prasad, **"A Novel Sensor Node Deployment using Low Discrepancy Sequences for WSN"**, An International Journal of Wireless Personal Communications, Springer Journal, ISSN 0929-6212, pp. 1-14, DOI 10.1007/s11277-017-5063-9, 2017.

4. **Nandkumar Kulkarni,** Neeli Rashmi Prasad, Ramjee Prasad, "Business Model Perception of Convergence of VANET and Cloud in IoT" (To be Submitted)

C. International conferences

a. First author

1. **Nandkumar Kulkarni**, Ramjee Prasad, Horia Cornean, Nisha Gupta, "**Performance Evaluation of AODV, DSDV & DSR for Quasi Random**

Deployment of Sensor Nodes in Wireless Sensor Networks", IEEE International Conference on Devices and Communications (ICDeCom-11), PP. 1-5, 2011.

2. **Nandkumar Kulkarni**, Neeli Prasad, Ramjee Prasad, "**MOHRA: Multi-Objective Hybrid Routing Algorithm for Wireless Sensor Network**", 3rd IEEE International Conference on Wireless Communications, Vehicular Technology, Information Theory and Aerospace & Electronics Systems (VITAE), Atlantic City, NJ, USA, PP. 1-6, 2013.
3. **Nandkumar Kulkarni**, Neeli Prasad, Ramjee Prasad, "**MMOHRA: Mobility Aware Multi-Objective Hybrid Routing Algorithm for Wireless Sensor Networks**", 4th IEEE International Conference on Wireless Communications, Vehicular Technology, Information Theory and Aerospace & Electronics Systems (VITAE), Aalborg University, Denmark, PP. 1-5, 2014.
4. **Nandkumar Kulkarni**, Neeli Prasad, Ramjee Prasad, "**G-MOHRA: Green Multi-Objective Hybrid Routing Algorithm for Wireless Sensor Network**", IEEE 3rd International Conference on Advances in Computing, Communications and Informatics (ICACCI), Greater Noida, Delhi, India, PP. 2185–2190, 2014.
5. **Nandkumar Kulkarni**, Neeli Prasad, Ramjee Prasad, "**H-MOHRA: Heterogeneous Multi-Objective Hybrid Routing Algorithm for Mobile Wireless Sensor Networks**", 1st IEEE Global Conference on Wireless Computing & Networking (GCWCN), Lonavala, India, PP. 249 – 253, 2014 (Best Paper Award).
6. **Nandkumar Kulkarni**, Neeli Prasad, Ramjee Prasad, "**An Evolutionary Mobility Aware Multi-Objective Hybrid Routing Algorithm for Heterogeneous Wireless Sensor Networks**", International Conference on Internet of Things, Next Generation Networks and Cloud Computing (ICINC 2016), 2016.

b. As Co-author

1. Vandana Rohoakale, **Nandkumar Kulkarni,** Horia Cornean, Neeli Prasad, **"Cooperative Opportunistic Large Array Approach for Cognitive Radio Networks",** 8th IEEE International Conference on Communications, Bucharest, Romania, PP:513-516, 2010.

Appendix B. Co-Author Statements

Co-author statement for the below mentioned scientific contributions are attached in the following pages.

AARHUS BSS SCHOOL OF BUSINESS AND SOCIAL SCIENCES
AARHUS UNIVERSITY

Declaration of co-authorship*

Full name of the PhD student: Nandkumar Prabhakar Kulkarni

This declaration concerns the following book chapter/article/manuscript:

Title:	Convergence of Secure Vehicular Ad-Hoc Network and Cloud in Internet of Things.
Authors:	**Nandkumar Kulkarni,** Neeli Rashmi Prasad, Tao Lin, Mahbubul Alam, Ramjee Prasad

The article/manuscript is: Published √ Accepted ☐ Submitted ☐ In preparation ☐

If published, state full reference: **River Publications, Role of ICT for Multi-Disciplinary Applications in 2030, Edited by Leo P. Ligthart, and Ramjee Prasad, ISBN: 9788793379480, 2016.**

If accepted or submitted, state journal:

Has the article/manuscript previously been used in other PhD or doctoral dissertations?

No √ Yes ☐ If yes, give details:

The PhD student has contributed to the elements of this article/manuscript as follows:
- A. Has essentially done all the work
- B. Major contribution
- C. Equal contribution
- D. Minor contribution
- E. Not relevant

Element	Extent (A-E)
1. Formulation/identification of the scientific problem	B
2. Planning of the experiments/methodology design and development	C
3. Involvement in the experimental work/clinical studies/data collection	B
4. Interpretation of the results	B
5. Writing of the first draft of the manuscript	B
6. Finalization of the manuscript and submission	C

Signatures of the co-authors

Date	Name	Signature
10/04/2017	Neeli Prasad	Neeli Prasad
10/04/2017	Tao Lin	
10/04/2017	Mahbubul Alam	

*As per policy the co-author statement will be published with the dissertation.

AARHUS BSS SCHOOL OF BUSINESS AND SOCIAL SCIENCES
AARHUS UNIVERSITY

10/04/2017	Ramjee Prasad	

In case of further co-authors please attach appendix

Date: 10/04/2017

____
Signature of the PhD student

*As per policy the co-author statement will be published with the dissertation.

AARHUS BSS SCHOOL OF BUSINESS AND SOCIAL SCIENCES
AARHUS UNIVERSITY

Declaration of co-authorship*

Full name of the PhD student: Nandkumar Prabhakar Kulkarni

This declaration concerns the following article/manuscript:

Title:	An Evolutionary Mobility Aware Multi-Objective Hybrid Routing Algorithm for Heterogeneous Wireless Sensor Networks.
Authors:	**Nandkumar Kulkarni**, Neeli Rashmi Prasad, and Ramjee Prasad.

The article/manuscript is: Published √ Accepted ☐ Submitted ☐ In preparation ☐

If published, state full reference: **International Journal of Rough Sets and Data Analysis (IJRSDA), Volume 4, Issue 3, Article 2, Special Issue Submission: Internet of Things, Next Generation Networks, Data Mining and Cloud Computing, 2016.**

If accepted or submitted, state journal:

Has the article/manuscript previously been used in other PhD or doctoral dissertations?

No √ Yes ☐ If yes, give details:

The PhD student has contributed to the elements of this article/manuscript as follows:

A. Has essentially done all the work
B. Major contribution
C. Equal contribution
D. Minor contribution
E. Not relevant

Element	Extent (A-E)
1. Formulation/identification of the scientific problem	B
2. Planning of the experiments/methodology design and development	C
3. Involvement in the experimental work/clinical studies/data collection	B
4. Interpretation of the results	C
5. Writing of the first draft of the manuscript	C
6. Finalization of the manuscript and submission	B

Signatures of the co-authors

Date	Name	Signature
10/04/2017	Neeli Prasad	[signature]
10/04/2017	Ramjee Prasad	[signature]

In case of further co-authors please attach appendix

Date: 10/04/2017

[signature]

Signature of the PhD student

*As per policy the co-author statement will be published with the dissertation.

AARHUS BSS SCHOOL OF BUSINESS AND SOCIAL SCIENCES AARHUS UNIVERSITY

Declaration of co-authorship*

Full name of the PhD student: Nandkumar Prabhakar Kulkarni

This declaration concerns the following article/manuscript:

Title:	A Novel Sensor Node Deployment using Low Discrepancy Sequences for WSN
Authors:	**Nandkumar Kulkarni,** Neeli Rashmi Prasad, and Ramjee Prasad

The article/manuscript is: Published √ Accepted ☐ Submitted ☐ In preparation ☐

If published, state full reference: **A Novel Sensor Node Deployment using Low Discrepancy Sequences for WSN", An International Journal of Wireless Personal Communications, Springer Journal, ISSN 0929-6212, pp 1-14, DOI 10.1007/s11277-017-5063-9, 2017.**

If accepted or submitted, state journal:

Has the article/manuscript previously been used in other PhD or doctoral dissertations?

No √ Yes ☐ If yes, give details:

The PhD student has contributed to the elements of this article/manuscript as follows:

A. Has essentially done all the work
B. Major contribution
C. Equal contribution
D. Minor contribution
E. Not relevant

Element	Extent (A-E)
1. Formulation/identification of the scientific problem	B
2. Planning of the experiments/methodology design and development	B
3. Involvement in the experimental work/clinical studies/data collection	C
4. Interpretation of the results	C
5. Writing of the first draft of the manuscript	B
6. Finalization of the manuscript and submission	B

Signatures of the co-authors

Date	Name	Signature
27/01/2018	Neeli Prasad	Neeli Rashmi
27/01/2018	Ramjee Prasad	Ramjee Prasad

In case of further co-authors please attach appendix

Date: 27/01/2018

Signature of the PhD student

*As per policy the co-author statement will be published with the dissertation.

AARHUS BSS SCHOOL OF BUSINESS AND SOCIAL SCIENCES AARHUS UNIVERSITY

Declaration of co-authorship*

Full name of the PhD student: Nandkumar Prabhakar Kulkarni

This declaration concerns the following article/manuscript:

Title:	Q-MOHRA: QoS Assured Multi-Objective Hybrid Routing Algorithm for Heterogeneous WSN.
Authors:	**Nandkumar Kulkarni,** Neeli Rashmi Prasad, and Ramjee Prasad

The article/manuscript is: Published √ Accepted ☐ Submitted ☐ In preparation ☐

If published, state full reference: **"Q-MOHRA: QoS Assured Multi-Objective Hybrid Routing Algorithm for Heterogeneous WSN", An International Journal of Wireless Personal Communications, Springer Journal, ISSN 0929-6212, pp 1-12, DOI 10.1007/s11277-017-5064-8, 2017.**

If accepted or submitted, state journal:

Has the article/manuscript previously been used in other PhD or doctoral dissertations?

No √ Yes ☐ If yes, give details:

The PhD student has contributed to the elements of this article/manuscript as follows:

A. Has essentially done all the work
B. Major contribution
C. Equal contribution
D. Minor contribution
E. Not relevant

Element	Extent (A-E)
1. Formulation/identification of the scientific problem	B
2. Planning of the experiments/methodology design and development	B
3. Involvement in the experimental work/clinical studies/data collection	C
4. Interpretation of the results	C
5. Writing of the first draft of the manuscript	B
6. Finalization of the manuscript and submission	B

Signatures of the co-authors

Date	Name	Signature
27/01/2018	Neeli Prasad	Neeli Rashmi
27/01/2018	Ramjee Prasad	Ramjee Prasad

In case of further co-authors please attach appendix

Date: 27/01/2018

Signature of the PhD student

*As per policy the co-author statement will be published with the dissertation.

AARHUS BSS SCHOOL OF BUSINESS AND SOCIAL SCIENCES
AARHUS UNIVERSITY

Declaration of co-authorship*

Full name of the PhD student: Nandkumar Prabhakar Kulkarni

This declaration concerns the following article/manuscript:

Title:	Performance Evaluation of AODV, DSDV & DSR for Quasi Random Deployment of Sensor Nodes in Wireless Sensor Networks.
Authors:	**Nandkumar Kulkarni,** Ramjee Prasad, Horia Cornean, Nisha Gupta

The article/manuscript is: Published √ Accepted ☐ Submitted ☐ In preparation ☐

If published, state full reference: **IEEE International Conference on Devices and Communications (ICDeCom-11), PP. 1-5, 2011.**

If accepted or submitted, state journal:

Has the article/manuscript previously been used in other PhD or doctoral dissertations?

No √ Yes ☐ If yes, give details:

The PhD student has contributed to the elements of this article/manuscript as follows:

A. Has essentially done all the work
B. Major contribution
C. Equal contribution
D. Minor contribution
E. Not relevant

Element	Extent (A-E)
1. Formulation/identification of the scientific problem	B
2. Planning of the experiments/methodology design and development	A
3. Involvement in the experimental work/clinical studies/data collection	A
4. Interpretation of the results	B
5. Writing of the first draft of the manuscript	A
6. Finalization of the manuscript and submission	B

Signatures of the co-authors

Date	Name	Signature
10/04/2017	Horia Cornean	Cornean Horia
10/04/2017	Nisha Gupta	[signature]
10/04/2017	Ramjee Prasad	[signature]

In case of further co-authors please attach appendix

Date: 10/04/2017

[signature]

Signature of the PhD student

*As per policy the co-author statement will be published with the dissertation.

AARHUS BSS SCHOOL OF BUSINESS AND SOCIAL SCIENCES
AARHUS UNIVERSITY

Declaration of co-authorship*

Full name of the PhD student: Nandkumar Prabhakar Kulkarni

This declaration concerns the following article/manuscript:

Title:	MOHRA: Multi-Objective Hybrid Routing Algorithm for Wireless Sensor Network.
Authors:	**Nandkumar Kulkarni,** Neeli Prasad, Ramjee Prasad

The article/manuscript is: Published √ Accepted ☐ Submitted ☐ In preparation ☐

If published, state full reference: **3rd IEEE International Conference on Wireless Communications, Vehicular Technology, Information Theory and Aerospace & Electronics Systems (VITAE), Atlantic City, NJ, USA, PP. 1-6, 2013.**

If accepted or submitted, state journal:

Has the article/manuscript previously been used in other PhD or doctoral dissertations?

No √ Yes ☐ If yes, give details:

The PhD student has contributed to the elements of this article/manuscript as follows:

A. Has essentially done all the work
B. Major contribution
C. Equal contribution
D. Minor contribution
E. Not relevant

Element	Extent (A-E)
1. Formulation/identification of the scientific problem	B
2. Planning of the experiments/methodology design and development	C
3. Involvement in the experimental work/clinical studies/data collection	B
4. Interpretation of the results	B
5. Writing of the first draft of the manuscript	B
6. Finalization of the manuscript and submission	C

Signatures of the co-authors

Date	Name	Signature
10/04/2017	Neeli Prasad	[signature]
10/04/2017	Ramjee Prasad	[signature]

In case of further co-authors please attach appendix

Date: 10/04/2017

[signature]

Signature of the PhD student

*As per policy the co-author statement will be published with the dissertation.

AARHUS BSS **SCHOOL OF BUSINESS AND SOCIAL SCIENCES** AARHUS UNIVERSITY

Declaration of co-authorship*

Full name of the PhD student: Nandkumar Prabhakar Kulkarni

This declaration concerns the following article/manuscript:

Title:	MMOHRA: Mobility Aware Multi-Objective Hybrid Routing Algorithm for Wireless Sensor Networks.
Authors:	**Nandkumar Kulkarni,** Neeli Prasad, Ramjee Prasad

The article/manuscript is: Published √ Accepted ☐ Submitted ☐ In preparation ☐

If published, state full reference: **4th IEEE International Conference on Wireless Communications, Vehicular Technology, Information Theory and Aerospace & Electronics Systems (VITAE), Aalborg University, Denmark, PP. 1-5, 2014.**

If accepted or submitted, state journal:

Has the article/manuscript previously been used in other PhD or doctoral dissertations?

No √ Yes ☐ If yes, give details:

The PhD student has contributed to the elements of this article/manuscript as follows:

A. Has essentially done all the work
B. Major contribution
C. Equal contribution
D. Minor contribution
E. Not relevant

Element	Extent (A-E)
1. Formulation/identification of the scientific problem	B
2. Planning of the experiments/methodology design and development	B
3. Involvement in the experimental work/clinical studies/data collection	B
4. Interpretation of the results	C
5. Writing of the first draft of the manuscript	A
6. Finalization of the manuscript and submission	C

Signatures of the co-authors

Date	Name	Signature
10/04/2017	Neeli Prasad	Neeli Prasad
10/04/2017	Ramjee Prasad	Ramjee Prasad

In case of further co-authors please attach appendix

Date: 10/04/2017

Signature of the PhD student

*As per policy the co-author statement will be published with the dissertation.

AARHUS BSS SCHOOL OF BUSINESS AND SOCIAL SCIENCES
AARHUS UNIVERSITY

Declaration of co-authorship*

Full name of the PhD student: Nandkumar Prabhakar Kulkarni

This declaration concerns the following article/manuscript:

Title:	G-MOHRA: Green Multi-Objective Hybrid Routing Algorithm for Wireless Sensor Network.
Authors:	**Nandkumar Kulkarni,** Neeli Prasad, Ramjee Prasad

The article/manuscript is: Published √ Accepted ☐ Submitted ☐ In preparation ☐

If published, state full reference: **IEEE 3rd International Conference on Advances in Computing, Communications and Informatics (ICACCI), Greater Noida, Delhi, India, PP. 2185-2190, 2014.**

If accepted or submitted, state journal:

Has the article/manuscript previously been used in other PhD or doctoral dissertations?

No √ Yes ☐ If yes, give details:

The PhD student has contributed to the elements of this article/manuscript as follows:

A. Has essentially done all the work
B. Major contribution
C. Equal contribution
D. Minor contribution
E. Not relevant

Element	Extent (A-E)
1. Formulation/identification of the scientific problem	B
2. Planning of the experiments/methodology design and development	B
3. Involvement in the experimental work/clinical studies/data collection	B
4. Interpretation of the results	C
5. Writing of the first draft of the manuscript	A
6. Finalization of the manuscript and submission	C

Signatures of the co-authors

Date	Name	Signature
10/04/2017	Neeli Prasad	[signature]
10/04/2017	Ramjee Prasad	[signature]

In case of further co-authors please attach appendix

Date: 10/04/2017

[signature]

Signature of the PhD student

*As per policy the co-author statement will be published with the dissertation.

AARHUS BSS SCHOOL OF BUSINESS AND SOCIAL SCIENCES
AARHUS UNIVERSITY

Declaration of co-authorship*

Full name of the PhD student: Nandkumar Prabhakar Kulkarni

This declaration concerns the following article/manuscript:

Title:	H-MOHRA: Heterogeneous Multi-Objective Hybrid Routing Algorithm for Mobile Wireless Sensor Networks.
Authors:	**Nandkumar Kulkarni,** Neeli Prasad, Ramjee Prasad

The article/manuscript is: Published √ Accepted ☐ Submitted ☐ In preparation ☐

If published, state full reference: **1st IEEE Global Conference on Wireless Computing & Networking (GCWCN), Lonavala, India, PP. 249-253, 2014 (Best Paper Award).**

If accepted or submitted, state journal:

Has the article/manuscript previously been used in other PhD or doctoral dissertations?

No √ Yes ☐ If yes, give details:

The PhD student has contributed to the elements of this article/manuscript as follows:

- A. Has essentially done all the work
- B. Major contribution
- C. Equal contribution
- D. Minor contribution
- E. Not relevant

Element	Extent (A-E)
1. Formulation/identification of the scientific problem	B
2. Planning of the experiments/methodology design and development	C
3. Involvement in the experimental work/clinical studies/data collection	B
4. Interpretation of the results	C
5. Writing of the first draft of the manuscript	B
6. Finalization of the manuscript and submission	C

Signatures of the co-authors

Date	Name	Signature
10/04/2017	Neeli Prasad	[signature]
10/04/2017	Ramjee Prasad	[signature]

In case of further co-authors please attach appendix

Date: 10/04/2017

[signature]

Signature of the PhD student

*As per policy the co-author statement will be published with the dissertation.

AARHUS BSS **SCHOOL OF BUSINESS AND SOCIAL SCIENCES** AARHUS UNIVERSITY

Declaration of co-authorship*

Full name of the PhD student: Nandkumar Prabhakar Kulkarni

This declaration concerns the following article/manuscript:

Title:	An Evolutionary Mobility Aware Multi-Objective Hybrid Routing Algorithm for Heterogeneous Wireless Sensor Networks.
Authors:	**Nandkumar Kulkarni,** Neeli Prasad, Ramjee Prasad

The article/manuscript is: Published √ Accepted ☐ Submitted ☐ In preparation ☐

If published, state full reference: International Conference on Internet of Things, Next Generation Networks and Cloud Computing (ICINC 2016), 2016.

If accepted or submitted, state journal:

Has the article/manuscript previously been used in other PhD or doctoral dissertations?

No √ Yes ☐ If yes, give details:

The PhD student has contributed to the elements of this article/manuscript as follows:

A. Has essentially done all the work
B. Major contribution
C. Equal contribution
D. Minor contribution
E. Not relevant

Element	Extent (A-E)
1. Formulation/identification of the scientific problem	B
2. Planning of the experiments/methodology design and development	C
3. Involvement in the experimental work/clinical studies/data collection	B
4. Interpretation of the results	C
5. Writing of the first draft of the manuscript	B
6. Finalization of the manuscript and submission	C

Signatures of the co-authors

Date	Name	Signature
10/04/2017	Neeli Prasad	Neeli Rad
10/04/2017	Ramjee Prasad	Rajee Prasad

In case of further co-authors please attach appendix

Date: 10/04/2017

Kn

____

Signature of the PhD student

*As per policy the co-author statement will be published with the dissertation.

AARHUS BSS SCHOOL OF BUSINESS AND SOCIAL SCIENCES AARHUS UNIVERSITY

Declaration of co-authorship*

Full name of the PhD student: Nandkumar Prabhakar Kulkarni

This declaration concerns the following article/manuscript:

Title:	Cooperative Opportunistic Large Array Approach for Cognitive Radio Networks.
Authors:	Vandana Rohoakale, **Nandkumar Kulkarni,** Horia Cornean, Neeli Prasad.

The article/manuscript is: Published √ Accepted ☐ Submitted ☐ In preparation ☐

If published, state full reference: 8th IEEE International Conference on Communications, Bucharest, Romania, PP. 513-516, 2010.

If accepted or submitted, state journal:

Has the article/manuscript previously been used in other PhD or doctoral dissertations?

No √ Yes ☐ If yes, give details:

The PhD student has contributed to the elements of this article/manuscript as follows:

A. Has essentially done all the work
B. Major contribution
C. Equal contribution
D. Minor contribution
E. Not relevant

Element	Extent (A-E)
1. Formulation/identification of the scientific problem	D
2. Planning of the experiments/methodology design and development	B
3. Involvement in the experimental work/clinical studies/data collection	B
4. Interpretation of the results	B
5. Writing of the first draft of the manuscript	D
6. Finalization of the manuscript and submission	D

Signatures of the co-authors

Date	Name	Signature
10/04/2017	Vandana Rohoakale	[signature]
10/04/2017	Horia Cornean	Cornean Horia
10/04/2017	Neeli Prasad	Neeli Prasad

In case of further co-authors please attach appendix

Date: 10/04/2017

[signature]

Signature of the PhD student

*As per policy the co-author statement will be published with the dissertation.