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Minimizing Rejection of Stranded User Equipment through Gateway Cluster Nodes for Routing towards Control Center

by

Bilal Ahmad

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This work is dedicated to my father and my late mother who always wanted me to complete higher studies. Without their moral support, guidance and continuous prayers this achievement would not have been possible for me.

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This is to certify that the research work presented in the dissertation, entitled "**Minimizing Rejection of Stranded User Equipment Through Gateway Cluster Nodes for Routing Towards Control Center**" was conducted under the supervision of **Dr. Mohammad Masroor Ahmed**. No part of this dissertation has been submitted anywhere else for any other degree. This dissertation is submitted to the **Department of Computer Science, Capital University of Science and Technology** in partial fulfillment of the requirements for the degree of Doctor in Philosophy in the field of **Computer Science.** The open defence of the dissertation was conducted on **September 09, 2024**.

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List of Publications

It is certified that following publication(s) have been made out of the research work that has been carried out for this dissertation:-

1. **Bilal Ahmad**, Masroor Ahmed, Nadeem Anjum, Masood Ur Rehman, Naeem Ramzan, "Energy efficient gateway based routing with maximized node coverage in a UAV assisted wireless sensor network," *PLOS ONE*, Volume No. 18, Pages e0295615, 2023. https://doi.org/10.1371/journal.pone.0295615.

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(Bilal Ahmad)

Abstract

UAV assisted wireless sensor networks deal with continuous challenges of optimized node deployment for maximizing node coverage and efficiently routing data to control centers in post disaster situations. These challenges impact the outcome in extending the lifetime of wireless sensor networks. This study presents a UAV assisted reactive zone based EHGR (energy efficient hierarchical gateway routing protocol) that is deployed in a situation where the natural calamity has caused communication and infrastructure damage to a major portion of the sensor network. EHGR is a hybrid multi layer routing protocol for large heterogeneous sensor nodes (smart nodes, basic nodes, user handheld devices etc.) The energy efficient hierarchical gateway routing protocol (EHGR) is tailored to achieve optimized node coverage during deployment phases and secondly to perform energy efficient routing for network life extension. The first part of EGHR focuses on maximized coverage during node deployments. Maximized coverage is an important aspect to be considered during the event of disaster since most of the nodes loose coverage and are detached from the wireless sensor network. The first part of EHGR uses state of the art game theory approach to build a model that maximizes the coverage of nodes during the deployment phase from all participating entities i.e. nodes and UAVs. Rather than fixing the cluster head as is the case in traditional cluster-based approaches EHGR uses the energy centroid nodes. Energy centroid nodes evolve on the basis of aggregated energy of the zone. This approach is superior to simply electing cluster head nodes on the basis of some probability function. The nodes that fail to achieve any successful outcome from the game theory matching model fail to get any association. These nodes will use multi hop D2D relay approach to reach the energy centroid nodes. Gateway relay nodes used with the game theory approach during the deployment of the UAV assisted WSN improves the overall coverage by 25% against traditional LEACH based hierarchical approaches. Once the optimum deployment phase is completed the routing phase is initiated. Aggregated data is sent by the energy centroid nodes (from the ECN) nodes to the servicing micro controller enabled un manned aerial vehicles. The routing process places partial burden of zone formation and data transmission to the control center

for each phase on the servicing UAVs. Energy centroid nodes engage only in the data aggregation process and transmission of data to servicing UAVs. Servicing-UAVs reduce energy dissipated of the entire zone which result in gradual decrease of energy for the zone thus increasing the network lifetime. Node deployment phase and the routing phase of EHGR utilize the computations provide by the micro controller enabled unmanned aerial vehicles such that the computationally intensive calculations are offloaded to the servicing UAVs. Experiment results of EHGR indicate an increase in the first dead node report, and last dead node report. Network lifetime is extended to approximately 1800 rounds where in traditional LEACH, DEEC protocols and all of its variants the entire network is dead at near 900 to 1000 rounds. In terms of comparison with the latest approaches such as GCEEC, CAMP, EECRP, MEACBM the EHGR extends the network lifetime by over 500 rounds. This achievement is due to the improvements in the routing process where hybrid routing is achieved in each round which increases the overall network lifetime.

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Abbreviations

CDG	Compressive data gathering
D2D	device to device
DEEC	Distributed energy efficient clustering routing protocol
ECN	Energy centroid node
EHGR	Energy efficient hierarchical gateway routing
EECRP	Energy efficient centroid based routing protocol
FANET	Flying ad hoc networks
FDN	First dead node
GCEEC	Gateway clustering energy efficient centroid
HAP	High Altitude Platform
ICR	Improved clustering and routing protocol
Iot	Internet of things
LAP	Low Altitude Platform
LEACH	Low energy adaptive clustering hierarchical routing protocol
MAC	Media access layer
MCBEAM	Mobile energy aware cluster based multi hop
MIMO	Multiple input multiple output
MEC	Mobile edge computing server
OLEACH	Optimized low energy adaptive clustering hierarchical routing protocol
SN	Sensor Node
UAV	Unmanned aerial vehicle
UAVWSN	UAV assisted wireless sensor network
UEs	User Equipment
UD-SCN	Ultra dense small cell network

VANET	Vehicular area network
WSN	Wireless Sensor Network

Symbols

LoS	Line of sight
Θ	Angle of elevation between the node and the UAV
$P(LoS, \Theta)$	Probability of received signal at angle Θ from LoS
$NLoS$	Non Line of sight
$P(NLoS, \Theta)$	Probability of received signal at angle Θ from $NLoS$
X	X-axis coordinate of a node.
Y	Y-axis coordinate of a node.
X_{ec}	X-axis coordinate of the ECN node.
Y_{ec}	Y-axis coordinate of the ECN node.
A_{dr}	The total data rate of any given node with a given uav
$Cls_{Throughput}$	Throughput of one zone of a given servicing uav
K_m	Set of nodes having l bits of data to send
$(\overline{x_{ec}}, \overline{y_{ec}})$	(x,y) coordinates of the energy centroid nodes
$E_o i$	The residual energy of the entire cluster
$E_T(l, d)$	Energy required to transmit l bits of data a distance d
C_o	Maximum channel capacity of according to Shannon capacity theorem
Cls	Cluster or a Zone
$E_T(l, d)$	Energy required to transmit l bits of data a distance d
$E_i r$	Residual energy of the i_{th} node at round r
$E_r n$	Residual energy of the n_{th} node
α	Ratio of built up land area to total area
β	Mean number of buildings per unit area
$E_r l$	Residual eneregy of the node after transmitting l bits of data

$E_T l$	Energy dissipated after transmitting $l$bit of data
$E_R l$	Energy dissipated after receiving l bit of data
$\epsilon_{fs} l$	Energy dissipation for opening transmit antenna for l bits
η_{LoS}	Excessive path loss in energy from line of sight
η_{NLoS}	Excessive path loss in energy from non line of sight

Chapter 1

Introduction

1.1 Background

Wireless sensor networks have become an emerging technology with its support in all of our daily application routines ranging from medical, military, surveillance, delivery services, manufacturing assist just to name a few . At the heart of sensor network are the sensor nodes sometimes also referred to as user equipment (UE) with various computational capabilities. The capabilities of the sensor nodes can be extended according the application domains in which these nodes will be deployed. For instance computation capabilities, GPS capabilities, communication capabilities are among the basic capabilities apart from secondary capabilities which can be integrated as per need. The objective in the design of a sensor node is to keep the cost to a minimum since the number of sensor nodes to be deployed in real time application domain can range from a few hundred to thousands. The sensor nodes thus can serve many different tasks and applications and therefore there capabilities can be enhanced by embedding a variety of technologies having different data transmission rate, frequency, distance coverage and power consumption such as Zigbee, Bluetooth, WiMax etc. Some of the sensor nodes can be advance nodes. Advance nodes are classified to have higher computational power, greater storage capacity and are capable to send data over a larger distance as compared to normal sensor nodes. In the literature the researchers assume half of the nodes to be normal and half to be advance that participate in the WSN. Once the data is gathered or the application senses from it surroundings an activity by using on board antennas of the sensor nodes the information is transmitted to the control center via its cluster head [1]. The control center can be near the deployed network or can be connected remotely over the internet which require that the sensor nodes send data to an control node connected with the internet and placed in the nearby vicinity so that all the nodes can have an access to it [2].

Apart from the great numbers of deployments of WSN and the cumulative benefits that are achieved from the WSNs a major problem still remains un solved which is that the sensor nodes are short lived due to limited battery power. In an IoT based environment where advance node can be deployed it is still a prime objective to preserve energy of the IoT nodes to increase the network lifetime. Energy efficiency of the sensor nodes is a major concern. In certain scenarios such as for example underwater acoustic sensor network in which the sensor network is deployed to monitor ocean phenomenons or a border surveillance sensor network deployed to monitor human activity etc. it is not feasible in these kind of the application deployment scenarios to change the battery of the sensor nodes quite as often as compared to scenarios where for example a patient is being monitored through some sensors in a hospital. Similarly in some scenarios it has a higher cost to change the battery and similarly in some scenarios it might be even technically not feasible to change the battery of the sensor nodes as they start dying out. Energy efficiency is therefore a major research area for wireless sensor networks. The TCP/IP protocol stack for the WSN is continuously updated to keep up with the challenges of optimizing various layers such as network layer, data link layer to incorporate the protocol changes for these layers that enhance network life time by optimally utilizing sensor node's energy [1].

1.1.1 UAV Assisted Wireless Sensor Network

In recent years state of the art WSNs have incorporated unmanned aerial vehicles (UAVs) or aerial drones. The UAVs provide connectivity services to the sensor nodes by hovering over the region of interest. Apart from connectivity services the

UAVs can be used to gather data from nodes within a network and forward the aggregated data to the near by stations for computation. The region of the sensor nodes connected with a particular UAV can be considered a cell due to limited cell like coverage of the UAV on the ground. The analysis related to the decision as to how many UAVs are to be deployed in the region can be calculated with the help of various tools that generate traffic map signatures or the log files from the recent nodes. UAV can be stationary where they simply hover over a surface for a given time period or they can move over designated route to provide various services to the sensor nodes on the ground. As pointed out by Azade Fotouhi et al in [3] the ability of the drone to hover and move in the coverage area can increase the distance coverage optimize the required throughput level. However in most part of the world the research on drones is still in early stages. In Ad-hoc WSN based public safety network routing is a crucial area that has been well researched. Traditional routing algorithms such as the Bellmanford cannot be used for routing in these networks due to heavy calculation involved in determining the shortest path towards the destination. These calculations if used cause early energy depletion thus reducing the lifetime of the sensor nodes that will reduce the active lifetime of the network. Many routing protocols have been presented by researchers focusing on solutions for energy perseverance issues a good example of these is presented in [2, 4].

1.1.2 Unmanned Aerial Vehicles

UAVs are resource constraints in many ways such as limited battery life, limited bandwidth due to which the UAVs can not provide service to all the user equipment continuously. UAVs are classified according to size, weight and power i.e SWAP. The parameters effect UAVs computation power, speed, altitude coverage, hovering capability etc. High altitude platforms cover higher altitudes with higher payload in comparison to low altitude platform. Fixed wings (not hovering capable) UAVs can fly at higher altitudes with grater speed and can carry higher amount of load and therefore more suited for package delivery, patient movement etc. While rotary wings (hovering capable) based drones fly at lower altitudes are energy constrained and can fly up to maximum 1 hour. Similarly low altitude platforms(LAP) based

Physical design	LAP	HAP	Rotary Wings	Fixed Wings
-Parrot Swing -Kogan Nano -Parrot Disco -DJI Spreading Wings -Scout B330 -Predator -Class II Battle drone -Class III Battle drones -with weight over 600kg.	-Low cost deployment -Quick coverage -More suitable for public safety comm. -Less reliable as compared to HAP. -Quicker battery drainage.	-Longer Coverage time -Longer life -provide maximum payload features. -Flight altitude over 17kms. -Quasi stationary ability. -Costly as compared to LAP.	-Limited Flight time -Ability to hover -Rapid deployment for coverage. -Deployed as a group of systems.	-Cover high speed. -Cover longer distance -Used for high reliability. -Aerial package delivery center. -flight for a longer duration.

FIGURE 1.1: Networking Diagram of the Wireless sensor network implementation.

UAVs are cheap since they can not fly at higher altitudes and for longer duration but are more suitable for situations where rapid deployment is required e.g. to meet bandwidth needs, or in a disaster zones to provide temporary communication services. Higher altitudes platform (HAP) based drones cover more geographic area, can fly for longer duration (day or weeks) and more suitable for situation where flight stability and reliability is required such as in cargo services [5]. Refer to figure 2 to see a summary of UAVs according to its types. Apart from the disaster zone application domain rapid deployment networks can be utilized in any situation where we need certain services for a limited time. There are multiple applications domains associated with this concept for example:

1. Providing connectivity services in a densely populated zone such as a stadium full of people in a football match.

2. Providing internet services to a press conference taking place in a deserted area.

3. Providing data forwarding services in locations that are hidden from normal coverage due to hilly or forest areas.

1.1.3 Routing inside UAV-assisted Wireless Sensor Network

Once the UAV deployment takes place and sensor nodes have been deployed routing in UAV-WSN succeeds. Routing in UAV assisted WSN is an important task that must be addressed. Sensor nodes that have been deployed will sense information from the surrounding and relay it to the control centers with the help of these UAVS. The communication drains most the sensor node's energy for which energy efficiency must be considered and routing protocols must be designed to keep the network alive for a longer duration.

Routing protocols for UAV assisted WSNs can be categorized into three broad categories as per [6]

i. Location based routing

ii. flat routing and

iii. hierarchical routing techniques.

Location based routing focuses on the nodes location with the objective to improve network scalability and reduce routing overhead. In location based routing the objective is to reduce the transmission of the routing control packets used by well know routing algorithms such AODV, DSR etc. that flood the network with the routing updates. A major drawback of location based routing such as LAR, DREAM, AADTR, and some earlier location based routing protocols is that they still use flooding techniques to some extent in order to predict the next location of the destination node. In flat routing algorithms a multi hop routing strategy is adopted by the nodes. Each node performs a similar type of task in order to construct a path towards the base station. when a node receives data packet it sends it to the next immediate neighbor in path towards the BS. The nodes have an identical role in the routing decision process. In flat routing protocols every node maintain an active path towards the base station and keep their routing tables updated due to which much of the energy of a node is depleted in performing these calculations. With large scale routing networks this aspect of flat routing become a serious issue. Scalability for network extension, load balancing are documented to be some of the issues in flat routing protocols. In hierarchical routing nodes are grouped together in clusters.

Clustering of nodes is performed by grouping nodes that have similar characteristics such as a common distance, certain attributed like node residual energy, urgency, received signal strength etc. The nodes are also divided into different roles according to these characteristics e.g. nodes with higher battery, processing power and are elected as the cluster head for a particular group.

The remaining nodes are considered as cluster members. Non cluster members transmit data to their respective cluster heads. The cluster heads aggregate the data generated from different non cluster members and then transmit the aggregated data to the base station. At the beginning of each round the clusters head selection process is repeated.
Hierarchical routing protocols draw their foundation from the well known LEACH protocol which over the years different researchers have presented variations on their algorithm design which mostly focuses on resolving energy depletion issue to increase network lifetime. Large scale deployments in WSNs benefit more from the hierarchical routing as compared to flat or location based routing protocols.
Recently surveyed by Muhammad K. Khan et al. in [1] indicates that hierarchical routing techniques suffer from energy depletion due to complex procedures used in cluster formation, cluster head selection, identification of cluster members and non cluster member, route calculations, residual energy calculations, overcoming routing hole problems. Keeping in view of the above problems khan et al. presented a dynamic priority based energy efficient hierarchical routing protocol most suitable for ad hoc WSN for measuring humidity, temperature from the agriculture farm lands. The calculations however are complex for an resource constrained WSN node to perform.

1.2 Research Contributions

Significant contributions for the proposed that we have presented and the experimentation that are conducted as a support for this study are unique since two important aspects of wireless sensor networks are considered in this study are as follows:
i. Optimized coverage of sensor nodes such that the rejection of the nodes is minimized with the help of D2D gateway nodes in each zone created. Node association rejection results either due to lack of available bandwidth or due to the placement of the nodes on the grid such that association is not possible with a zone head. and
ii. A hybrid Energy efficient routing mechanism to extend network lifetime with help of energy centeroid nodes(ECN) for reducing the hot spot problem that most

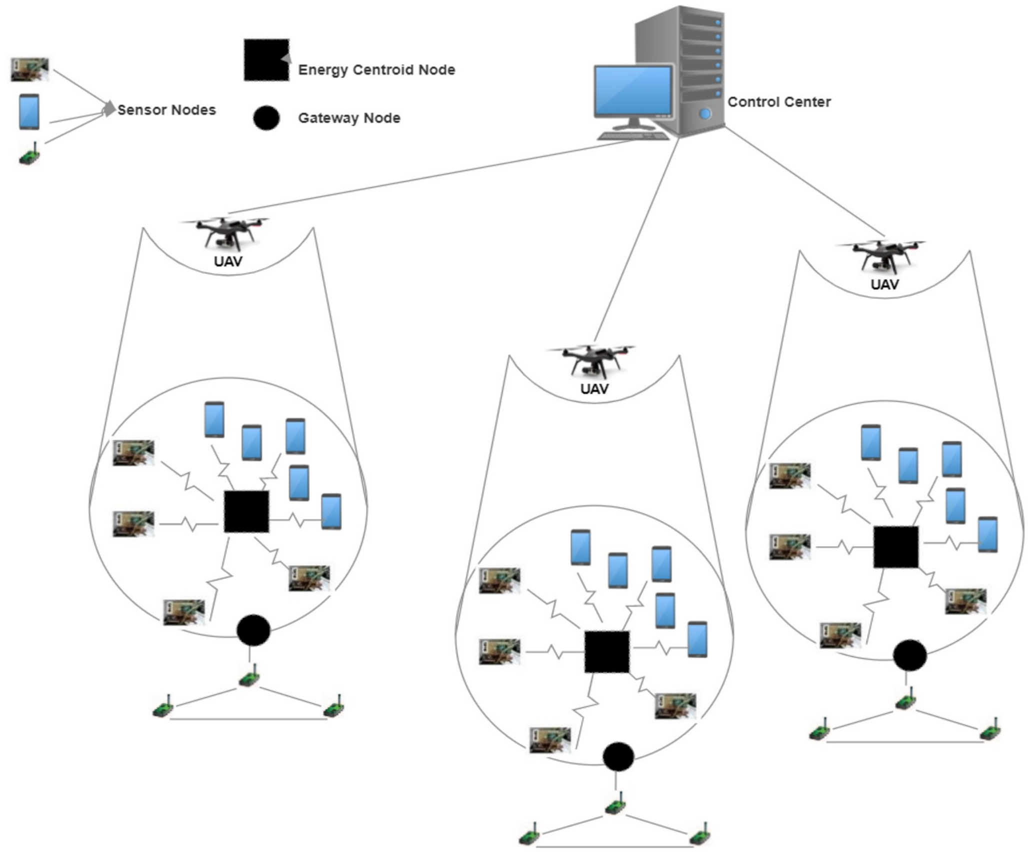

FIGURE 1.2: Networking Diagram of the Wireless sensor network implementation.

of the hierarchical routing protocols face.

To achieve the first objective a disaster region is simulated using Matlab in the wireless sensor network. D2D based Gateway nodes are used to extend network coverage for the sensor nodes which are deployed randomly in the effected region. Some the sensor nodes randomly get placed outside the coverage of a particular servicing UAV due to which these displaced nodes are not able to connect the network. Similarly some the random nodes that get positioned with in the coverage zone of a servicing UAV fail to get association from the servicing UAV. This happens when some of the criteria is not met either by sensor node or the servicing UAV or it can also happen that all the parameters are matched such as line of sight and non line of sight received powers but the servicing UAV can not accommodate any further nodes due to bandwidth shortage.In such scenarios the network coverage is extended using gateway nodes. After the deployment of the UAVs and the nodes gateway nodes are used to increase coverage and in scenarios where maximum coverage is required gateway nodes can be used. Post disaster deployments focus on associating maximum nodes with minimized rejection. The association of the sensor nodes with the servicing UAVs is an important aspect for node association weather a disaster has struck or not. The approaches presented in the first part satisfy the objectives presented above.

The second contribution focuses on routing data inside the UAV assisted wireless sensor network. Routing inside sensor networks is a prime objective despite the fact that whether a disaster has struck. For iot based devices and all types of nodes basic and advanced dissipate energy during data reception,transmission. It is estimated that over 75% of the node's energy is lost during these operations. Since the sensor nodes suffer energy drainage problem sending data from the sensor network towards the control center depletes most of the energy of the sensor nodes thus creating early routing holes. In the second part of this our study energy efficient hierarchical routing is proposed that places partial burden of cluster head selection for each iteration and the network formation for each iteration on the servicing UAV for that particular cluster based network. A prominent feature of the hierarchical gateway routing protocol is that instead of using the traditional cluster head based on distance like the k means algorithm this study employs the concept of energy centroid nodes (ECN). The ECN node calculation presented in subsequent chapters has proven to be more effective in helping to minimize the network holes that generate in routing processes for hierarchical protocols.

To the best of our knowledge the techniques presented in this study for both the objectives i.e. deployment and routing will act as the foundations for UAV based deployment and energy efficient routing. Routing results presented here in this study indicate a great success in offloading partial calculations to the servicing UAVs to enhance network lifetime. Examining figure 1.2 it shows a heterogeneous network of sensor nodes. The network is divided in clusters based zones where each zone is serviced by the servicing UAV. The cluster/zone head takes the responsibility of data aggregation from the member nodes in different rounds during each iteration. Some of the cluster member are advanced nodes such that they are equipped with higher computational, storage and communication hardware. Some of the nodes are basic nodes. In a real time deployment scenario some of the nodes will fail to become part of the network but they are present on the grid. Such nodes are mostly ignored in many hierarchical routing protocols but in this study we device a technique to service these orphan nodes using gateway nodes. Each cluster member is allowed to behave as a gateway node for such nodes that have data to send to the control center but fail to become a member of a zone. Also in the figure 1.2 each zone is controlled by a energy centroid node called the ECN node. The concept of the ECN node is such that for each round in the routing process the ECN node is identified and the calculations are carried out by the servicing UAV. The ECN node performs the same function as that of the cluster head nodes used in the hierarchical routing protocols. Selection of the cluster head node is different from the selection of the ECN node. Each node in the hierarchical routing calculates a random value that determines weather a node in the cluster will be cluster head or not. This causes rapid jumps in the cluster head selection and zone formation however with the use of ECN node the transition of the energy centriod is gradual which keeps the zone formation over a longer number of iterations.

1.3 Motivation

As discussed in the previous section that routing is a crucial component in wireless sensor networks. Developing an energy efficient routing protocol that extends the overall network lifetime is an important objective. In this study we analyzed that providing maximized coverage along with energy efficient routing extends the routing protocol even further. Therefore our motivation in this study increased from not developing an energy efficient routing but maximizing coverage in the sensor network at the same time. The EHGR protocol achieves both of the objectives with the overall coverage of 98% due to which the throughput of the network is also increased. The coverage of the nodes is maximized by developing line of sight and non line of sight communication model and then by applying device to device relay based nodes to that provide extension in the connectivity.

Another factor that has motivated us that the existing routing protocols are placing to much burden on the sensor nodes in the network setup phase due to which the overall network lifetime is reduced. In LEACH protocol the nodes participate in the selection of the cluster head in each round, in the GCEEC protocol the nodes not only calculate cluster head but also the selection of energy centroid nodes is done by the same nodes these calculation reduce the network lifetime significantly due to complex computations. Hence it is necessary to develop a routing protocol in which the burden of network formation is not placed on the nodes. In the EHGR the burden of network formation is placed on the servicing UAVs and only data collection and data forwarding is done at the node level. Although in the literature review the problem statement and research questions have been addressed in light of the state of the art literature however a statement both are presented in this chapter to highlight the significance about the problem that we have just discussed in the motivation and research contribution.

1.4 Problem Statement

In light of the literature review the problem derived is that given a certain number of Iot based smart devices or sensor nodes in a heterogeneous wireless sensor network having a certain number of UAVs how can we efficiently provide coverage to all the nodes deployed such that the data is collected by all the nodes and no node having data for the control center is left behind? Secondly how to route in an energy efficient manner such the network lifetime is maximized and minimum burden is placed on the sensor nodes?

1.5 Research Questions

Research Question 1 How to use deployment algorithm efficiently in a UAV assisted WSN such that the coverage of the nodes is maximized.

Research Question 2 How to route data between nodes in an energy constrained environment by optimizing power to increase network lifetime?

Chapter 2

Literature Review

2.1 Introduction to Wireless Sensor Networks

A sensor network is a collection of smart IoT enabled nodes grouped together and deployed in the application domain to deliver data gathered from surroundings to remote control centers for pursuing further analysis or actions. In the early 2000 feasibility studies were initiated by researchers to demonstrate the use of WSN in everyday applications. Two decades after the WSNs have become a part in almost every single application domain such as medical industry, remote patient monitoring, farming, surveillance, military, construction, package deliver and smart cities. The integration of WSN is now a reality for all the mentioned domains. The primary reason behind the adaptability are the smart sensor nodes. The sensor nodes have gone through a significant change in terms of engineering modules that have been integrated to it. From a simple mote having few kilo bytes memory and limited processing capabilities and limited communication range the modern sensor nodes are network communication enabled with multiple standards support, have greater processing capabilities and posses large storage. In addition the modern sensor are considered to be smart meaning that the nodes are not only equipped with multiple sensors that take sensed data to the remote control center but also they are equipped with transducers that allow the nodes to take necessary action in the environment where they are deployed through IoT based smart gateways [7] [8].

Current industrial revolution as pointed out by Majid et al. in [8] has made it possible to produce smart sensor nodes that can perform a wide range of functionalities with reduced computation, storage and communication cost.
Sensor nodes can be basic nodes called motes or they can advanced nodes having multiple capabilities integrated on a single chip. Through out this study we have made an assumption the sensor nodes are advance sensor nodes. Advance sensor nodes have greater hardware capabilities as compared to basic nodes and are more expensive as compared to basic nodes.

2.2 Challenges Faced by State of the Art Wireless Sensor Networks

IoT networks are dominating in every application domain due to which wireless sensor networks have become the favorable choice for networking in real time applications due to cost effective and economic deployment, cheaper computation and greater agility as compared with the rest of networks. However the wide adaptability of WSNs still face a lot of challenges. A few of the prominent ones are highlighted as follows.

1. Limited Energy

Sensor nodes have a short life and much of the energy is dissipated when the node receives or transmits. Generally it is assumed that the energy required to receive/transmit 1 bit of data is equivalent performing 3000 cycles of computation. During network formation and maintenance phases the energy of the nodes is further wasted since nodes need to discover the cluster heads or maintain adjacency tables of the neighboring nodes. Once a sensor nodes depletes its energy the network formation is broken and the remaining nodes have to rework tables and routes towards cluster heads which further reduces the overall network lifetime. Keeping this in light researchers have proposed many energy efficient protocols for data transmission, routing procedures, deployment and network formation improvement to over come this challenge [9].

2. Dynamic Nature

The WSN is dynamic in nature since the network faces continuous changes. Old nodes die due to which new nodes are added. The new added nodes require new routes and paths to reach the destinations. The network topology is continuously facing changes due to which every node accommodates updates. The challenge for researchers is to design protocols that determine the efficient and cost effective paths to reach the destination in these dynamic situations [8, 9].

3. Routing Holes

The wireless sensor network accommodates continuous changes in topology and deployment of the sensor nodes. Sensor nodes that are deployed in the application domain sense data and transmit it to the control center placed near by. The network is arranged in a topology which requires continuous management of the topological structure for example in cluster formation sensor nodes have to calculate the cluster head that will route the data to the control center in each round. Similarly for nodes that use next hop neighbors to reach the control center maintain adjacency tables of the next hop in route towards the destination. The adjacency information is updated periodically and all the nodes must participate. These extra calculations drain the battery of the sensor nodes. When the node dies out a routing hole is created. Approximately 90% of the routing paths faced this problems as higligthed by Mohemed et al. in [10]. The remaining nodes have to rework the path due to this situation. A major challenge for a WSN is to design energy efficient routing protocols that overcome routing holes and extend the network lifetime. In this study the routing hole problem is further elaborated in the next section that covers hierarchical routing protocols.

4. Optimum Deployment

Deployment of sensor nodes in the application domain impacts the connectivity and the network lifetime. Optimal deployment leads results in maximum utilization of limited resources such as networks bandwidth, battery power etc. Researchers have provided many techniques to tackle the optimum deployment of sensor nodes.

These techniques according to [11] can be classified according the following broad categories: i. Random deployment ii. placement strategies iii. Usage based deployment iv. Indoor / outdoor placements iv. AI based deployment approaches. Mostly the sensor networks adopt a cluster formation to group nodes within cluster. If the deployment strategy is overlooked then some nodes are unable to join any cluster due to which relaying information to the control center becomes a challenge. In this study we use gateway based relay nodes to overcome this situation.

5. Privacy

Since WSN have become an active industry with large scale integration of smart devices and sensor nodes that are used in almost every aspect of our routines. These node contain important information related to human activity that can be exploited by various means. In tele-medicine domains where doctors monitor remotely the sensor nodes are used for monitoring patients and these node send the sensitive information gathered over to the doctors using wide area networks. This sensitive information can be exploited if in the worng hands as pointed out by [7]. Another challenge as pointed out by Jinfang Jiang et al. in [12] for sensor nodes is that to keep the node anonymous since it can be backtracked to identify the node that has generated the data and the entire scenario can be reworked. Keeping the WSN secure is therefore another major area in which the research is ongoing to tackle all possible cases where the WSN can be exploited against legitimate users.

Wireless sensor networks have become an active network industry with large scale production of smart devices that are communication and computation enabled. This industrial revolution as pointed out by Mamoona et al. in [8] has caused a shift in research paradigm and researchers from the previous decade onward have pointed out multiple techniques to integrate IoT smart devices into the existing WSN technology. From 2014 and onward it has now become impossible to separate the two since their aggregation has resulted a shift in automation, agriculture, transportation, medical, control, weapons industry.

2.3 Analysis of the TCP/IP Protocols Stack for Using UAV and Wireless Sensor Network

In most part of the world the research on drones is still in early stages. State of the art WSNs use unmanned aerial vehicles (UAVs) or aerial drones. The UAVs provide connectivity services, deployment services, data extraction services for the sensor nodes by hovering over the effected region. The area that is connected with a particular drones can also be considered a cell. After a careful analysis of the deployment region it is also possible to identify total number of drones that will be required to service an area completely. As pointed out by Azade Fotouhi et al in [13] the ability of the drone to hover and move in the coverage area can increase the distance coverage optimize the required throughput level.

Current development in the telecommunication industry have integrated un manned aerial vehicles(UAVs) in routine operations to assist in various tasks.In this section we examine layer by layer advantage provided by the UAV for the entire TCP/IP protocol stack all of which suggest that the furutre of WSNs will realy on UAVs side by side.

For **application layers** the UAVs collect data from the applications and transmit it to near by fog placements or data centers for further processing. Since the smart devices/ sensor nodes are energy constraint and if these nodes transmit data and request action it will drain the energy further. To increase the life time for these applications UAVs are deployed to collect data where multiple UAVs visit the exact node ready for transmission to the server and offload the sensor node. Data collection at fog nodes also require a routing strategy that is usually determined before the deployment of entire scenario. This approach has been adopted by Oman Bouhamed et al. in [14] and it has shown to improve the network coverage over preconfigured path. For applications focusing telemedicine, disease survallience, remote vaccine delivery, pandemic control data from biomedical implants and medical sensor etc. can be collected from sink nodes by the UAVs for enroute towards remote hospital control servers. Saif Saad et al. [15] used a UAV to based medical sensor network to predict fall detection using FDB-HRT prediction technique in elderly patients their work has demonstrated that the early prediction system integrated with the

UAV arrival at patient site is faster then the medical respone teams which saves approximately 32% time as compared with the traditional approaches.

In **network layer** routing is done and the sensor nodes transmit the data to control center. The wireless sensor network can benefit greatly to increase the efficiency for the routing process and increase network lifetime. In routing process the sensor nodes can reach the control center or the cluster head with the help UAV. The objective in wsn is to increase the network lifetime therefore partial or complete load balancing of topology maintenance, routing table updates, route discovery, cluster formation, neighbor discovery can be performed at the UAV end which will save much of the node's energy. In this study we have proposed a technique that partially balances the load of the routing processes to increase the network lifetime. Energy efficient routing using UAVs is a rich domain in which the routing protocols are designed in combination with utilizing multiple UAVs by researchers that target to increase network life time and balance the node energy a very good survey is provided by Petros S. Bithas et al. in [15] in which AI based taxonomy of UAVs based routing protocols is presented all of which are classified into supervised, unsupervised and reinforcement based strategies. The survey is unique since its presents recent 129 routing algorithms all of which are UAV based which suggest that the routing process of the WSN layer in coming years will functioning with UAV to increase network life time.

In the **media access (MAC) layer** network formation takes places and the physical network is deployed by placing the sensor nodes. Utilizing UAVs at the MAC the WSN can have a greater coverage. The placement of sensor nodes is very crucial optimum deployment can increase network lifetime and its coverage. Placing nodes optimally is an active research problem as indicated in [11]. Since UAVs are capable of hovering over the region of interest the coverage of the network can increase manifold. Some of the sensor nodes lye outside the region due to which these nodes are unable to transmit their data to the control center. Relay nodes can be used alongside UAV to reduced the rejection of such scenarios to a minimum level. In this study the optimum deployment of the relay nodes with the alongside UAVs are utilized to reduce rejection of the sensor nodes. The results presented in this study are promising that through gateway nodes the UAV coverage can be increased over 25% as compared to the existing literature where the maximum connectivity is limited at 73% to 75%.

2.4 Application Domains for UAV-assisted Wireless Sesnor Networks

Multiple application domains exist that are being revolutionized by utilizing unmanned aerial vehicles. To name a few:

2.4.1 Application Domains

(i) Coverage extension for rapid deployment

(ii) Disaster zone recovery and public safety

(iii) Rapid ground base stations and data offloading

(iv) IoT based communication using aerial drones

(v) Smart City

(vi) Serving applications with high bandwidth requirements

(vii) Drone as supply chain

(viii) Transportation

With the advent of 5G based smart devices the requirement for bandwidth is always increasing. The existing cellular networks are resource constrained and due to this abundant of other network technologies have risen to the picture in-order to fill in the gap and to satisfy the demands placed by various applications such as WiFi hot-spots for device to device communication, ultra dense small cell networks (UD-SCNs) used in next generation networks by G. Yang et al. [16], Millimeter wave providing tera-bit rate (Tbits) for vehicular networks by K. Z. Ghafoor [17] are few of the well known latest technologies.

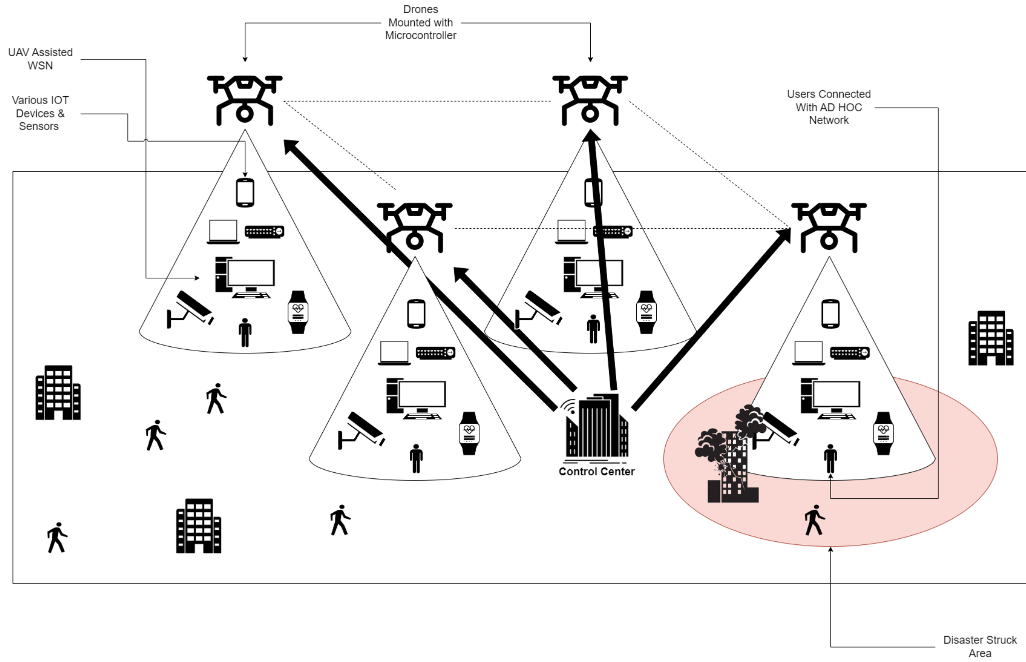

FIGURE 2.1: Deployment of UAVs in for coverage extension

2.4.2 Coverage Extension for Rapid Deployment

Although these technologies have limitations of their own integrating UAVs will add further challenges and new requirements will be considered for the future of next generation networks.The new challenges will also provide an opportunity window to extend the communication range to points where normally it would have been difficult. Figure 2.1 depicts multiple possible situation where communication range is required to be extended but in some of the regions infrastructure is partially or completely destroyed. Using drones might be the only possible options and as it can bee seen that part of the area can not be covered due to limitations such as terrain, climate etc. Using low altitude and high altitude based drones in a rapid deployment situation VoIP, bandwidth aggregation during public processions, live matches, vehicular networks and disaster zone recovery as discussed in [18, 19] are a few latest research that advocate UAVs for future applications. In some of the cases as depicted in figure 2.1 it can be the case that the bandwidth falls short due to increase in the number of devices connected in different zone again to provide connectivity and data transmission facility to maximum number of devices UAV deployment will be only options to provide network extension.

2.4.3 Disaster Zone Recovery and Public Safety

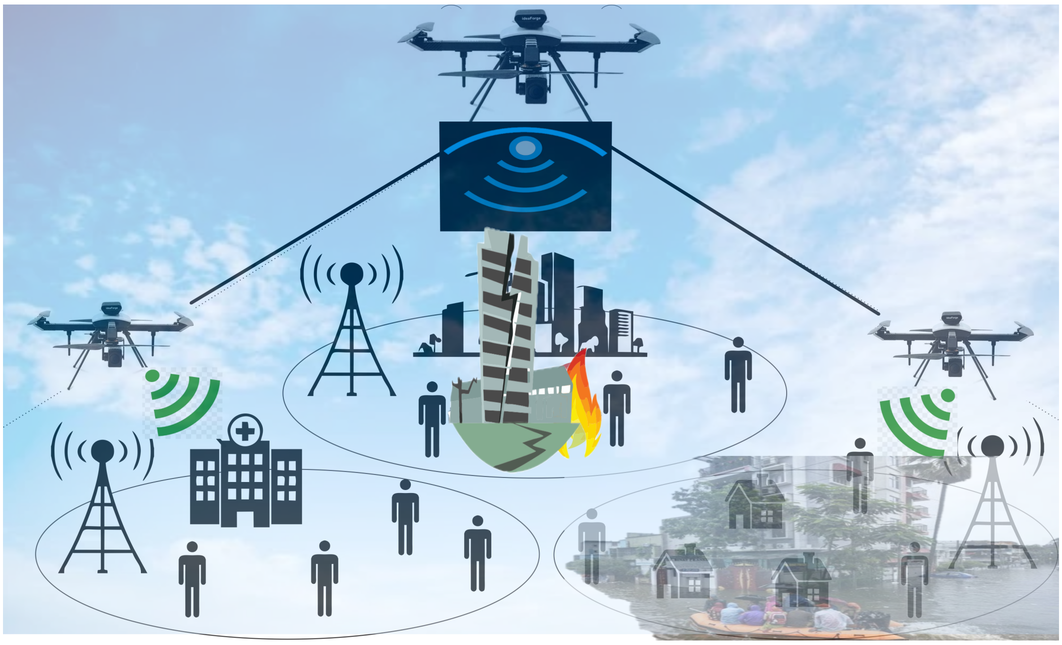

Figure 2.2: Deployment of UAVs in disaster regions to provide communication services

Disaster zone communications is one the most researched areas of wireless networks. Recent usage of drones for disaster zone recovery has led to the start of a new dimension that is attracting reach in this direction. If we examine Figure 2.2 multiple regions hit by natural disasters are observed where there is communication outage in the areas in these scenarios aerial drones can be deployed to provide coverage to the stranded users. Various drone will be used to provide services to the most suitable candidates i.e. those candidate that can achieve maximum data rate from the particular drone with which the user equipment is establishing association. Once the connection has been established the drones in the affected will relay the data to the back haul base station by using data forwarding to drones one level above it for global coverage. Furthermore in the event of a natural disaster such as hurricanes, tsunami, earth quake and man made disaster the entire area looses communication [20–22] and in such scenarios deploying a system of drones to act as a base stations that are used for data forwarding of stranded users is the main purpose of disaster zone recovery. Stranded users can communicate with each other using aerial deployments these deployments can be temporary and can aid the existing cellular networks where bandwidth requirements are increasing. Rescue teams and volunteers also use these services and therefore demand for increasing bandwidth based applications are the latest research trends. Aerial deployments in such scenarios focuses on providing communication services and at the time many researchers have classified traffic in such scenarios due to bandwidth limitations e.g. the emergency traffic should be routed with minimum delay where as normal traffic where stranded users want to inform their loved one about their status can be momentarily blocked in case if rescue workers are facing communications issues due to the scarcity of available bandwidth.

2.4.4 Rapid Ground Base Stations and Data Offloading

In situations where the network is mobile and the the senders and receivers are moving with high speed such as in vehicular networks the drone based networks provide connectivity for data forwarding between vehicles. Similarly data offloading from mobile sensor nodes based on some task similarity to nearby computing sites to increase the sensor network capacity and its life time is another usage area where aerial drones play an important role increasing network efficiency and lifetime. Task offloading can also be used in case where the task its self requires heavy processing power exceeding the capacity of the sensor nodes such video surveillance[23, 24]. In vehicular networks where cellular coverage is weak the use of aerial drones can improve connectivity of D2D interaction and specially if drones are being used to surveillance purposes on the highway or deserted tracks[25].

2.4.5 IoT Based Communication using Aerial Drones

Internet of thing is perhaps a futuristic networks still in its early stages that will eventually encircle every thing that we use, wear, communicate with, eat with store with and will become an umbrella network. Small gadgets each with its unique identification [26–28], sensor, actuators, data processor and network interfaces connect with each other without any human intervention to make our lives, businesses and environment more informed, intelligent and productive. The small sensor nodes used in IoT communicate with one another and in environments that might be un accessible by human beings for daily access. Using aerial drones in such scenarios where network coverage is not strong can improve the IoT system. IoT based network application generate terabytes of data and can place limitations on the existing networks in terms of bandwidth availability[29, 30]. These situations advocate the need for drones that will solve the problems faced in most of the scenarios. Similarly communication of different networks with the IoT based systems also require seamless connectivity and data routing where e.g. a user might be handling his home based network from his vehicle. Data routing from VANETs to his home requires complex forwarding using drones for such communications might help the user to stay connected with his home networks.

2.4.6 Smart City

Smart city[31] has a growing demand on communication infrastructure. The applications documented over the years targeting smart cities are tremendous but all have network communication in common. Similarly IoT will become the hub of future smart cities. Drone deployment in smart cities can be used for data collection from various regions of the city and later send it to a remote for analysis. Ad hoc aerial drone systems can be deployed to scenarios where bandwidth requirements have increased momentarily[32, 33]. Similarly fog computing using drones for scenarios where task offloading is required in smart cities is another area where the application scenario can benefit greatly from the usage of drones.

2.4.7 Serving Data Hungry Applications using 3D-MIMO

Explosions of smart phones in the recent years has generated a demand on variety of application's services that are multimedia based such as social platforms and live streaming platforms. Channel capacity can increase with the addition of multiple antennas on board and therefore today UAV based base stations are equipped with multiple input and multiple output antennas[34]. Use of multiple antennas allows for beam forming and diversity but the beam is only in the downward direction whereas in the real 3D features are involved. In real world where users in a zone are distributed in a 3D zone the beam tilting feature in 3D improves the overall throughput. This fact can be seen in Figure 6 where the UAV on top left mounted by an array of multi dimensional antennas is providing connection to the base station towers and the installation facilities such as factories where bandwidth requirement has increased. This way users can communicate with each other via system of UAVs even if the cellular networks falls short of the available bandwidth. 3D based MIMO are adopted in the latest technologies such as LTE deployment that can be seen again in Figure 6 depicts MIMO coverage using UAVs with beam forming techniques. Major applications scenarios today focus on using aerial drones that exploit 3D MIMO based infrastructure due to its high coverage rate.[35]. Mohammad Mozaffari et al. in [36] used quad rotor as an aerial antenna array to service ground users in minimum time frame and also reduced the control time required to position the drone to the optimum location. To determine the optimum position perturbation technique is used and then after the calculation of drone spacing each drone is able to adjust the antennas according to ground users. Antenna array for drones have numerous benefits over the conventional antennas such as higher gains through beam forming and better beam forming due the drones movement capabilities. The reason is that through multiple antenna arrays simultaneous data streams can be established between the ground users and the aerial drones this concept increases the spectral efficiency. The number of antennas can range from hundreds to thousands while at the same time reducing small scale fading and transmission energy. Multiple scenarios exist in which aerial drones if deployed can increase spectral efficiency at pointed out by Irfan Ahmed et al. in [37].

2.4.8 Drones as a Supply Chain

Major business are starting to consider the user of aerial drones as a support for their supply chain needs. Companies like Amazon have already started to deploy drones for package deliver. Similarly from logistic point of view aerial drones can reach greater distance with lesser cost for companies[38, 39] also some companies will be focusing on hybrid technique where UAV will be used to cover maximum distance and then the packages will be offloaded to a delivery truck[40]. Movement and tracking of orders or industry inline items to be used as a part in an end product is another daunting area that requires a lot of man power to keep track off. Using drones for warehouse item tracking and identifying parts to be used in an assembly line will become easy to manage used drones based techniques[41].

2.4.9 Transportation

The aerial drones have shifted from *"just observe and don't touch the surroundings"* to be able for their use in moving object in the real world [42]. Their ability to grasp has gained momentum in the transportation industry.

The gripping technology of the drones have increased over years and this has led many researchers in developing light weight and economical mechatronics grippers for UAVs that also preserve battery power to be used for transportation purposes [43]. In the years to come the drones will become a smart choice to transport good in a controlled and open areas. This is due to their ability to move in the 3d space. In [44] Ruggio et al. mentioned two ways which can be used on drones in transportation one in which the grippers can be mounted on the drone and the other in which a separate arm like extensions can be made to the UAV to perform more complex gripping.

In the future hexa rotor drones will be used having multiple grippers and offering more stability and payload functionality for the applications.

2.4.10 UAVs State of the Art

In this section we examine the latest state of the art deployments considering UAVs in areas such as defense etc. Providing seamless network connections is a requirement for all networking scenarios weather in civilian or military application domains. X. Li et al. in [45] provided a model for improving energy efficiency in order to provide seamless connectivity to the densely populated urban cells. Their concepts uses rechargeable aerial drones. The drone having limited residual energy return to the charging station and in the mean time another drone fills in the vacated position to carry on network services. The authors have proposed an optimization technique that is solved using particle swarm optimization algorithm. Yixuan L i et al. in [46] implemented a logistic based scenario which is one of its kind for aerial drones where the objective is to increase the degree of satisfaction by hitting all the targets for package delivery destinations. The authors in [46] have considered the load that the UAV can take as a utilization factor to be calculated along with the flight path and the number of UAVs available. Another notable work done in UAVs usage as a flying ad hoc networks (FANET) is done by Jingjing Wang et al. in [47] where the authors have surveyed the existing protocols available for utilizing UAVs massively in any network environment. The authors have also suggested protocols by different authors at various levels in the TCP/IP protocols stacks to be used for FANETs.

2.5 Approaches for UAV Deployments in Disaster Regions

Research related with the UAVs deployment in WSN disaster regions can be divided into the following categories.

1. Cluster identification-based techniques
2. Path planning approaches

2.5.1 UAV Clsuter Based Deployments

Deployments of wireless sensor networks focus on establishing networks in isolated regions in disaster zones. These networks focus on establishing sub networks (i.e cluster) which are designed to maximize network lifetime. This natural alignment has led researcher to focus on clustering techniques while solving problems related to the optimum deployment of UAVs in disaster zones [48–50]. Nodes in WSN can be organized in clusters according to the

1. Identifying task similarity regions.
2. Routing data of different clusters based on company policy or preference characteristics like bandwidth, latency, privacy etc.

3. Bench marking data generated from different clusters with in a zone for scheduling requirements.

4. Designing routing algorithms at the network layer for energy efficient forwarding and routing towards destination.

Clustering techniques try to achieve similar groups of multiple nodes according to the Eculidean distance between nodes, task similarity, processing capability, demographics etc. [51]. Clusters reduce dis similarity between candidate groups. In wireless sensor networks clustering can be beneficial to increase the network life time as indicted by Wendi Heinzelman et al in [52] as compared to non cluster approaches. Cluster based approached optimize energy consumption of the overall network ensuring that the limited resources are optimally utilized and allocated only in the designated group [53]. Every cluster is composed of several nodes that exhibit similar features such as distance, energy, temperature etc. and a cluster-head [51, 53, 54]. The nodes select a cluster head which is a node having greater processing power, energy etc. compared with the rest of the nodes with in that group. Cluster heads communicate with each other to route data on behalf of the member nodes. Cluster formation can be centralized or distributed. In centralized approach the cluster nodes and cluster heads are formed through a central entity such as a server that collects all the information and than makes clusters and communicate it to the entire group. Centralized cluster approaches for wireless sensor networks such as in [55] by Hassan Echoukairi et al. have shown to increase the network life time. In distributed clustering [51, 53, 54] all nodes perform the calculations locally to identify their clusters and cluster heads without any help from remote control centers.

Fen Cheng et al. in [48] have tried to maximize the number of connected user devices to be served in a disaster zone. The network is established with a simulation of 200 sensor nodes that are uniformly spread in a 200 by 200 meter-square. Two UAVs at the 100m height are used at with the UAV capacity of 8Mbps i.e connecting 16 users. To increase the number of users that can be served in a disaster zone with the UAVs reaching its maximum capacity the authors have proposed two solutions **i.** Clustering approach **ii.** Relaxed optimization approach. In the first clustering

approach the 16 nodes that (8 with each UAV) are connected with UAVs are used as a device to device (D2D) service points. The nodes that are not having any connectivity (i.e the reaming users) will calculate their distance with each one of 16 nodes initially treated as the equal number of K=16 clusters each of these K points also being a cluster center for the rest of users. The UAV-connected devices can be treated as a vector for each individual UAV. The remaining devices that are not yet connected will request to build association with the UAV-connected devices from which they calculate the minimum distance while also satisfying a quality of service threshold. This will increase the number of connected devices. In the second approach the binary variables are relaxed and treated as continuous values ranging from 0 to 1. Here again the optimization scenario is kept same as that of the first scenario with the difference that the variables are treated as continuous to achieve sub-optimal solution. The results indicate that the both the approaches achieve similar results in the simulations. The downside is that only distance is used a clustering approach. Networks parameters such as energy consumed of the overall network to increase life time, emergency distress nodes situations are ignored.
K. Kim and C.S. Hong in [56] used machine learning algorithm to gather data (task) by UAVs and found the optimal mobile edge computing server placed near by to offload the task. The mobile edge computing server that a UAV opts for is the one that will cause the UAV to travel minimum thus saving is battery life and also each UAV before opting for a MEC server will make this calculation. Also, every time when the UAV has a task to offload then the UAV recalculates its best choice of MEC server. Other criteria for optimal MEC sever selection is taking into consideration of the task queue load at the server and the CPU computation required by the task . Each UAV uses the Shannon capacity theorem to calculate the data transfer rate between the UAV and the MEC server for each task and also calculates the energy that will be consumed by the drone to first reach the task and than from task to MEC server and then back. Once these calculations are made the task clusters are identified using the k-means cluster approach. Each cluster is a one on one mapping between the UAV and the cluster. Within the cluster the travelling salesman problem is adopted to calculate the cost of visiting each task by a UAV. This problem is then converted to Q learning method where action is the

selection of the MEC server considering the states. The reward function allocates higher value to the case where the distance travelled by the UAV is less while also considering the queue length and the CPU utilization at the MEC server. The entire scenario is simulated and the results are compared with the greedy algorithm. The results indicate a significant improvement in energy efficiency as compared to greedy algorithm. As the number of tasks increase to 80 and beyond the energy consumption increase thus draining the UAV of its limited battery life. However, the processing time is improved by one only 10 units and this remains fixed for different number of tasks.

The drawback in this approach is that network coverage and optimum placement of UAVs for achieving maximum coverage is not considered. The placement of drones for achieving maximum coverage is not considered also since cluster establishment is only on the basis of tasks. It can also be possible that each UAV can service two or more clusters from point view of clusters while also being close to the MEC server.

L.D Nguyen et al. in [57] proposed a technique for effective UAV placement and resource management. The K means clustering approach is used to determine the clusters based on the distances between the user equipment and the aerial drones. The Euclidian distance between the UEs and the drones is used for this purpose. The authors also propose and an efficient technique for energy optimization in the distributed drone's deployment system. Both air to air ATA and air to ground ATG channels are modeled. In the first phase the power received from the base station to the drone is calculated and the base stations calculates the down link MRT pre-coders which is a common technique used in massive MIMO based networks. The signal received by the drones from the base stations is forwarded to the user equipment and the throughput is calculated of each UE during both the phases, finally total end to end throughput of the entire cluster is calculated. Clusters of user equipment are identified using Euclidian distance and using their points on the gird. After the clusters are identified the drones placement is finalized accordingly by using the constrained clustering approach using the must link and must not link constraints using the path loss threshold.

The proposed algorithm provided by the authors tries to calculate the optimum

number of UAVs to be placed for m clusters. In order to increase end to end throughput for each cluster the exchange of information between UAV and the BS about the UEs and their power allocation takes place and for each cluster the algorithm proposes a power scheme for the power coefficients variables while fixing the control power coefficients for other clusters fixed. Varying number user equipments are considered in the disaster zone while the size of the disaster zone considered is up to 2000 meters while each cell has a radius of 500 meters.
The simulations indicate that the system has fast convergence with just 8 iterations with 200 user equipments and 48 UAVs. Similarly, the time required for cluster identifications and deployments for the same scenario is just 45msec. The execution time is compared in the last which indicates that distributed computing for optimal UAVs placements calculations out performs the centralized computing approach by more than 25 percent.
Table 2.1 presents latest approaches that involve the use of UAV in their deployment for their state of the art applications. These are general approaches and cover the deployment aspects and the routing for wireless sensor networks.

TABLE 2.1: State of the art UAV deployment approaches

Ref.	**Technique**	**Parameters**	**Key Features**	**Observations**
[48]	K-means clustering & Relaxed optimization.	Bandwidth utilization = 23.5 % (Clustering) & 24 % (Relaxed optimization)	Coverage maximization in disaster region.	Low coverage in D2D routing. Two UAVs are used but rejection increases as UAVs are added.
[50]	SVM with Quadratic Kernel. Linear Regression.	Packet transmission Prediction error = LR (1.71%, .228%) LR4th,LR7th respectively.	Prob. of data delivery calculated to predict success/failure. Monte Carlo Simulation data points are used to train LR and SVM-QK.	For Time varying UAV network routing between UAVs is un predictable.
[58]	Decaying deep Q network	UAV energy reduction of 11.7% using NOMA	Use of RIS on UAV to increase connectivity in LoS & NLoS links. RIS reflections increase connectivity	Mobile users increase number of states increase decreasing the convergence time of the network
[59]	ML contract theory approach b/w UAV and BS.	10% reduction in weighted mean error. 4 * increase in throughput to normal BS throughput	WEM to predict hotspots for distribution of users and traffic demand and assist base stations for data offloading in congested zones.	Contract policy can not be utilized in a real scenario as its focus on one principle and multi agent having no competition between competing UAVs and BSs.

Ref.	Technique	Parameters	Key Features	Observations
[60]	Path loss model with LoS and NLoS. Bisection search algorithm.	(a, b, ηLoS, ηNLoS) Different combination pairs used in deployment of UAVs in different regions	Prediction of UAV deployment in a region by adjusting environment parameters to assist in data offloading	The placement of UAV for increasing network revenue decrease drastically as the obstacles increase as in high rise urban area
[61]	Game Theory approach with LoS and NLoS	73% increase in throughput. .1% blockage probability.	Deployment of UAVs in disaster hit areas. Improving channel access with GT to accommodate high priority data.	Decrease in throughput as the number of UE increase. Single UE tries to associate with multiple UAVs.
[62]	ML based Genetic Algorithm for UAV deployment. .	The chromosomes are the coordinates of all the UAVBS	21% increase in throughput when 50% of the BS are destroyed. 176% increase in throughput when 97% of the BS are destroyed	Increase in traffic density cause throughput to decrease. Scenarios of high priority traffic in a disaster zone needs to be considered.
[62]	K-means clustering.	10% increase in network coverage. 9* Reduction in energy dissipation of UAVs	Efficient placement of UAVs(ABs) to map UEs in a disaster region while observing QoS parameter i.e. Energy of ABs	Central dependency on a node. In case the user density increase the overall approach is compromised since the decision has to be central.

Ref.	Technique	Parameters	Key Features	Observations
[63]	K means clustering for PSN	40% Gain in throughput with Kmeans-GW. 15% Gain in energy efficiency	Efficient placement of the UAVs in PSN & energy efficient routing.	Inclusion of multiple UAVs reduce the network throughput reducing coverage.
[64]	Mean phase shift algorithm.	14% increase in task collected after visiting 35 locations in 10 UAVs.	Tasks are identified prior to deployment of UAVs in disaster region on a certain path.	Increase in task cause increase in interference between UAVs.
[65]	Stochastic learning automata & joint optimization.	Fast network convergence.	Multiple UAVs and relays to increase network bandwidth in D2D networ	Throughput decreases as UAVs are increased. Maneuverability of UAVs can increase throughput
[66]	UAV-Artificial bee colony algorithm. Euclidean distance calculation between UAVs and UAVBSs.	50 to 400 Mbps higher as compared to PSO,Greedy algorithms. 580 seconds faster network convergence as compared to DI-PSO	Post disaster deployment of UAV increase network throughput and reduce deployment cost. Continuous improvement of fitness function to determine the optimum position of UAVs.	Throughput decreases as the number of UAVs increase since the flight path & placement decisions are server based.

2.5.2 Path Planning Approaches

Research trends in the UAV deployment in disaster regions indicate that the focus has shifted towards determining a collision free path for the UAVs [67]. Path planning is an important step to establish a reliable forwarding services in order to reach destination. 2D algorithms that deal with path planning in disaster regions are not sufficiently usable in the 3D domain due to multiple parameters such dimensionality, physical and temporal constraints. With the use of multiple UAVs the 3D mapping of the association between user equipment and the UAVs become even more challenging. That is why multiple techniques focus on improving the trajectories of the UAVs system to increase network coverage [68].
In the following path planning categories with state of the art research are presented.

2.5.2.1 Conventional Algorithms

In [69] the authors have used a conventional rapid random tree approach to determine the ideal path towards the destination that the UAV will adopt in presence of 20 obstacles. Path planning is achieved in advance with the objective of identifying collision free zones. A multi state tree is generated to list all possible options satisfying the probability fitness function.Rapid random trees are most suitable in cases where there is high unpredictable or changing environment. Another famous conventional approach adopted by authors [70] in which potential field algorithm is adopted to identify collision free path. The UAVs are stimulated as particles reacting in the potential field. Potential field algorithm is low in complexity in terms of computation. This approach helps in establishing a collision free path in case of hidden obstacles. The authors in [71] adopted a voronoi algorithm approach to identify a collision free path to reach destination in 20second. This methodology adopts a chebyshev arrangement in the disaster region. Faculty and non overlapping UAV leave the system while healthy once join periodically.

2.5.3 Cell Based Algorithms

Xijian Zhong et al. in [72] proposed a D2D UAV network in which the path towards the destination is established by calculating the cost of each path using

A start algorithms. Benefits of the A star approach is to avoid dead ends in the trajectory.The benefits of using cell based algorithms is the lower cost involved in reaching towards towards destination as compared to genetic or greedy algorithms. The D star algorithms calculate shorter path lengths towards destination in comparison to A start. D star algorithms also identify emerging obstacles known as popups better then A star. Authors in [73] use another well known Dijkistra algorithm approach to determine the shortest path to reach the destination in a disaster zone. The algorithm works on nodes and edges where each edge has a cost and the objective to find a group nodes connected with edges towards destination having minimum cost.

2.5.4 Model Based Algorithms

Model based algorithms identify the environments to gather values like receive signal strength, distance, images etc. to determine the collision free path for the UAVs. Model based algorithms are divided into mixed integer linear programming, mixed integer non linear programming models. The authors in [74] used a MILP technique for path optimization and identifying the UAV trajectory towards destination using just one UAV. In [75] a non linear technique is presented where a specific target it tracked. The authors have shown the improvement that MINLP can have over MILP based approaches.

2.5.5 Learning Based Algorithms

Learning based approaches to identify UAV flying path are similar to how a human would make a decision in real time. In 1995 the first neural network was presented by Glasius et al. The proposed work by Glasius identified targets and also the obstacles to reach a given destination. Neural networks since then have been used in UAV path planning mission where different trajectories are identified for the disaster region. The authors in [76] presented an improved neural network system for a system of UAV in 3D environment that has a high recognition speed. In [36] a neural network based path planning is achieved for surveillance and security. The proposed network minimizes the processing requirements and reduced computational cost.

Evolutionary algorithms focus on improving the various factor of the disaster region by resembling a natural phenomenal. The objective is to optimize fitness function values that aid in identifying weather an obstacles exits or not and achieve a collision free path towards destination by maximizing different components such as cost reduction, energy reduction etc. Ant colony optimization is a nature inspired technique adopted to mimic ant movement. The authors in [38, 39] have proposed a similar technique to find the shortest path the UAV will cover to reach the destination.Similarly particle swarm optimization techniques, artificial bee colony approach are also recent techniques that focus on natural sequence of event to identify a path for the system of UAVs. The limitations of the nature inspired approaches is the convergence times.

2.6 Routing Protocols of UAVs-assisted WSN in Disaster Regions

Faults in wireless sensor networks can arise due multiple reasons such as dead nodes whose batery life has finished or natural calamity that has disrupted working of the WSN. In such situation the smart device / sensor nodes can lose network coverage partially or completely. In such scenarios the control center can establish the extent of damage by analyzing the number of smart devices that need connectivity through traffic heat map software tools that indicate the required number of UAVs to disperse for covering the entire region. In 2014 Jó Ueyama et al. [77] presented their study in which UAVs are deployed over the disaster hit WSN to increase the resilience. The authors use a terrestrial WSN with communication micro controller embedded to the UAV in which the sensor nodes provide information about urban flooding. The work done by Gurkan Tuna et al. [78] use UAV for poster disaster monitoring of the WSN. The post disaster activities for the un attended WSN presented by the authors allow the rescue teams to gather important data to asses the situation. The table 2.2 presents the taxonomy of the division of the hierarchical

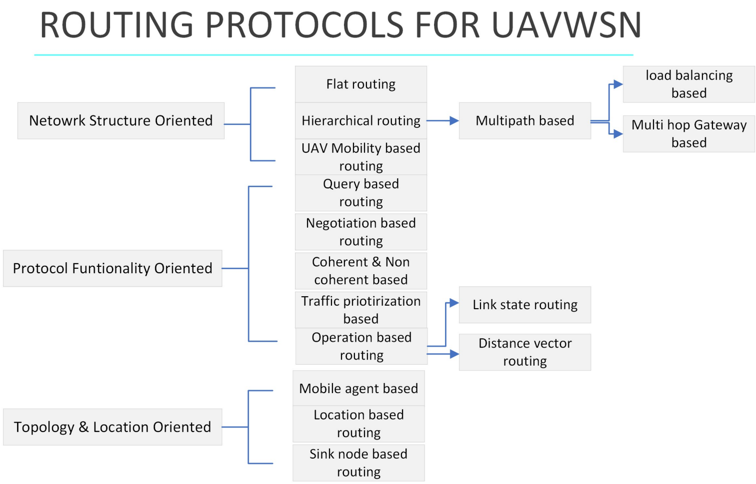

FIGURE 2.3: Routing protocol summary for UAV assisted wireless sensor networks.

routing protocols divided into multiple categorizes i.e., flat routing protocols and the hierarchical routing protocols.

TABLE 2.2: Taxonomy of routing protocols for WSN

Taxonomy of Routing Protocols for Wireless Sensor Networks			
	Structured Oriented		
Flat Routing			
Flooding based			
Gossiping based			
Information negotiation based			
Application aware directed diffusion			
Gradient based			
Optimized link state			
Hierarchical Routing			
Cluster Based	**Tree based**	**Multi-Hop Gateway based**	**Multi-Hop Gateway & Load balancing**
Grid cluster, Chain cluster, Block cluster, Scalable energy efficient cluster, hierarchical cluster, k-means, k-nearest neighbor	UAV enabled aerial data collection, Location aware, UAV sink node based, UAV based data diffusion & compression	C-SSA cat (CSO)-slap(SSO) swarm routing, SI routing using GWO for path selection, Self organizing multi-hop routing, Energy aware multi-hop routing EMAR	Energy efficient hierarchical gateway routing EEHGR

2.7 Routing Inside UAV-assisted Wireless Sensor Networks

Table 2.3: Table highlighting state of art flat routing protocols

S#	Protocol Category	Key Features	General Observations
[79] **Ant Col-ony**	Flat routing Evolutionary algorithm	Ant colony distance based energy efficient routing. Multi hop relay.	Rapid creation of hotspots which increases routing holes visiting multiple sites on the optimized calculated route. Reduced network lifetime.
[80] **PD-OR-P**	Flat dynamic source PDORP routing. Hybrid of DSR & PEGASIS	Reduction of communication distance using multi dimensional transmission scheme which increases energy efficiency of the sensor network. Peer list generation to receive no acknowledgment packet to further improve node's lifetime.	Protocol failure for alternate path calculation. Not suitable for dynamic real time situation. Calculation overhead to generate peer list.
[81]	Flat routing for UAV assisted WSN border survalliance	Deployment of UAV to determine human border crossing. First layer of sensors sense human intrusion and second layer uses multimedia through UAVs to inform control center.	Rapid reduction for WSN lifetime as number of human intrusions increase.
[82]	Flat routing for UAV assisted WSN node deployment	Deployment of sensor nodes through UAVs and path identification using the the vehicle reporting problem VRP. UAV follow a path to visit each destination which save nodes battery life.	Although network extension is an objective but multi hop routing is not used which limits the networks reach ability to the radio cover of the sensor nodes on specific path.

6th generation and beyond networks address communication and energy issues of wireless sensor networks in emergency disaster regions to support time sensitive connections. Advancements in the 6th generation networks and beyond advocate Ultra reliable and low latency use based data driven unlimited connectivity between sensor nodes, IoT smart devices, hand held user equipment maximized network throughput and abundance of energy [83]. These networks will allow sensor nodes to communicate with each other in an infrastructure less manner. Application requirements are increasing continuously such as use of interactive maps, video streaming etc. Supporting multiple sensor nodes/IoT devices to communicate and route data from one point to another in the WSNs the network layer continuously witnesses improvements.

The table 2.3 presents UAV assisted flat routing protocol summary as per the latest state of the art literature review that has been discussed in the sections.

UAV assisted IoT based networks are becoming a viable options for on demand routing between movable ground devices and non stationary nodes. The existing routing protocols have to be redesigned for UAV assisted WSN that can accommodate continuous change due to high mobility and rapid topology changes.

2.7.1 UAV-assisted Flat Routing Protocols

In flat routing nodes perform similar tasks and exchange similar information between nodes depending on the network architecture. Xun Liu proposed an optimal distance based ant colony algorithm for routing in WSNs in [79]. Network lifetime is increased using the optimal transmission distance calculation using ant colony optimization algorithm. Initially all nodes are evenly deployed with the same amount of the battery power over a circular grid divided in omega sectors having a single sink node. Most energy efficient distance is calculated for multi hop environment that ensures maximum energy preservation. Data is collected by visiting different sites/nodes moving from once sector to another. However the protocol presented adopts a many to one transmission approach where in such scenarios a hot spot is created which can drain battery of the nodes residing near the sink nodes thus reducing network lifetime [84] .

Gurbinder Brar singh et al. proposed Pegasis dynamic source routing in [80]. The protocol reduces the communication distance using mutli dimensional transmission scheme which reduces energy consumption of the nodes. Nodes further preserve energy by generating a peering list against which no acknowledgment will be sent for received data packets against the listed peers.

Cheng Zhan et al.distance based in [85] proposed energy efficient data collection flat routing technique tailored for UAV assisted WSN where the UAVs adopts a schedule of data collection from the sensor nodes. The UAVs hover over the sensor nodes on a predetermined path to gather data for the active nodes and deliver it to a near by control server. A non-convex mixed integer approach is adopted by to determine the ideal path through an iterative algorithm. Mohamed Lamine Laouira et al. presented a flat communication multi layer approach for a UAV assisted WSN in [86] to track human intrusions. Their work is divided into multi layer where the scalar sensor observe seismic activity and inform the second layer multi media sensors which use data fusion activities to inform the the nearby control center. The UAVs are manually deployed once the human activity is observed however the energy of the UAVs drain quicker as the number of intruder activities are increased as compared to the random deployment approaches.

Gomez et al. in [82] used a flat routing protocol for unmanned aerial vehicles for wireless sensor networks to acquire data from the centers to offload at a nearby control center. The path that the UAV will take is pre configured. The method proposed by Gomez et al. is used in locations where it is not possible for human to physically deploy the sensor network. The UAVs are used for the deployment purpose. Once the sensor are deployed the UAV follow a pre configured path to collect data from the sensor nodes. The sensor nodes are aware of the location of the UAV and turn the radio on only when the UAV is determined to be close enough. This technique increases the node's lifetime since the UAV visits each sensor that has data for transmission to control center. Since the UAV follows certain paths for data acquisition therefore multi hop routing is not used which further increases the node's lifetime.

TABLE 2.4: Review of the state of art Hierarchical routing protocols for wireless sensor networks

S#	Protocol Category	Key Features	General Observations
[15] **IRP**	Hierarchical progressive distance based routing	Threshold distance is used in which a node is allowed to send data directly to the sink node bypassing the CH.	The direct transmission generates routing holes rapidly.
[87] **GCE-EC**	Hierarchical distance gateway based routing	Selection of gateway nodes to reduce the burden of the CH. The nodes can use dual transmission by opting to send data directly to the ink node or use the CH. CH in turn uses the gateway node if the distance increases a threshold.	Computation performed by a sensor node are complex which reduce network life. Multiple CH in one zone which creates routing holes at a rapid pace. Since two cluster heads exist in every zone the interference at the MAC layer increases.
[4] **CAMP**	Hierarchical zone based multipath routing	Use of IRP for non cluster members to save the load on CH from sending data directly to the sink node.	Energy calculations performed are complex due to which delay in the routing process is greater as compared to LEACH. Divides the network in equal size of cluster.

[88] **MEA-CBM**	Hierarchical zone based energy efficient routing	Establish clusters and sub-clusters. Maintain network connectivity through multi hop relay for subclusters. MDC node is associated with each CH and calculates the optimum route towards the destination.	Establishment of sub-cluster drains th network energy rapidly and leads to reduced network lifetime.

TABLE 2.5: Review of the state of art Hierarchical routing protocols for wireless sensor networks

S#	Protocol Category	Key Features	General Observations
[89]**-TES-EES**	Hierarchical zone based energy efficient routing for heterogeneous network	Energy efficient routing IoT based wsn. Device makes decision to transmission using TMCCT algorithm to control un necessary drainage of batery power.	Relay node used for data transmission rather then network extension. Although network life is extended substantially as compared to leach based protocols but in real time ad hoc network this approach is not suitable as it ignore the coverage aspect.

[90]-**MRP-GTCO**	Multihop hierarchical zone based routing and game theory for coverage optimization in Iot based sensor networks	Use of relay for intra cluster data forwarding to the control centers. Uniform distribution of clusters so as to keep the energy dissipation from transmission to minimum. Placing game penalty on greedy nodes protecting their energy for not participating in the cluster head node selection phase.	With the use of optimized coverage strategy the algorithm the first dead node is reported between 800 to 1000 rounds. Similarly the last dead node is reported between 1200 to 1500 rounds.
[88] **ICR**	Hierarchical zone based energy efficient routing	Establish clusters and sub-clusters. Maintain network connectivity through multi hop relay for subclusters.	Extended node coverage is achieved however the protocol works partially as flat routing.
[91] **DSC**	Hierarchical zone based D2D routing	Establish clusters with UAVs using game theory approach .	Large number of rejections are reported since the DSC protocol focuses on providing efficient coverage to the nodes.

TABLE 2.6: Low energy adaptive clustering hierarchical protocol working model

LEACH Model	
Network Setup Phase	
1. Scattered nodes on the network grid	G non cluster head nodes
2. Randomized clustering algorithm:	$x_i \; in \; c_i \;, \forall \; r \; rounds \; \forall \begin{cases} \text{if } i = \mathbb{R} \\ \text{if } i \in G \end{cases}$
3. Cluster head selection	$c_i \rightarrow h_i \begin{cases} \text{if } h_i = 1, h \in \mathbb{R} \\ \text{and if } n - randval_{h_i} \leq T(n) \\ \text{where } T(n) = \frac{p}{1-p(r \, mod \, p))} \forall r \; rounds \\ \text{and } c_i \; after \; \frac{1}{p} \; rounds \end{cases}$
Steady Phase	
4. cluster Head broadcast, $h_i \rightarrow N_i \forall \; i \in \; \mathbb{R}_{nodes}$	
5. Each node n_i belonging to $\mathbb{R}_{node_i}$ performs signal strength comparison.	
6. Each node n_i belonging to $\mathbb{R}_{node_i}$ selects c_i cluster head such that $c_i \in G_i$ where G_i are nodes not selected as the cluster head in at least. $\frac{1}{p} r_{rounds}$.	
7. Energy required to tranmit l bits at a distance: $E_{t_i}(l, d) = E_{elec}. \; l + \; \in_{amp} \; .l \; .d^2$ $E_{R_i}(l) = E_{elec} \; . \; l$	
8. $d_i \oplus \mathbb{R}_{node_i} \; \forall \; c_i$, Data diffusion for each node with active schedule	
9. End of one iteration	

2.7.2 UAV-assisted Hierarchical Routing Protocols

In this approach the sensor network is divided into a hierarchical structure to establish clusters formation or tree like topology of the entire WSN. The objective of the hierarchical routing is to group the nodes together according to some feature such as battery power, priority concerns, usage criteria and etc. The groups are identified with the objective that the sensor network life can be increased if the possessing similar features are grouped together. This group reduces the routing

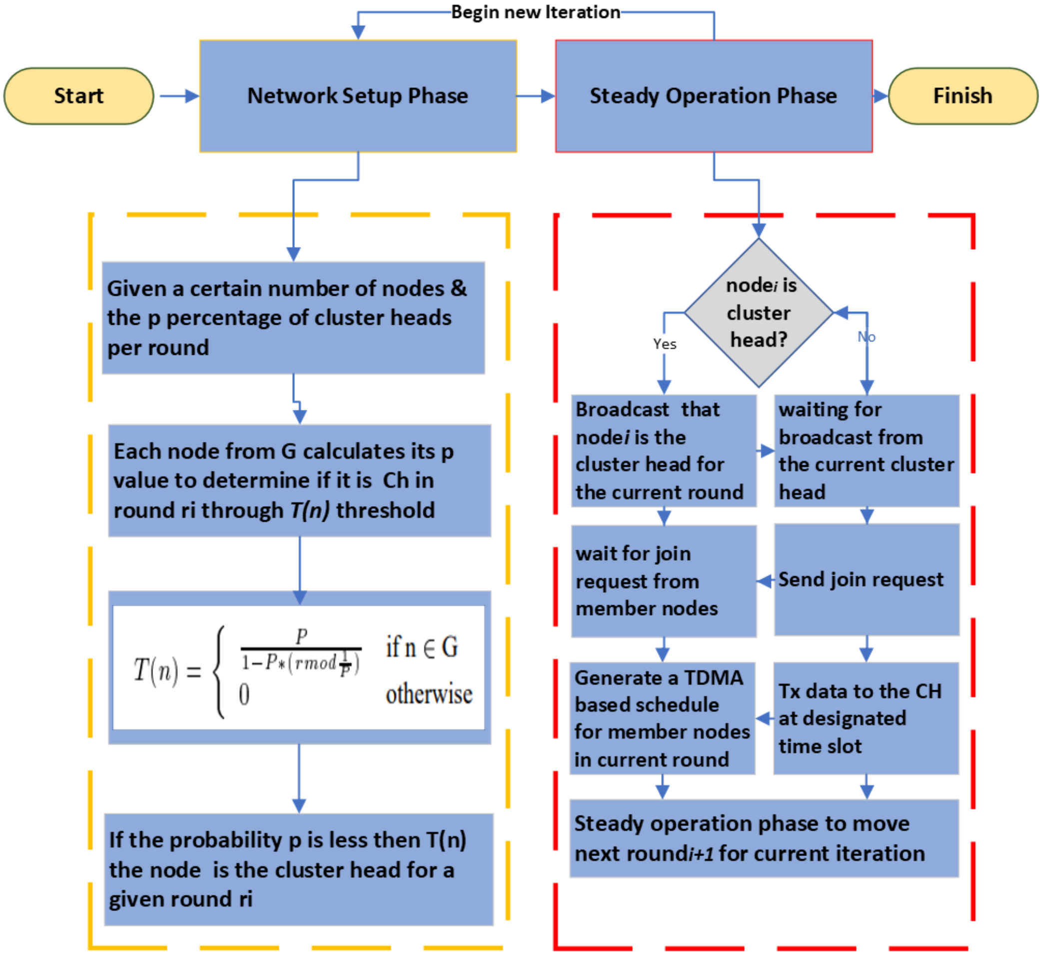

FIGURE 2.4: Working flow of leach and leach extended protocols.

burden on the network since nodes reside at nearby location. Tasks allocated to the sensor nodes can vary depending on the residual energy. Nodes having less energy can work as simply sensor nodes and the nodes having a specific power can perform multiple tasks such as data aggregation and also as a relay node.

In 2000 Wendi Heinzelman et al. [54] proposed LEACH an energy efficient protocol that is considered to be the first hierarchical routing protocols. In the LEECH protocol the network is divided into clusters. In each iteration the sensor nodes calculates a probability density function and the node that obtains a specific value becomes the cluster head for that iteration based on probability value obtained. The value is calculated at the start of each round by all the sensor nodes. Once a node determines itself to be a cluster head it broadcasts this message to the entire cluster to inform the member nodes. The member nodes transmit data to the cluster head which later on sends the data to the remote control center. In the simple LEACH protocol the nodes after each iteration calculate the probability value through the probability function and there is no limit for a node to become a cluster head again and again. The swapping role of cluster head selection in the simple LEECH protocol suffers energy drainage more rapidly as compared to the rest of the member nodes for that cluster thus creating routing holes.

In LEACH the cluster head must transmit the aggregated data to the control center using a single hop connection which drains the nodal energy even further thus speeding the process of creating routing holes. LEACH protocol uses the probability density function for cluster head selection therefore a node with a low residual energy will have equal chance of becoming a cluster head this will cause the node with low energy to die out faster. Modern wireless sensor networks are considered to be heterogeneous having rich set of nodes, smarts devices, gadgets all of which want to communicate with the control center. The distributed energy efficient cluster based routing protocol DEEC was proposed by Li Qing et al [92] in 2006. In DEEC after each iteration the cluster head selection takes places with two values the probability values, the remaining residual energy of the network. DEEC also limits amount of time a node can become cluster head by decreasing its probability value after each iteration to address the network hole problem. A short coming of DEEC is that the calculations to select a cluster head takes too long due to which simple DEEC protocol is not sufficient for modern WSN. The working model of DEEC is presented in the table 2.7 at the end of the current chapter. Over the years both LEECH and DEEC protocols have witnessed many modification by researchers. New variants of both the LEACH and DEEC focus on trying to improve the network lifetime by minimizing the energy that is wasted in the routing process by shifting the load of cluster head selection to the mobile sink nodes. The mobile sink nodes also act as the root node of the particular cluster and are equipped with more energy and computation resources. The mobile sink nodes identify cluster head at the beginning of each round by examining network residual energy and other parameters. In table 2.4 and table 2.5 a summary is provided about the clustering technique used in the LEACH and the DEEC routing protocols and the associated energy model proposed by Wendi Heinzelman.

Muhammad K. khan et al. in [93] discussed various descendants of Leach such as Leach-E which focus on the residual energy only for cluster formation but at the same requires the global knowledge of network energy, M-Leach which is an extension to Leach-E but for multihop networks, Leach-B in which the frequency of the cluster head selection is controlled by examining the total energy dissipated by a node in a round and the descendants of DEEC such as HEED in which a hierarchical energy efficient distributed clustering hierarchy uses probability random variables in correlation to the node's residual energy for cluster head selection but in non heterogeneous networks nodes with low residual energy can end up with a higher probability function as compared to the nodes that have actually larger residual energy values and many more protocols exhibit that these protocols focus primarily on cluster head selection. Once the cluster heads have been established the protocol moves to the operational phase in which each node makes energy calculations and diffuses data to the cluster head. In both the phases the calculations are performed by the sensor nodes which can drain a node's energy quickly thus most of these protocols are not suitable for real time deployment in the UAV based WSNs.

TABLE 2.7: Distributed energy efficient clustering routing algorithm

Distributed energy efficient clustering DEEC Model
Network Setup Phase
1. Scattered nodes on the grid N nodes Two types of nodes advance & normal called G node **2.** node n_i to be cluster head c_i for round $r_i = v_i \frac{E_i(r))}{AE(r_i)}$ $\forall n_i \; where \begin{cases} \text{if } 0 \leq v_i \leq 1 \\ \text{if } v_i \; \leq Th(n_i) \end{cases}$ where $Th(n_i) = \frac{p_i}{1-p_i(r_i \; mod \; \frac{1}{p_i})} \forall n_i \in G$ G is set of nodes n_i not selected as ch_i in round r_i
Steady Phase
3. Each node associated with ch_i calculates the average energy of the network $AE(r_i) = \frac{1}{N} E_{total}(1 - \frac{r_i}{R_T})$

4. $d_i \oplus \mathbb{R}_{node_i} \forall c_i$, Data diffusion for each node with active schedule

5. Calculate the total energy dissipated in the current round as:

$E_i(r_i) = L\ bits(2NE_{Tx} + NE_{DF} + k\varepsilon_{mp}d^4 + N\varepsilon_{f_s}d^2)$

here L is the packet size, E_{Tx} is the energy dissipated by the transmitter.

E_{DF} is the data aggregation energy, and $k\varepsilon_{mp}d^4$ and $\varepsilon_{f_s}d^2$ are amplifier energy dissipated when sending data to the BS and the cluster head node

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Aljapur vinitha et al in [94] proposed an energy efficient multi hop routing protocol for WSN. The C-SSA protocol is a two step based protocol in which the first phase is the selection of cluster head in which a leach based cluster head selection method is adopted for data aggregation. Once the cluster formation is established then in the second phase routing is performed by combining the two swarm intelligence algorithms slap-swarm optimization and cat-swarm optimization algorithms using a mulitvalued objective function. The objective function used intra-cluster distance, link quality and lifetime, residual energy of the cluster and delay to select the most optimum distance for routing from source to the destination. The design objective of the multi hop routing algorithm is to reduce the number of hops which increase network lifetime. Mohamed Elhoseny et al. in [95] proposed a multi hop routing algorithm for wireless sensor networks that used the swarm intelligence based cluster establishment and for choosing the cluster head more efficiently as compared to the leach protocol. Once the cluster formation is established and cluster head are identified the routing process uses the path having the minimum number of hops using the gray wolf optimization algorithms. The results reported by M Elhoseny indicate a higher network lifetime usage in which the network is extended to having report the last dead node at 2000 rounds as compared to the traditional leach routing protocol having the last dead node at near 700 rounds. Hassan et al. presented a hierarchical energy efficient routing inside a public safety network using only two UAVs in [63]. A disastrous attack scenario is presented where the objective of the UAVs is to carry user sensitive data either using UAVs directly for communication within the cluster or by D2D gateway nodes in situations where the devices/sensor nodes lie outside the cluster head coverage to extend the coverage of the UAV aided PSN. The energy efficient routing algorithm proposed increased the energy efficiency by 15% as compared to traditional approaches.

2.7.2.1 Low Energy Adaptive Clustering Hierarchy Evolution

Over the years LEACH protocol has gone through multiple improvements in which most of the research has targeted optimized coverage or energy efficient routing towards control center. Optimized leach i.e., O LEACH protocol achieves the optimized coverage in terms of reducing the number of orphan nodes that are created in every round. As the cluster head selection of the LEACH protocol is random therefore in every round 12% of the nodes get dropped. Therefore to increase the connectivity of the node coverage the OLeach protocol uses relay techniques to bring these nodes back on the network for transmission of data to the control centers.

In 2010 Said et al. presented A leach protocol in which heterogeneous network is presented and some of the nodes are equipped with more energy as compared to the rest of the nodes. The advance energy nodes act as relay nodes for the cluster heads. This concept reduces the burden of data aggregation and data transmission to the control center the advance nodes that have more battery power as compared to the rest. The first dead node is reported at 1000 rounds and the network remains alive till 9000 rounds.

Similarly in 2018 Alnawafa et al. presented the distributed leach that is multi hop known as the DMHTLEACH. The protocol preserves the network energy by improving the process of the network setup phase in which the cluster head selection takes places. The placement of the nodes in the cluster is balanced for by limiting the number of nodes that can join each cluster. Each nodes waits for a Hello beacon from the cluster head and then selects the cluster head from which the shortest distance is reported. DMHTLEACH protocol reports the first dead node report at the 450th round which is double to that of the traditional Leach protocol. However the entire network is dead near 1000 rounds.

2.7.2.2 Energy Centroid Node in Hierarchical Routing Protocols

Cluster based routing protocols which are descendants of LEACH or DEEC focus on establishing cluster heads having higher residual energy without regard to the actual occurrence of the cluster head nodes in real time deployments. In case the cluster head turns out to be an edge node then the distance from base station to the cluster head node increases. Member nodes will consume higher amount of transmit power to reach the cluster heads which in turn will use even more transmit energy to reach the control center. Such a scenario will reduce the network life time rapidly. Establishing an optimum point using energy consumption is important in hierarchical energy efficient protocols.

The centroid is a logical point as pointed out initially by Yu lui et al. in [96] where in clustering scheme it is assumed that the mass of energy is present. This is a logical point that represent the location on the 2-D grid that has large energy concentration as compared to the rest of the grid. To identify the energy centroid position for the respective cluster the x axis and the y-axis (x,y) location of all the nodes in the cluster is taken in to account the calculation of the points is a follows:

1. $x_{ec} = \frac{\sum_{i=0}^{n} \frac{E_{ir}}{E_0}.X}{N}$

   centroid point along x-axis

2. $y_{ec} = \frac{\sum_{i=0}^{n} \frac{E_{ir}}{E_0}.Y}{N}$

   centroid point along y-axis

In both the equations above

E_{ir} is the residual energy of the ith node at round r_i

X and Y are the 2D grid point of node i and

N is the total number of the nodes. In the ECN pairs mentioned the x_{ec} and Y_{ec} is attained by dividing the residual energy of each node with the initial energy of each round denoted by E_0 and then taking the average.

Once the pair (x_{ec} , y_{ec}) are figured out then all the nodes with the particular cluster use the euclidean distance to compare their position with the energy centroid pair to be elected as cluster head. However this operational phase is shifted to the control center to establish the network and broadcast the cluster head to the member nodes. The member nodes can later on chose to be associated with a given cluster head based on the distance or other parameters.

Jia shen et al. proposed an energy efficient centroid based leech-c (variant of LEACH) routing protocol for ioT assisted WSN in [97].

Jia Shen et al. proposed a new concept called energy centroid which represents a location calculated by sink node in the WSN where concentration energy of sensor nodes is high. The sink node initially gathers the energy of the sensor nodes and the node closet to the centroid location is chosen as the cluster head. After each iteration of data transmission the cluster head calculates the node nearest to the energy centriod location and the new node is chosen as the cluster head. The protocol is self adaptive in the sense that after the initial selection of the cluster head through sink node the sensor nodes determine the next cluster heads locally to uniformly distribute energy depletion problem among the entire cluster thus increasing network lifetime. However it is observed that the concept of maximum distance consumes energy rapidly for the cluster heads due to caching and relaying data to the sink node. When the distance between the current cluster head node is greater then the max threshold the cluster head node waits for the next round. This caching can result loss in the data packet sent to the sink node along with added cost of subsequent data aggregation.

Distributed clustering algorithm to establish cluster based on residual energy and distance of each node from the sink node is proposed by Khalid Mahmood et al. in [81]. Cluster of different sizes are established by calculating RSSI values. Within the cluster node having highest residual energy is selected as the cluster head. The cluster size is kept minimum for the nodes laying near the sink node to preserve energy during realying and increasing the life time of the network. However it is observed that routing holes will be formed thus decreasing network life time. A new hierarchical intelligent routing process (IRP) protocol was proposed by Mohit ajwan et al. in [98]. Through the IRP a node can choose to send data directly to the sink node bypassing the cluster and this is done through multihop communication using the progressive node set. A node can cancel multi hop if the next hop selected towards the destination is a cluster member node in which the cluster head will be used to reach sink node. A distance threshold is defined that satisfies the transmitter free space energy and multipath energy consumption model which reduces the energy wastage. The proposed protocol improves network energy due this constraint by 97% as compared to the traditional LEACH algorithm. However it is observed that the energy calculation are too complex to be implemented in real time since node energy will be depleted quickly.

Kashif naseer et al. in [87] proposed a new generation of hierarchical cluster routing protocol for WSNs in the agricultural sector to monitor humidity, temperature and vital crop statistics. The algorithm uses gateway nodes for routing towards the control center and the routing is energy efficient and reduces the burden of the cluster head nodes. Initially a cluster is selected near the energy centroid location and then the gateway node within that cluster which is the edge node. The gateway nodes lye on the overlapping region within clusters en route towards the sink node. Similarly all the nodes in the overlapping region can be considered as gateway nodes however a node for which the node weight reaches a given value only that is selected. The nodes weight is based on the residual energy, distance from the neighbour cluster head and the distance from the sink node. For each iteration energy centroid location is calculated and the new cluster heads are selected along with new gateway nodes. This way the energy depletion is shared equally among the entire WSN. However it is observed that these calculation are far too complex for sensor nodes to carry on in a real time deployment scenario.

2.7.3 UAV-assisted Location Based Routing

For WSN networks which are data centric the application deployed in the field generates more data that must be routed in a timely constraint as compared to the deployments in which data generation is less and time is relaxed. Such scenarios create routing holes much faster as compared to hierarchical based techniques. Since WSN is a multi hop network the nodes that carry data for the multi hop routing environment over a fixed path closer to the destination have the nodes deplete their energy quickly since the entire data forwarding depends on these nodes. Such environment for WSN the routing process can benefit heavily with the deployment of un manned aerial vehicles. Zema et al. in [99] proposed an on demand distributed UAV path planning technique in which the trajectory of the UAV is calculated at run time based on a nodes geographic location. Each sensor node having data to transmit inform the cluster heads and the UAVs collects data by generating a run time trajectory map to visit each cluster head dynamically for data collection. The map that the UAV will generate is different and based on routing table updates of previous entries. For WSNs having mobile nodes the technique proposed by Zema et al. results in longer lifetime of the WSN. However a this technique is not much resilient with the failure of the cluster head node. Similarly the approach by Zema et al. does not consider the optimum route and due to this as the number of sensor nodes increase the performance of the routing process degrades the node's lifetime.

Routing process for location aware data collection services optimize the UAV trajectory to increase the wireless sensor network's lifetime. Xiaoyan Ma et al. in [100] proposed a dynamic location based routing for data collection in which both the sensor nodes and the UAV are mobile and the network topology is changing with the sensor nodes. Each trajectory that the UAV will adopt is broken into a linear path trajectory to reach the sensor node from which the data is to be collected. The placement of the UAV takes into account of multiple UAVs and each UAV covers its own trajectory with varying altitudes to minimize co channel interference. Four different data collection algorithms are considered with varying velocity, altitudes and network density are examined against the proposed algorithm. General observation is that since data collection time is important and as the network density increases so does the contact time of the UAV due to which only local data fairness is achieved. Li et al. [101] proposed a long range intelligent transportation system in which the UAV are deployed with the objective to increase fairness in data collection by adjusting the speed of the UAV in densely populated sensor nodes zone so that the contact time with the number of nodes can increase above a threshold level using the USCFDC algorithm. The algorithm gives a minimum flight time according to which the UAVs select the contact time for data collection from the sensor nodes. The flight path is divided into mulitple line segments which are used a vertices which is later converted into a directed acyclic graph and each vertex can have multiple sensor nodes.

Jaeuk Baek et al. in [102] proposed an energy efficient location based routing in which the UAV is dispatched to the sensor nodes for data collection in the wireless sensor network using shortest path routing. The authors propose the shortest path for routing to reach the destination sensors from which the data collection will take place. Baek et al. use the voroni diagrams techniques in which the WSN is divided into multiple regions. The UAVs hovers over the region longer that have been identified through the voroni diagram with less energy remaining. This way network lifetime can be extended sine the sensor nodes will conume less residual energy. The position of the placement of the UAV is adjusted according to the energy graph that is generated through the voroni vertexes where the graph indicates the sensor zone having energy less the threshold. A general observation for this approach is that the authors use the sensor node's residual energy to dissect the voroni diagrams to extend the node's lifetime but the average contact time with the node is ignored which means that as the network becomes dense there will be delay in the routing process.

Qawy et al. in [103] proposed a multi level hierarchical routing protocol threshold oriented energy harvesting multi level stable election TEMSEP for large scale heterogeneous networks. Instead of continuous data transmission at regular intervals the TEMSEP protocol allows the node to respond only when the node senses a change in the data sensed. In TEMSEP a novel approach for sliding window concept is used which is reactive in nature and each node during its transmission time period will determine whether to transmit or remain asleep by examining a threshold. This method in which a node that not witnessed any change in the parameters of study will choose to keep its radio off thus increasing node lifetime. The energy harvesting nodes are deployed that provide intermediate forwarding service to the cluster heads to reduce the burden form the cluster head nodes. TEMSEP uses the first order energy dissipation model as proposed by Heinzelman in leach. The extensive experimentation indicates a 73% less energy dissipation and an increase by 69% in the network lifetime as compared to traditional hierarchical approaches.

Qawy et al in [89] proposed an improvement over TEMSEP and proposed a reactive routing protocol to save the unnecessary data transmission which results in extending the node lifetime with in a each zone. The proposed routing protocol threshold enabled scalable & energy efficient TESEES. TESEES is a hierarchical zone routing protocol for large scale heterogeneous iot enabled WSNs. The protocol regulates the uplink data transfer in different zones against a threshold for controlling nodal energy. TESEES uses a sliding window in which every member within a zone can decide weather to transmit data or remain asleep by examining its threshold against the allocated time frame within the sliding window. The threshold algorithm TMCGT is deployed at each node individually and examines the past transmission event history to identify weather to transmit in real time against various parameters. TESEES divides the network according to different layers the second layer deploys relay nodes that harvest energy and forward the sensed data to the sink nodes. The initial network formation is divided into three phases static zones establishment, random node deployments and placement of relay nodes. Once the network is formed the weighted election heuristics algorithm is run for zonal heads called ZA's nodes and the zonal aggregation group called ZAG. The ZAG election procedure is based on the MWEH algorithm which is based on multiple parameters as opposed to the traditional leacg based approaches. TESEES uses the TEMSEP thresholding algorithm to control the number of times a given node will be transmitting the sensed data. This approach limits the number of nodes within each zone that will keep their radio on or off according to the sliding window.

2.8 Maximizing Connectivity at Routing Layer

Examining figure 2.5 a network region is presented. The region is divided into zones and in each zone a node dedicated as the cluster head (represented in large black) performs the data aggregation task of that particular zone. The sensor nodes (represented as small black dots) send data to the control center through the cluster head nodes. The cluster head nodes perform dual operation i.e. data aggregation and transmission to the control center. In the cluster zones some of the nodes fail get any association from the cluster nodes and are referred to as orphan nodes(represented as red nodes). The orphan nodes also need to transmit their data to the control center but have been dropped out. In this study our objective will be to maximize the coverage by bringing these orphan nodes as active member on the network gird. Multiple solutions exist however we will use D2D gateway nodes (represented as green)to achieve our objective.

2.8.1 Hierarchical Routing Protocols and Zone Formations

Hierarchical routing protocols establish clusters in which a group of sensor nodes or iot devices are connected. The group is coordinated through a cluster head which diffuses data from all the nodes and sends the data to the control center for future processing. The cluster head allocates a time slot similar to the TDMA technique or a schedule for each node in the cluster. Each node must follow the schedule if it has any data to send to the cluster head. Cluster based approaches focus on the routing so as to preserve the energy of the cluster to extend network lifetime. Apart from energy efficiency another important objective for the hierarchical energy efficient routing protocols is to extend the network coverage to over come the short comings that rise from the cluster based deployments.

Most of the LEACH descendants use a single level hierarchical structure in which the cluster member nodes use a single hop to transmit data to the cluster head. The cluster head uses a single hop to transmit the diffused data to the control center. In real time scenarios sending data directly to the base station drains the cluster heads node's energy rapidly since the exact location of the cluster formation can be far and more energy would be required to transmit the data over a single hop as compared to the rest of the cluster heads having distance closer to the control center. Hence most of the leach based descendants can not perform efficiently in real time situations such as a disastrous scenario. Non cluster member nodes which fail to receive any cluster head join broadcast from the respective cluster head during the network setup phase will not be able to transmit their data to the control center since their placement is far from any cluster head and these nodes are not a member of the any cluster. Since the number of round in hierarchial

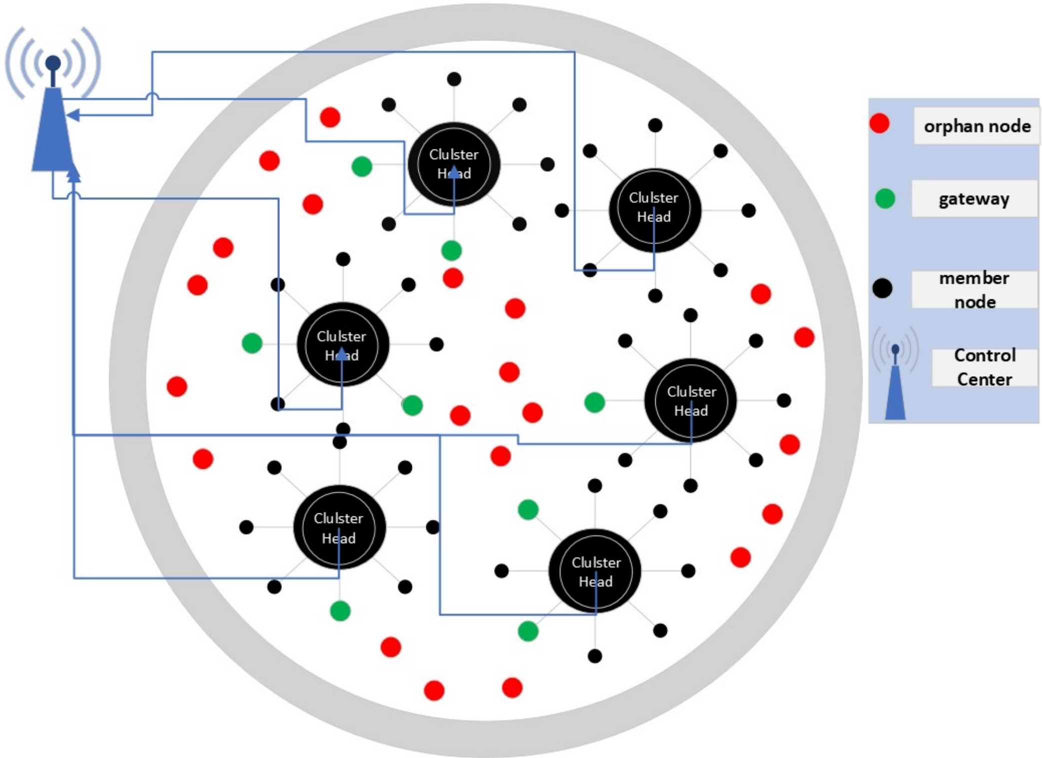

FIGURE 2.5: Extending Node coverage through gateway nodes.

routing repeat after $\frac{1}{p}$ rounds where p is the number of cluster heads required, which means that for all the rounds in an iteration the group of nodes that lye on the edges will not be able to communicate at all [104].

The leech and deec based models investigated in this literature review generate an irregular establishment of the clusters formation when implemented on Matlab to observe the behaviour of both protocols. The network setup phase had 160 nodes all of which were labeled as normal nodes initially. Both LEACH and DEEC based models use initial probability of the number of cluster heads labelled p. The value of p was set to 10%. Later on in the next phase the nodes were divided to normal nodes and emergency nodes and the emergency nodes were taken to be 25% from the total nodes. The network setup phase was run with 200 iteration for both the normal and emergency scenario and the results are shown in figure 2.6 and figure 2.7. Since the network establishment phase of hierarchical protocols focuses on only establishing cluster groups. Many irregularities arise with un even deployments. In both the figures it can be seen that some of the cluster fail to group any node in realtime. Although nodes were marked before the experiment started so the missing nodes are definitely lying outside the clusters or on the edges due to which they were not able to receive the joining broadcast message from the cluster heads. Although the missing nodes are present on the grid they are just not associated with any cluster. It means that those node will not be able to send their data to the control center. In an emergency situation the high priority nodes will also fail to send their data to the control center.

Table 2.8: Protocol Summary of protocols with respect to network coverage

S.No	Technique	Network Coverage with gateway nodes	Multi hop	IoT/WSN
[105]	OLEACH	yes	No	Yes
[106]	ICR	yes	yes	yes
[104]	leach	no	no	yes
[87]	GCEEC	yes	no	yes
[4]	CAMP	no	no	yes
[91]	D2D routing in multi hop in disaster zone	yes	yes	no
[88]	MEACBM	yes	yes	yes
[92]	DEEC	No	No	Yes

Addressing the problems in the scenarios highlighted in Figure 2.6 and Figure 2.7 researchers have presented muti hop gateway nodes as a viable solutions. Multi hop gateways allow for the nodes to be connected that fall outside the coverage zone of clusters heads but are present on the network grid. Therefore multi hop gateway nodes can be utilized to achieve the objective of maximizing network coverage as pointed out earlier. Wassim Jerbi et al in [105] presented Orphan-Leach or O-Leach a leach based variant. In O-Leach the once the cluster is established during the network set up phase then it doesnt change until $\frac{1}{p}$ rounds. The nodes that fail to join a cluster are labeled as orphan nodes for the next $\frac{1}{p}$ rounds. In o-leach the algorithm initially identifies all the orphan nodes. A cluster member within distance threshold of the orphan nodes is chosen to be the gateway node. If however the number of orphan nodes crosses the number of cluster member nodes then a subcluster is created and the cluster member node nearest to the orphan group becomes the cluster head of the orphan cluster. In O leach the performance

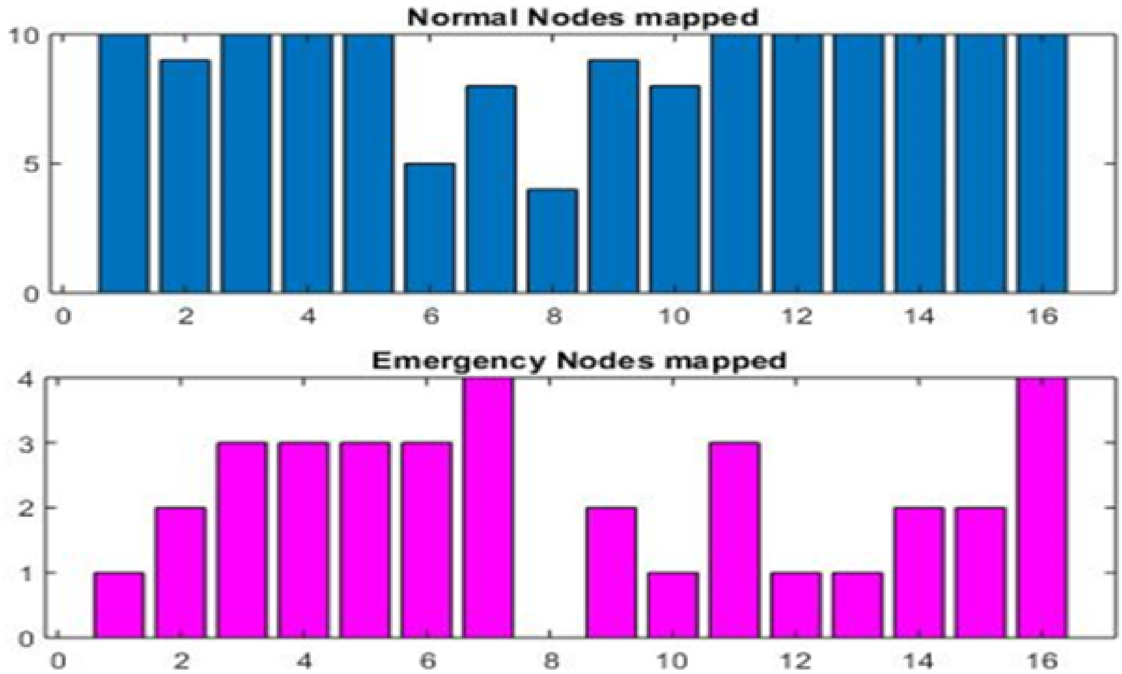

FIGURE 2.6: Network setup phase for LEACH and DEEC. Blue color are normal nodes and pink are emergency nodes.

of number of nodes connected to the cluster for sending data to the control centers rise to more than 20% as compared to the traditional leach. However aprart from the increased network connectivity o-leach exhibits the life cycle for the sensor nodes as compared to the leach protocol. Another issue in the O leach is that the gateway nodes are selected without consideration of the residual energy.

M.Ali Alharbi et al in [106] have presented a blended routing technique called improved clustering and routing ICR-routing in which the routing protocol is divided into two phases. First phase is to establish cluster and the load for cluster establishment is shifted to the control center which defines all the possible neighbours of all the nodes and also determines the clusters and the cluster heads. The control center broadcasts initial message to a group of nodes such that it reaches a subset of area within the cluster labeled as A1, later on the initial message sent by the nodes from A1 set to the second layer of the nodes within the cluster labeled as A2, and so on with group label A3 etc. This way the cluster is broken into multi layers. Nodes overhearing the first broadcast set the forward path towards the base station. All nodes overhearing the broadcast set forward path towards the base station along the direction of the broadcast. The initial set up phase is

similar to leach but instead the control center divides the fix area for clusters. Node with the highest residual energy broadcast its self to the restricted cluster area to which all nodes within the area respond. Once the cluster heads are established the control center broadcasts all the forward and backward nodes to all the members in that cluster. The forward and backward nodes are used for routing. In the routing process the nodes behave like DV routing techniques in which each node determines the hop count to reach the control center. ICR is blended routing protocol in which the maximum network coverage is provided first by establishing clusters and second using multi hop routing in the cluster using forward and backward nodes.
The mapping of leach,O leach and ICR protocol reveals that the nodes in ICR the cluster partions are fixed and the node remains a part of the cluster and at the same time also behaves as a member of a flat routing routing protocol like a distant vector approach to increase the connectivity. This reduces the network lifetime since nodes perform dual functionality in the routing process which drains energy quickly.

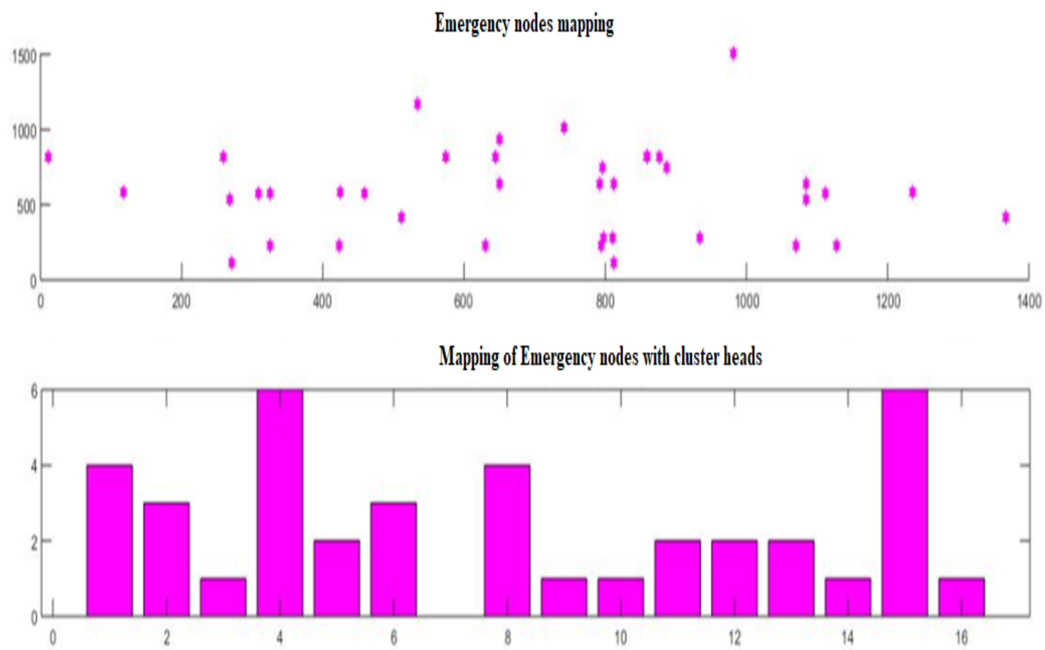

FIGURE 2.7: Network setup phase for LEACH and DEEC with 25% of emergency nodes mapping.

Overall the coverage of the all the protocols that try to achieve optimum deployment in their network has been presented in table 2.8.

2.9 Limitations of the Hierarchical Approaches

2.9.1 Routing

From the literature review presented it can be concluded that the simple hierarchical approaches suffer in providing extension to network lifetime in many ways that can be summarized as follows:
In simple hierarchical approaches the network protocols are divided into two phases the setup phase and the steady phases. The nodes in the setup phase participate to create clusters. The nodes once becoming a member of the cluster participate in the selection of the cluster head.
Both the above mentioned steps consume a considerable amount energy since the activity has to be repeated after each round. These steps cause a node to dye out very quickly. The hierarchical approaches report a first dead node from 150 to 400 rounds and also due to this factor the last dead node is reported at near 800 rounds this means that the entire network is dead at near 1000 rounds of hierarchical approaches.
From the literature review it is clear that the energy centroid approaches offer an improvement in the selection of the head nodes for the established clusters however the selection process of the ECN nodes its self is computationally extensive jobs and again just like simple hierarchical approaches all nodes have to participate in the selection of the ECN nodes for each round. The ECRP routing protocol offered the use of ECN nodes initially in 2017 later on the approach was adopted by many scholars similarly the GCEEC is also a hierarchical ECN based routing protocol for wireless sensor networks but again the issue both these protocols suffer is that in both the routing protocols the computation burden is placed on the sensor nodes so even though that these protocols are latest state of the art but still they fail to extend the network lifetime to a considerable level beyond 1000 rounds.

2.9.2 Optimized Coverage

From the literature review it is clear that another important aspect of energy efficient routing protocols is that it should reduce the orphan nodes in the routing process. However LEACH based descendants mostly ignore this aspect due to which throughput of the overall protocols fails to extend 30,000 packets per round as we have seen in GCEEC, EECRP, MEACBM,ICR protcols. Network extension is an important aspect that if considered can increase the coverage of the nodes that have been dropped out during the network setup phase of hierarchical approaches.

2.9.3 Single Point of Failure

In simple hierarchical approaches the nodes send and receive data from the cluster head node which induces a natural single point of failure in the routing aspect. However in case of UAV assisted wireless sensor networks the nodes communicate with multiple UAV which offload the data to the control centers. In the EHGR routing protocol the UAV collect data from the ECN nodes only and therefore even if there is a failure from the UAV due to some event the network still remains operational. The EHGR routing protocol covers only the communication between the sensor nodes and the ECN nodes. In an extension to the EHGR routing protocol we will take another research initiative in which UAV to UAV routing will be explored currently we have made an assumption that there is sufficient amount of UAVs available that can be replaced without affecting the normal functioning of the protocols.

2.10 Problem Statement

In light of the literature review the problem derived is that given a certain number of Iot based smart devices or sensor nodes in a homogeneous wireless sensor network having a certain number of UAVs how can we efficiently provide coverage to all the nodes deployed such that the data is collected by all the nodes and no node having data for the control center is left behind? Secondly how to route in an energy efficient manner such the network lifetime is maximized and minimum burden is placed on the sensor nodes? The problem statement has highlighted two important aspects of the energy efficient routing protocols i.e., optimized coverage for throughput maximization and secondly energy efficient routing towards the control center that will extend network life time.

2.11 Research Questions

Research Question 1 How to use deployment algorithm efficiently in a UAV assisted WSN such that the coverage of the nodes is maximized.

Research Question 2 How to route data between nodes in an energy constrained environment by optimizing power to increase network lifetime?

In the next chapter the methodology of the experimental setup is designed such that both the research question are addressed systematically in various phases. The first phase will be addressing the deployment aspect of the nodes such that the coverage is maximized and no node having data for transmission is not dropped out from getting association from the servicing UAV's and the energy centroid nodes. The second phase will address research question 2 where routing is performed to minimize the energy consumption during the routing phases by offloading power intensive calculations to the servicing UAVs.

2.12 Summary of Literature Review

In this chapter we initially presented the LEACH and DEEC models of the hierarchical routing protocols. It is observed that the nodes perform extra calculations in both the steady and the setup phase of the protocols similarly the descendants of both the protocols adjust the threshold according to weights, residual node energy or residual cluster energy to select the cluster heads for the next round however the calculations burden is still placed on the sensor nodes to carry out these calculations henceforth the network lifetime reduces and fails to exceed 1000 rounds. In the literature review we introduced the concept of the energy centroid nodes. ECN nodes are an efficient state of the art head node selection technique which ensures that the head node is always the center of the network energy. Similarly the changes in the Ecn node per round wise are minimum as compared to the exiting hierarchical approaches in which the head node changes after every round which also changes the network topology in each round. Therefore we have concluded at the chapter at the point that hierarchical approaches can extend network lifetime if the head node is changes by the ECN node selection technique.

Chapter 3

Network Setup and Implementation

3.1 Introduction

In this chapter we provide implementation details and the mathematical modeling used to implement the energy efficient hierarchical gateways routing (EEHGR) protocol.

3.1.1 Relay/Gateway Nodes for Network Extension

Not all of the deployed nodes in the network become associated with the cluster heads. Nodes can be placed at points locations where broadcast from the cluster heads are not received. Such nodes will be isolated and not be able to transmit information to the control center. Similarly some of the nodes fail to receive any association due to bandwidth limitations from cluster heads. These nodes can be a part of the cluster but still not be able to communicate to the control center since the servicing UAV or the cluster head is not able to accommodate any further connections. Therefore in one complete iterations these nodes remain idle and can not transmit the data towards the control center [107]. Such nodes can be accommodated with the help of gateway nodes. Gateway nodes help to over come the limitations that generate from the non uniform deployments of nodes. Different researchers have used the concept of gateways differently over the years. Gateway nodes can be used for:

(i) Network Extension

(ii) Joining Disjoint Network Partitions

(iii) Maximizing Coverage

(iv) Offloading Cluster Heads

(v) Bandwidth Sharing

(vi) Inter Cluster Routing

(vii) Multi hop Routing

The use of gateways for routing has been proposed in [87] by Kashif Naseer et el. and in [81] by Khalid Mahmood et al and by Jian Shen et al. in [108] but routing is primarily based on cluster formation in the network setup phase in which the sink nodes send location data to the nodes which later on establish cluster heads. The cluster heads select member nodes and the selection of suitable gateways for each cluster is identified. These scenarios suggest advance knowledge of geographical locations and accurate placement of sensor nodes to produce desire results. However disastrous regions can not be predicted in advance their size, the terrain etc. In such scenarios ad-hoc on demand placement of sensor nodes without prior knowledge of sink node initially and relays nodes are the only available options at hand. In such scenario the proposed routing protocol will be deployed on demand and will adopt the approach of game theory to dynamically establish cluster like formations without running the clustering algorithms. Dynamic selection of gateways will be performed that will change in iteration to preserve the energy of the WSN network. A prominent problem highlighted in the literature is the energy hole problem. Nodes acting as relay nodes and cluster head nodes drain their battery power quickly as compared to the rest of the nodes and due to this these nodes die out fast. The dead nodes create hole and routing becomes difficult since these hole in routing data through network cause isolated groups of nodes that can not communicate with each other as pointed out by Arfat et al. in [14]. To tackle this problem the proposed protocol will select different gateway node after each iteration and selection of energy centroid nodes that uni formally depletes the energy of the entire cluster thereby making sure that the energy hole problem is kept at minimum. The UAVs perform partial calculations thereby offloading major computationally intensive calculations from the sensor nodes which reduce fast depletion.

3.2 Network Setup Phase

In the disaster region UAVs have been considered to be ideal due to their ability of providing cellular and data services. The UAVs can increase the productivity of WSN in terms of data communication and aggregation among the nodes. Use of UAVs for routing in WSN is an emerging domain with scarcity in terms of the available literature for UAV assisted routing protocols. Dariush Ebrahimi et al in [109] UAVs are used to gather data from cluster heads in sensor networks and route it to the nearby sink node for data processing thus increasing network lifetime. The entire network is arranged into hierarchical cluster and UAV route is analyzed in prior using the compressive data gathering (CDG) approach. Dac-Tu Ho et al. in [110] proposed a UAV based energy efficient communication topology to reach destination with reduced bit error rate as compared to LEACH protocol. Swarm intelligence is used to figure out the path that reduces the UAV travel length with reduced bit error rate. Jaeuk Baek et al. proposed an energy efficient routing in UAV assisted WSN for data collection in [102]. Energy maximization against residual energy is achieved by using the graph based voronoi diagram to identify the shortest distance during routing process. Once the shortest path is calculated the UAV hovers to the target location to gather data coming from multiple sensor. UAV assisted WSN offload the burden of cluster heads during data aggregation and increase network life time by delivering the data to the nearby control centers. Hierarchical protocols mostly use machine learning techniques for clustering algorithms. Contrast to the traditional hierarchical approaches used for node association this study uses game theory approach. Game theory uses various optimization functions in which all parties within the model use to achieve maximum benefits. Game theory modeling approaches in mapping WSN nodes for resource maximization are suitable for developing associations between nodes and cluster heads and the servicing UAVs. Maximization functions can be used for energy efficiency maximization as Muhammad Sohail et al. in [111] or node associations by Yin-Di Yao et al. in [112].

3.2.1 Implementation Details

Initially K sensor nodes are deployed in the network simulated gird generated using the matlab tool. We assume a control center with a configured location that will act as the last establish point beyond which there is no established network infrastructure.

The sensor nodes are randomly deployed on the network area.

Let K be set of sensor nodes also referred to as user equipment.

$\{k \in Sn_p\}_{k=1}^{n}$

Each Sn_p is aware of its GPS location relative to the network. Initially a node from set (Sn_p) receives line of sight and non line of sight transmission signals generated from the UAVs. Line of sight (LoS) and non line of sight (NLoS) are the received signal a nodes calculates from a direct link from the UAV and non line of sight is the signal value a node receives indirectly by reflections, refraction, free space signal shadowing etc. These values were initially pointed out by Al-Hourani et al. in [113] for low altitude platforms and can be approximated by the sigmoid function and is expressed as a probability function which states that the probability that whether a nodes receives a signal from line of sight at an angle theta from a given low altitude platform is expressed as below

$$P(LoS, \Theta) = \frac{1}{1 + \alpha.e^{(-\beta(\Theta-\alpha))}} \tag{3.1}$$

and

$$P(NLoS, \Theta) = 1 - P(LoS, \Theta) \tag{3.2}$$

here α , β represent the built land and average buildings in respect to total deployment area respectively. We use both the values in our energy model. Reference of the model is established in figure 3.1.
Θ is the elevation angle according to Al-Hourani et al. and can be expressed as $\Theta = arctan(h/r_{kn})$ where h is given UAV altitude and
r_{kn} is the ground distance from each user equipment /sensor node Sn_p with the UAV.
The sensor node will initially be associated with one UAV over this path in the first phase to become a member of cluster. In the association phase each sensor node receives a hello message from the UAV either through line of sight or non line of sight. Each sensor node will calculate the achievable data rate from each UAV before placing a request for association which is given by

$$\begin{aligned} A_{dr} = P(LoS, \Theta) * (20log(d)) + 20log(f) + 20log(4\pi/c) + \eta_{LoS}) + \\ P(NLoS, \Theta) * (20log(d)) + 20log(f) + 20log(4\pi/c) + \eta_{NLoS}) \end{aligned} \tag{3.3}$$

According to equation 3.3 the achievable data rate for a given node is sum of the signal values it receives from $P(LoS, \Theta)$, $P(NLoS, \Theta)$. These values are multiplied with the free space path loss values as represented by $(20log(d)) + 20log(f) + 20log(4\pi/c) + \eta_{NLoS}$.

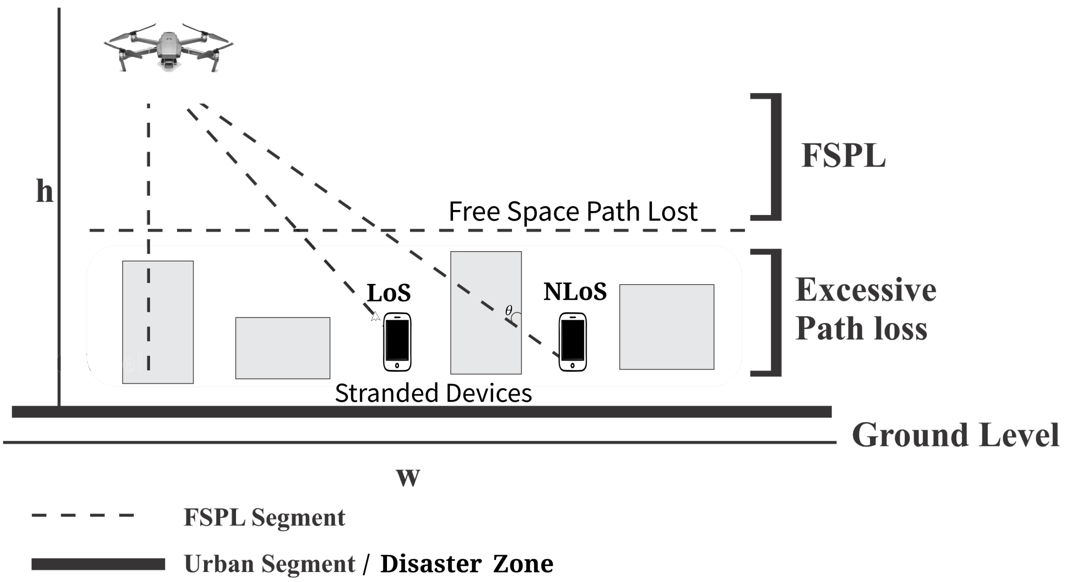

Figure 3.1: Line of Sight and Non Line of Sight Model

Another way to represent this equation according to equation 3.3 is $P(Los) * PL_{LoS} + P(NLoS) * PL_{NLoS}$. In equation 3.3 d is the Eculidean distance between the node and the servicing UAV, f is the frequency according to the Al hourani lap altitude model and c is the speed of light.
Equation 3.1 , 3.2 and 3.3 can be represented in the figure 3.1 which highlights the above equations designed for the path loss model using line of sight and non line of sight. A low altitude platform LAP is positioned at height h from the ground as shown in the first dotted line coming straight down the drone. The objects that are in direct line of sight on the ground with the UAV are labeled as LoS and the objects that are not in direct line of sight e.g. the second mobile device is behind the building are labeled as NLoS since they are receiving signals but not directly. The user equipment positioned on the ground having either LoS or NLoS path towards the UAV will try to develop association. The user equipment will be at an angle θ from the UAV as can bee seen in the diagram.

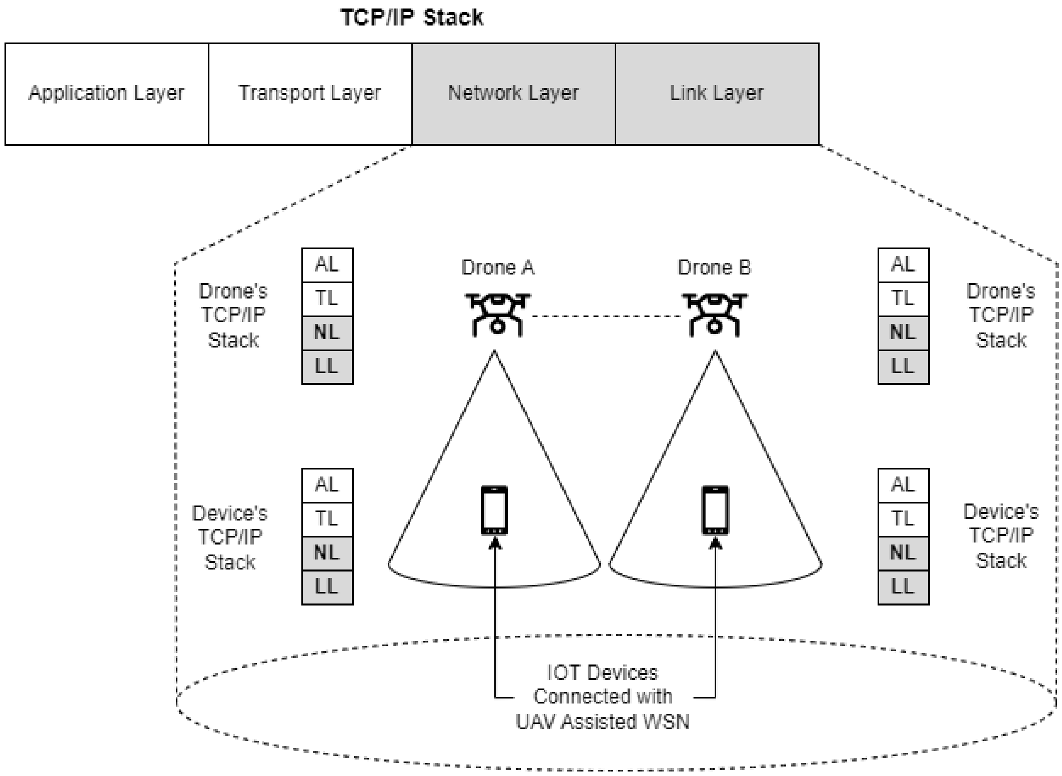

FIGURE 3.2: Line of Sight and Non Line of Sight Model

The same UAV which will select a suitable energy centroid node in the next phase from these associated nodes in the network. Here d is the distance between sensor node and the UAV having projection on ground as shown in Figure 1 which is calculated by

$d = sqrt(h^2 + r^2)$ f is the given frequency.

The total achievable rate is the throughput of the cluster from a single UAV which is given as

$$Cls_{Throughput} = \sum_{k \epsilon K} A_{dr}, if k_{th} \ \ node\ connected\ with\ i_{th}\ UAV \\ 0, otherwise \tag{3.4}$$

It should be noted that in the equation 3.3 the distance between the node and the LAP device is calculated with the help Euclidean distance approach. Multiple approaches exist in the literature such as received singal strength indicators i.e., RSSI values but however according to the Friss equations of path loss the distance between the nodes is the Euclidean distance. When the nodes are deployed on the network gird the it is assumed that the ground projection is calculated according to the euclidean approach.

It should be noted that the values presented in line of sight values (LoS) and non line of sight (NLoS) are updated each time the experiment runs since the angle of θ is change each time and hence these values are dynamic and no values is fixed. Because of this each time the protocols run the achievable data rate is also changed due to which the final result of the optimization equations change as well. It is this dynamic nature of the EHGR protocol that simulates a real time environment as compared to the traditional approaches.

Examining the figure 3.2 the EHGR target two important layers of the network stack i.e the transport and the data link layer. In the data link layer the objective of the EHGR protocol is to maximize the network connectivity. The connectivity is initially carried out by the game matching theory algorithm as can be seen in equations 3.5, 3.6, 3.7. However when the zones are established and the energy centroid calculations have been carried out the rejection of valid nodes is still considerably high to as near as 30%. The rejected nodes are the nodes that also have important data to transmit but due to any reason such as node placement,terrain or a lowerA_{dr} values received by the UAV from this node at the time of sending association request got the node rejected by the servicing UAV hence the EHGR protocol uses the concept of gateway nodes where each node that has been validated by the UAV are allowed to act as a relay node for the nodes which have these node as a single hop neighbor. This increases connectivity of the entire network from where multiple nodes rejected in different zone get a chance to be associated in the network for data transmission. This approach as shown in the results chapter 4 proves to provide an improvement of 88% over the traditional LEACH protocol and 13% improvement over the ICR routing protocol. The maximum connectivity increases the servicing capacity of the UAVs which ensures optimum resource utilization. An important aspect of the deployment phase is that the UAV offloads the computationally intensive tasks from the nodes and takes the responsibility of ECN node calculation during each round, initial zone formation, broadcasting to member nodes about the newly identified ECN node which along with optimum deployment saves much of the battery power of the nodes.

Once the connectivity of the nodes are finalized the second phase of the EHGR begin which is the data transmission phase. Member nodes transmit data to the ECN node. The ECN node sends the aggregated data to the servicing UAV which again improves the lifetime of the network since the ECN node offloads data at a very near location i.e the servicing UAV instead of sending it to the sink node over a longer distance.

The two phases of the overall working of the EHGR protocol are defined in the figure 3.3 it can be seen that the first phase is focused on the optimum deployment of the nodes. First module of this phase is the random deployment module and the second module is the coverage extension module which uses the D2D gateway nodes for network extension. In the random deployment unlike the ICR routing protocol mentioned in [106] where the deployment is predetermined and remains fix the EHGR protocol keeps the deployment truly random which keeps a close resemblance to the real time scenarios. In the second phase of the figure 3.3 the first module is of data sensing, data forwarding and data aggregation. Data transmission takes takes place at the member nodes when the nodes have data to send to the ECN and also when the ECN offloads the aggregated data to the servicing UAV for data transmission to the control center. Once the data transmission complete the next step is to update the residual energy of the nodes and the entire network. Again as just like the first phase of node deployment in this phase also the servicing UAV offloads the computationally intensive tasks from the nodes which again increases network lifetime in the routing process. In both the phases of the EHGR protocol the energy wastage is minimized which results in very slow decrease of battery power and thereby which ultimately results in extended node life time. Due to this gradual decrease in network energy a node once selected in a zone to serve as the energy centroid node is unchanged over a large number of rounds. This is different form the LEACH based hierarchical protocols which not only ignore the battery power at the time of cluster head election but also ignore the placement of cluster head in each zone.

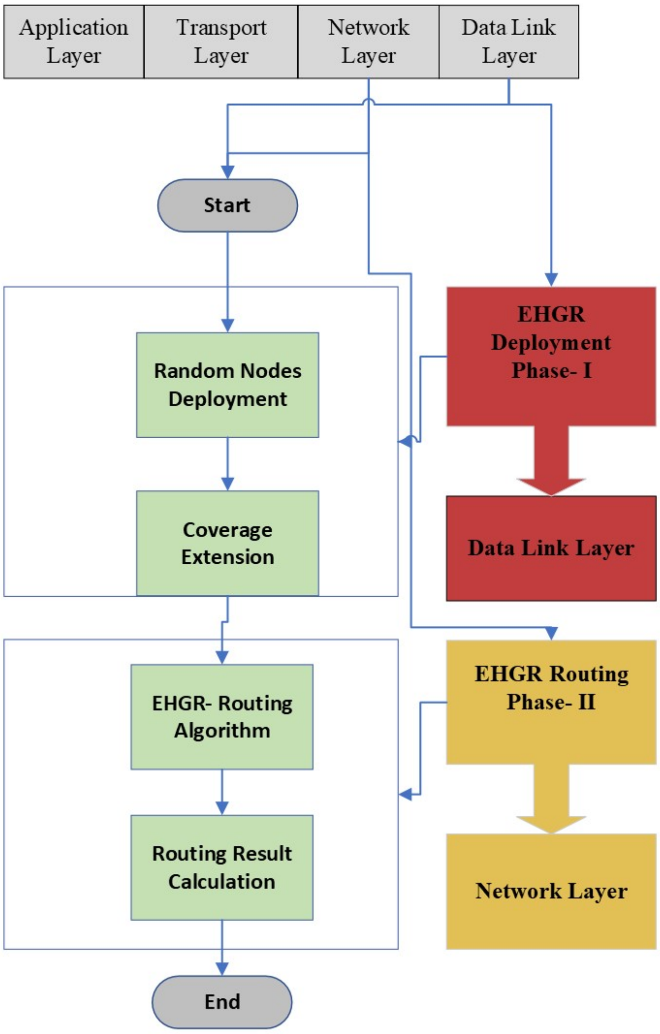

FIGURE 3.3: Overall flow of the EHGR phases

3.2.2 Node Association & ECN-Energy Centroid Node Selection Phase

Network model from Figure 3.1 can be seen that sensor nodes that are in the range of a UAV will be grouped together to establish cluster formation. The cluster formation here is established with the help of a game theory approach.
In game theory the routing is based on cost and payment model where both sides try to maximize the gain. In the association phase the both the parties the sensor nodes and the UAV want to maximize their throughput which means that the sensor nodes try to be grouped with the UAV from which maximum A_{dr} is calculated and vice versa.

The objective function is to

$$max_{A_{dr}} Cls \tag{3.5}$$

$$\sum_{n \epsilon N} \leq 1 \exists \ k \ s.t \sum_{k \epsilon K} A_{dr} \ > 0 \tag{3.6}$$

$$\sum_{k \epsilon K} A_{dr} \leq B_{bandwidth} \exists \ n \epsilon N \ s.t \ B \leq C_o \tag{3.7}$$

As per equation 5 the objective is to maximize the throughput with in each cluster. In equation 6 suggests that a sensor node whose A_{dr} value is greater than zero can be associated with a single UAV or not associated at all. Similarly in equation 7 it is clear that achievable rate can not exceed the channel capacity which sets an upper bound on the used bandwidth. The above equations can now be taken as an optimization problem which is non linear in nature.
The optimization techniques presented in this problem are based on calculating the Line of sight and non Line of sight signal values that were originally presented in the hourani model and hence the optimized problem are concave optimization problems with multiple parameters to be addressed.

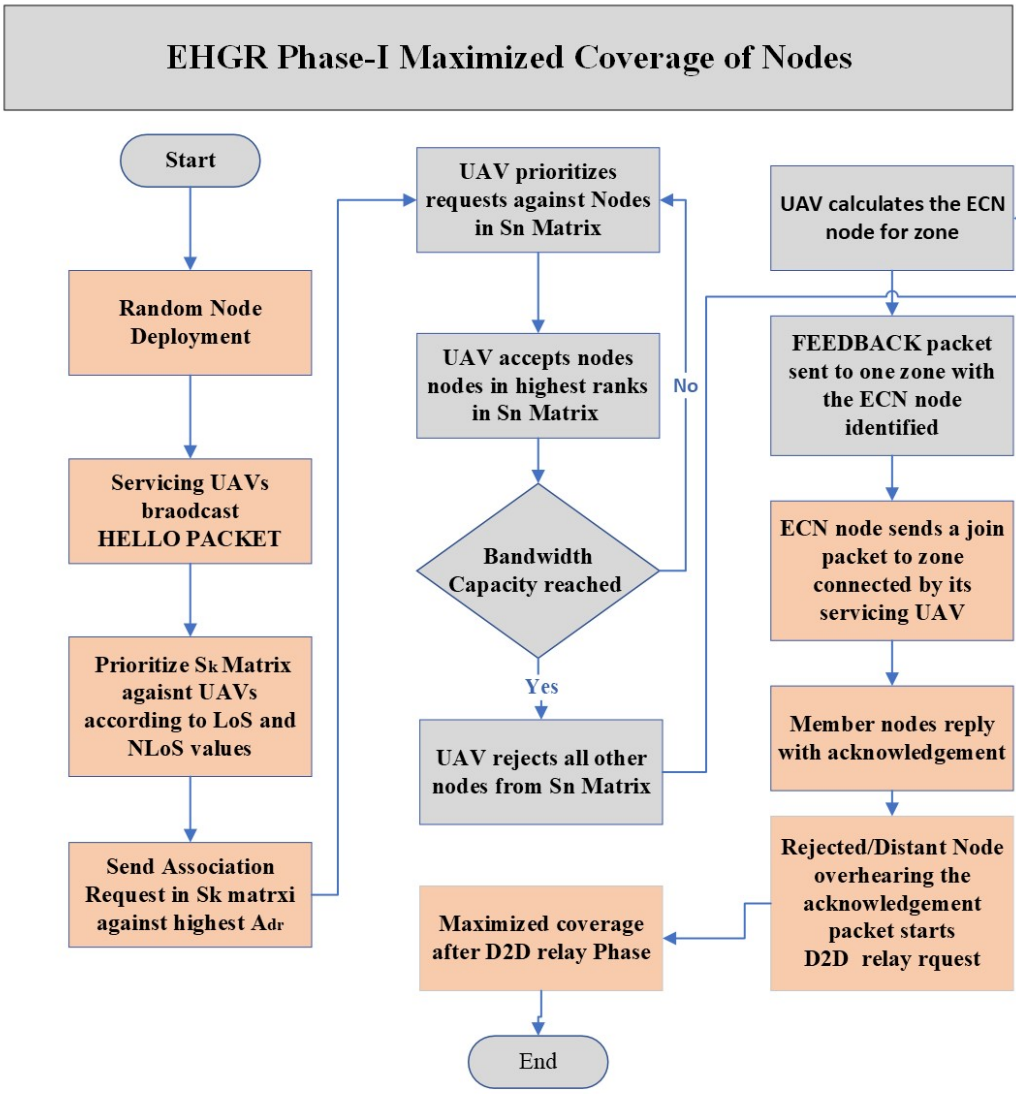

FIGURE 3.4: Node Deployment-first phase of the Deployment of EHGR

The figure 3.4 presents the deployment phase of the EHGR routing protocol. The deployment steps are highlighted below and the same can be followed in the deployment diagram.

3.2.2.1 The First Phase of Deployment

1. Initially **K** set of nodes will be randomly deployed on the network gird and **N** set servicing UAVs will be used for this purpose. Each UAV will have a limited bandwidth available due to which it might not be possible to connect all the nodes from one region.

2. Once the nodes have deployed randomly. The UAVs send a HELLO beacon to the nodes that have been deployed randomly. The beacon packet used for deployment saves individual node's battery power which would otherwise be wasted in sending broadcast messages to one another for zone establishments and cluster head selection an approach adopted by LEACH and DEEC based approaches. Each hello beacon ID of the servicing UAV along with its euclidean coordinates. Each node uses these coordinates received from all the servicing UAVs in the matching theory to identify the uav from which the maximum signals are received.

3. Each node that receives a hello beacon prioritizes the servicing UAVs according to the received signal strength values. The equations used in this process are presented in equation 3.1,3.2 representing the $P(LoS, \Theta)$ and $P(NLoS, \Theta)$ of which an aggregate value is calculated against the achievable data rate as represented in equation 3.3 representing A_{dr}. Each node from the 200 set of K nodes updates the values in a special matrix noted as S_k as can be seen in the table 3.1. The S_k has K row and N coloumns an entry for each node against each servicing UAV.

4. Each node from the S_k matrix select the entry against from the N servicing UAV columns and sends an association request to get associated as a member of the nodes that will be serviced from this particular UAV.

5. In the game theory approaches both sides i.e. the nodes and the UAV's try to optimize the maximum A_{dr} values that are received as represented by equation 3.7.

6. Just like the nodes each servicing UAV has an entry in the S_n matrix as represented in table 3.1 which is used to rank all the nodes from the S_k matrix from which highest achievable data rate will be achieved.

7. Each servicing UAV will reject the remaining nodes from the S_k matrix against the ones from which an association request were received.

8. The procedure is repeated for each servicing UAV until all the maximum capacity is achieved.

9. Once the zone has been identified by the servicing UAVs each of the aerial drones in the zones uses the following equations to update $\overline{x_{ec}}$ and $\overline{y_{ec}}$ to calculate the energy centroid node (ECN node).

$$\overline{x_{ec}} = \frac{\sum_{i=0}^{n} \frac{E_r i}{E_o i} . X}{N}$$

$$\overline{y_{ec}} = \frac{\sum_{i=0}^{n} \frac{E_r i}{E_o i} . Y}{N}$$

   The ECN node is established against the coordinates calculated by the UAV from euclidean pair $(\overline{x_{ec}}, \overline{y_{ec}})$. This is coordinates where the energy of one zone is concentrated. Once the coordinates are figured out the servicing UAVs use the Euclidean distance to figure out the node nearest to these coordinates. This node identified will serve to the ECN node of the zone.

10. The servicing UAV will send a feedback beacon packet to the newly identified member nodes of the zone. The feedback beacon contains the ID of the servicing UAV a value which will be used by ECN node during data offloading and for member nodes to use when providing gateway relay servicing to the non member nodes. The feedback beacon contains the ID of the ECN node that will be used by the group members when the nodes send data to the ECN node and also the average energy of the entire zone.

11. After the feedback packet the ECN node sends a join request packet to the members nodes. The join request from the ECN node itself to the member nodes.

12. Member nodes reply to the join request sent by the ECN node. The nodes that overhear acknowledgment of the nodes but and are still not associated will start the D2D relay method function. The nodes rejected are the valid nodes that must also communicate but get dropped against the servicing UAV due a lesser value of the reported achievable data rate calculated from equation 3.9 as compared to the achievable data rate against other nodes. A node that selects the particular servicing uav from a giving list makes is reported as the first entry in the S_k matrix finally if this node does not have a

corresponding entry in S_n means that this node was dropped in the matching process as the UAV found another node whose A_{dr} reported a higher value. Similarly in the EHGR deployment algorithm all the nodes rejected can be identified by making a comparison of the S_k and S_n matrices.

13. The nodes rejected from the S_k matrix will try to get connected using the gateway network extension techniques.

The second part of the first module is to establish zones when the feedback beacon are sent to the member nodes.

3.2.2.2 The Second Phase of Deployment Module

Once the random deployment is completed and the servicing UAVs share the feedback beacon which indicates the servicing uav id the zone formation phase starts. The zone formation phase save energy of the member nodes which would otherwise spend multiple packets to elect cluster heads and member nodes like in the traditional hierarchical approaches. After the zone formation phase the network extension phase is started to extend the network coverage as presented in the figure 3.6.

The steps of the flow diagram presented in the zone formation figure 3.5 are explained as follows.

1. Once the feedback beacon is received from the servicing UAV by the nodes each zone member examines the energy centroid id to either mark its self as the ECN node or wait for the ECN node to send it a joining request in case it is not the ECN node.

2. Each member node marks its self as a member node and updates it ECN id.The member nodes also mark the id of the servicing UAV to which this zone member belongs to.

3. Each node identified as the energy centroid node sends a join request to the member nodes containing its id along with the ID of the servicing UAV id.

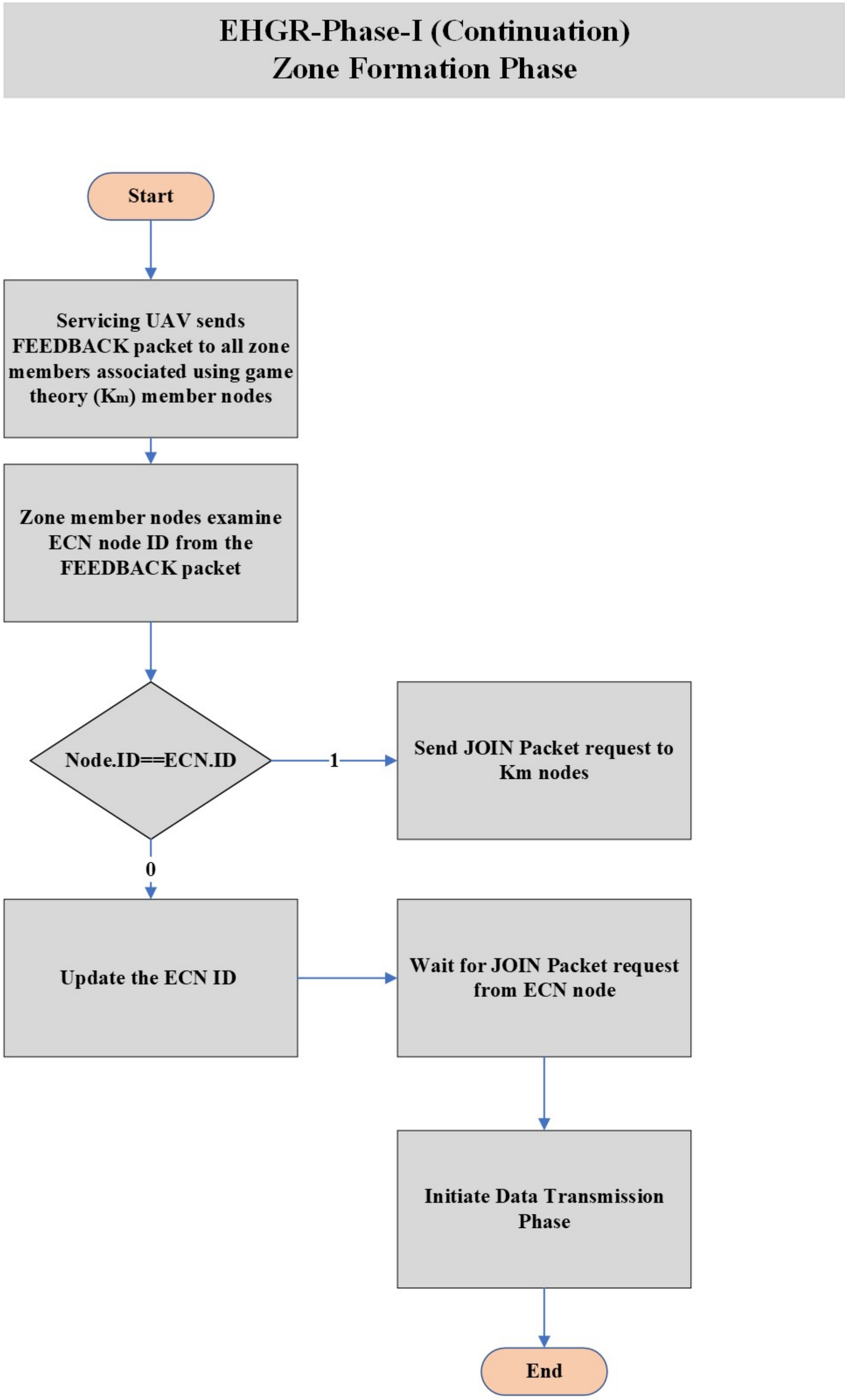

FIGURE 3.5: Network Extension - The second phase of the Deployment process of EHGR

4. Member nodes acknowledge this join request. The nodes that have been dropped out by the servicing UAVs react to the final acknowledgment sent by the member nodes and initiate the final stage of the deployment process which is the network extension process using gateway nodes as explained in the next phase.

Once the deployment phase has been completed each node is mapped to a particular zone which is serviced by one UAV. However some of the nodes fail to be associated with any of the UAV and thus fail to become a member of a zone. The EHGR protocol uses the concept of gateway nodes to map such nodes that have data for transmission to the control centers but fail to get any association from a give zone. Each node that over hears the final acknowledgment of zone members nodes and finds its self to be having the ECN node entry empty knows that it will be opting for the multi hop relay.

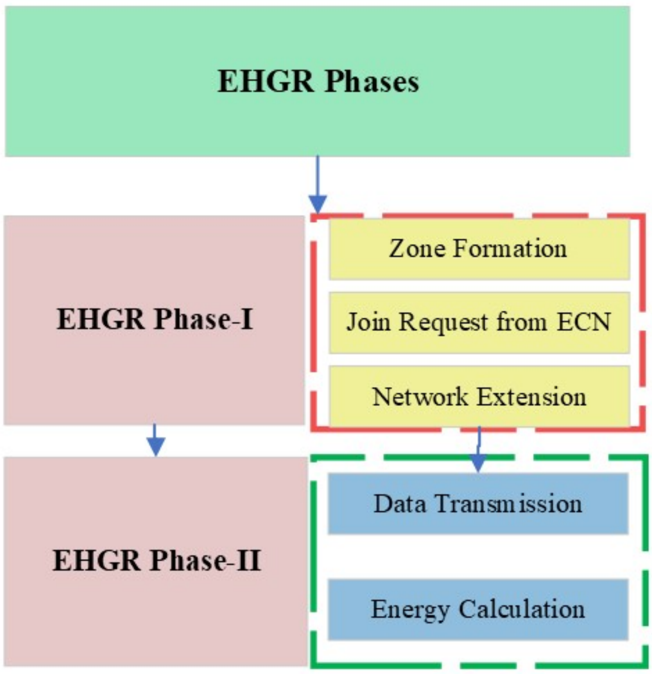

FIGURE 3.6: Overall sequences of the phases in EHGR

The final module in phase-I of the EHGR deployment process is to perform the network extension and nodes that have fail to obtain any association from the servicing UAVs will use D2D mechanism and opt to transmit data to the ECN node through member nodes of a given zone.

The overall sequence of the phases of the EHGR routing protocol are presented in figure 3.6. From this figure it can observed that the first phase of the EHGR is the deployment phase which is further divided into three phases as shown in the red dotted lines. Figures 3.4, 3.5 and 3.6 all conform to the first phase of the EHGR protocol. Once the first phase is complete the routing phase is initiated. It is important to note that the input to the second phase is the final mapping of the nodes from the output generated from phase I. The modules of the phases II are shown in the green dotted lines and the figures 3.8, 3.9 both conform to the second phase of the EHGR protocol.

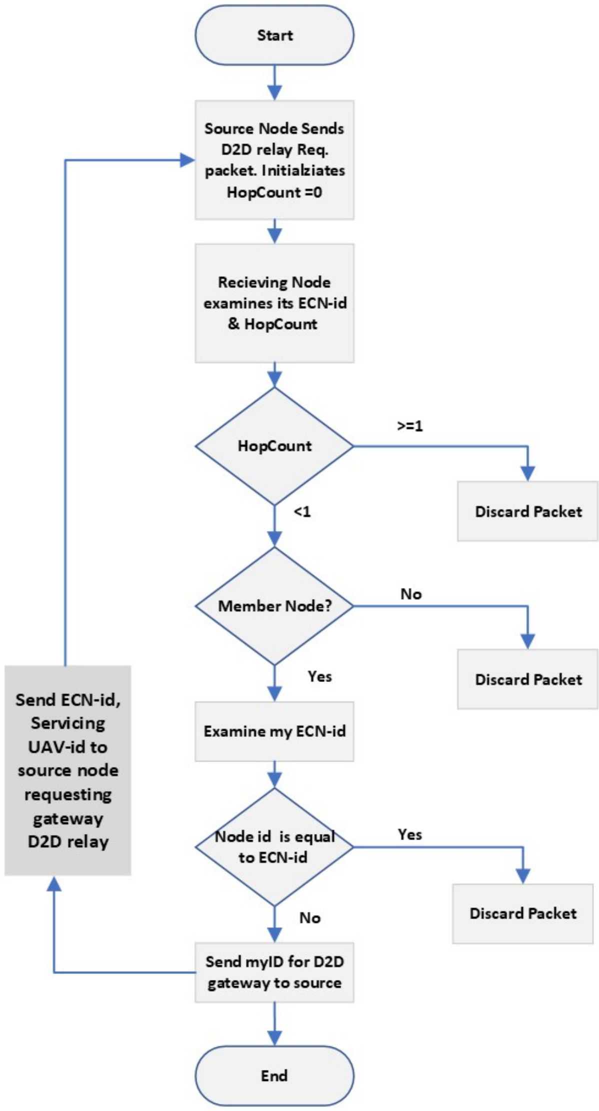

FIGURE 3.7: Network Extension for Maximizing Coverage through D2D Relay Node

Examining the figure 3.7 the deployment process further progresses in an attempt to maximize the nodes rejected from the deployment phase. Note that not all the nodes can be connected first because in a random deployment some of the nodes get placed in the far edge of the zone and it can be possible that these nodes miss the broadcast send by the servicing uavs and the re acknowledgments sent by the member nodes to the servicing uavs secondly the nodes can also be rejected due to the fact that no one node hop relay node is identified in which scenario it will be dropped since the EHGR covers only relay requests of node having a maximum of one hop distance from the member nodes that will be identified to serve as the gateway node to relay data to its ECN node. If the recipient node determines the ECN id and identifies that it is itself the centroid node of the then again it will drop the D2D request packet since in this study we have made an assumption that the zone head node will not relay data for the nodes sending it the request for D2D forwarding.
The flow chart in figure 3.7 is explained as follows:

3.2.2.3 Network Extension Module 2 Phase-I

1. The servicing UAV sends feedback beacon to the nodes associated from the game theory. These node receive the servicing ID of the UAV of that zone along with the ID of the energy centroid of the node. The nodes use these values in the data transmission process to send the sensed data to the ECN node for forwarding it to the control center.

2. The dropped nodes now considered as the source node will initiate the D2D relay request from the neighboring nodes. The source node will set the initial Hopcount to 0.

3. The member node that received the D2D relay request will check the hop count of the requesting source node and if the hop count is greater then one the request of the source node is dropped since only one hop nodes will be considered.

4. If the receiving zone member node finds that the hop count is valid it accepts the requesting source node's D2D relay packet but at the same it examines

the weather it is an ECN node for the zone or not. Only member nodes are allowed to serve as the gateway node. In case the node finds itself to be the ECN zone it again discards the source's request.

5. If however the member nodes accepts the request it checks to see weather it is a member node or not again if the node finds its self to be one of the nodes dropped by the servicing UAVs earlier it again discards the source node's requesting packet.

6. If however it is a zone member node it then accepts the request for acting as a relay node for the current source node. The node sends the source node its id alon gwith the servicing ID of the ECN node. The new node becomes a member of the current node and hence capacity of the network is increases along with the capacity of the servicing UAV.

Once the deployment phase is completed all possible nodes having data for transmission to the control center have been mapped. Chapter 4 highlights the results of the deployment which indicate a significant improvement as compared to the existing literature in the network deployment phase. EHGR out performs the existing protocols since the deployment phase of the nodes is itself a multi step in which first zones are established with the help of servicing UAVs which also establish zones and identify the ECN nodes. Once the zones are mapped on the network grid D2D mechanism is initiated and all the remaining nodes having data for transmission but not associated are further brought into the network for data transmission. All these steps combined establish a superior connectivity and coverage of the wireless sensor network.
The second phase of the EHGR protocol is the routing phase. The input to the routing phase are the zones and mapping of the nodes in respective zone. Therefore the input of the routing phase is the final mapping the deployment phase I.

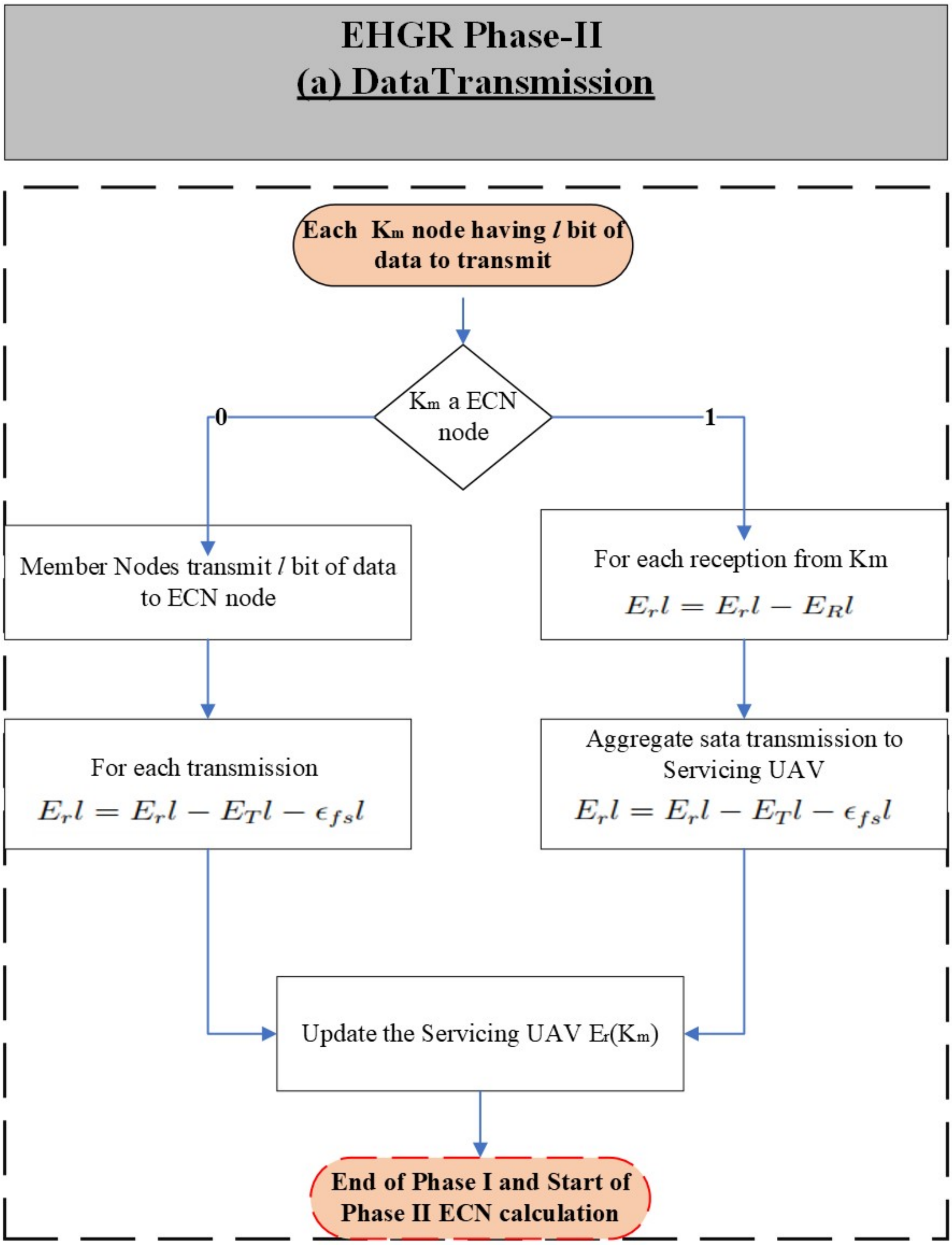

FIGURE 3.8: Routing and data transmission Phase II first module

3.2.2.4 Start of the Routing and Data Transmission Phase-II

The starting input to the phase II routing is the set of the mapped nodes considered as the K_m node. Each K_m node belongs to a zone and if it has data to transmit it will initiate the routing phase. The red dotted line over the figure 3.8 indicates that the starting point of this phase is the input of the final completion of the deployment phase.

In the EHGR routing protocol once the deployment phase has been finalized which means that the maximum number of nodes are connected along with those nodes that were originally rejected by the servicing UAVs due to either placement or having a lower values of the A_{dr} of the node from the UAV. After the deployment phase the next phase of the data transmission begins. Figure 3.8 gives the details about the working of the flow chart which covers the first module of the routing process. The details are as explained as follows:

1. Each node from the member nodes of the K_m set which has l bit of data to transmit will wait for its turn. After the feedback beacon from the servicing UAV the ECN node sends a join request for all the member nodes to which each node replies with an acknowledgment. The ECN node sends a schedule in the join request which all the nodes in the zone under the particular ECN node comply. This approach is similar to the LEACH based hierarchical approach. In the traditional leach based hierarchical approaches this schedule is generated from the cluster head node for one cluster similarly in the same way the ECN node also creates a schedule which indicates the time slot when each node will get a chance to transmit data.

2. At the time of data transmission an energy model is adopted in which for each transmission the node is updated it residual energy accordingly. The energy dissipation is calculated at the time of receiving as well. The energy model is presented in equation 3.10 and also used in the table 3.5. In case if a member node wants to transmit data to the ECN node then according to table 3.6 the
$E_r l = E_r l - E_T l - \epsilon_{fs} l$
are used to reduce the energy of the member node. In this model $E_r l$ is the residual energy of the node remaining after transmission of the l bits of data. $E_T l$ is the energy that is dissipated for a single node for one time transmission of l bits of data to the energy centroid node. Each time a node transmits data packet of l bit 50 nJ /bit are deducted.

3. If however it is the energy centroid node then each ECN node not only receive data from the cluster member nodes but also transmits data to the servicing UAV. Hence the energy model updates the energy of the ECN node twice one for the duration when data is received and one when data offloading takes place.
   When the ECN node receives data from the cluster member it uses
   $E_r l = E_r l - E_R l$
   $E_R l$ is the energy that is dissipated for receiving l bit of data from each member node. The data receive activity is repeated for all the member nodes and each if it has data to transmit it will do so at the designated time slot. When the data receive is completed from all the member nodes data offloading phase begins. The ECN nodes transmit the aggregated data to the servicing uav and the
   $E_r l = E_r l - E_T l - \epsilon_{fs} l$
   equation is used to update the dissipated energy of the ECN node.

4. After the data transmission round and before the beginning of the next round each member node along with the ECN node again sends the residual energy of the servicing UAV. The servicing UAV use these values to update the energy of the entire zone. Each time the update is sent to the servicing UAV before the start of the next round the UAVs calculate the energy centroid coordinates to identify the new ECN node. The procedure adopted offloads major computational overhead from the individual member nodes which are already battery constrained. This approach extends the network lifetime which also increases individual nodal life.

In the figure 3.9 final phase of the routing module of the EHGR routing protocol is presented. This module start with the completion of the data transmission phase. Once the data transmission module in the routing phase is completed all the member nodes transmit their residual energy to the servicing UAV. The flow chart is explained below as follows:

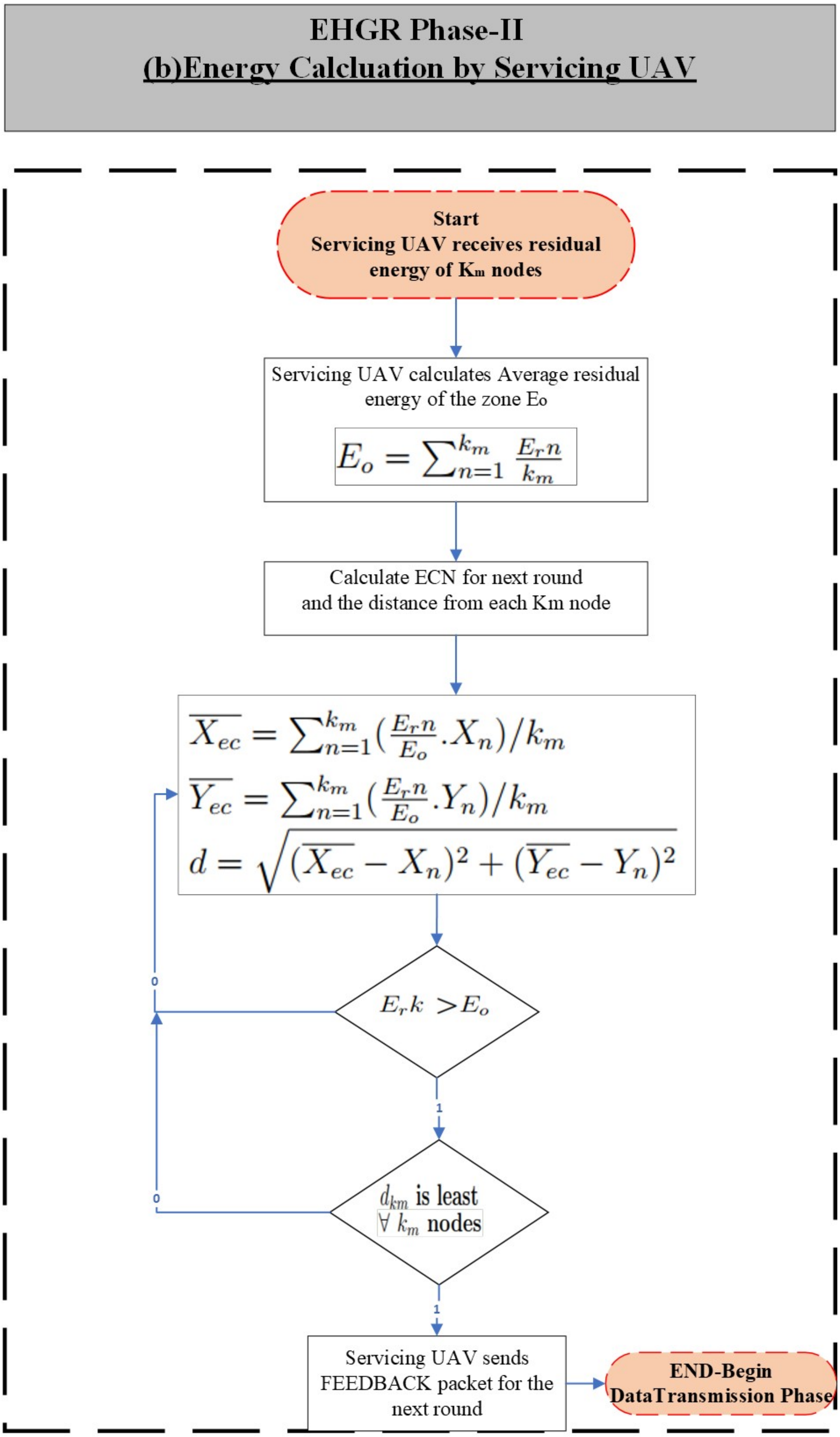

FIGURE 3.9: Routing and data transmission Phase II Second module

1. Each of the servicing UAVs calculates the residual energy of the entire zone. All member nodes transmit their residual energy of which an average value noted as E_o is calculated for the next round.

   $E_o = \sum_{n=1}^{k_m} \frac{E_r n}{k_m}$

2. Before the start of the next round the residual energy of the nodes is used in the calculation of the new coordinates.

   $\overline{X_{ec}} = \sum_{n=1}^{k_m} (\frac{E_r n}{E_o}.X_n)/k_m$
   $\overline{Y_{ec}} = \sum_{n=1}^{k_m} (\frac{E_r n}{E_o}.Y_n)/k_m$

   both the x coordinate and y coordinate identify a new coordinate on the zone where the center of the energy is concentrated. After this the UAV will use the euclidean distance to figure out the member node that lies closet to the calculated coordinates. This node will serve to be the ECN node for the next round. Note that in the LEACH protocol this calculation is performed by the cluster members which is another major source of energy drainage of the node due to which network lifetime is reduced. However in EHGR this task is also shifted to the servicing UAV to increase the network life time.

3. Information of the newly selected node that will serve as the ECN node is broadcast to the zone members through the feedback beacon that is used to start the data transmission process.

3.2.2.5 Node Association Algorithm

In Table 3.1 the algorithm of Matlab program used for UAV nodes association is presented. The 2 kilometer grid is simulated on the Matlab sensor nodes are randomly deployed on the grid belonging to the set K. The algorithm is run by all the sensor nodes and the UAVs at the same time in parallel. Both the nodes and the UAVs try to maximize the values obtained from equation 3.5, 3.6, 3.7. Each node generates a list of servicing UAVs from which LoS and NLoS signals are received. The nodes try to develop association with the UAV from the list of servicing UAVs from which it is having highest received signal strength reported from Los and NLos values calculated through A_{dr}. Each UAV will be generating its own list from the K set of nodes. The bandwidth is limited with the UAVs and it is not possible for the UAV to accommodate all the nodes requesting for association. Just like the nodes each UAV will confirm the association request acknowledgment for only those nodes from which highest A_{dr} values are reported. Since the bandwidth is limited on each servicing UAV therefore a node that has marked a given UAV for association from its list might be rejected from that UAV due to bandwidth limitation. The optimization functions of game theory can be used against multiple criteria to develop associations between participating entities. In the current scenario it can be used against battery power, LoS, NLoS values, traffic prioritization etc. In this study only the line of sight and non line of sight Los and NLos values are used to develop association between the nodes and the servicing UAVs. The target of the node association program is to have a maximum association.

Table 3.1: Matching Algorithm for Association between sensor nodes & UAVs

Algorithm for Node Association
Input Data: K, N, B **Output:** Maximiaze Node Association **Vector Matrix Initializations:** S_k, Matrix of all k belong to K node, S_n, Matrix of all n belong to N UAVs
Initial Deployment phase
Each node k belong to K generates a list of each UAVs with in distance r B_n total bandwidth of the UAV or the resources
Application of the UAV and the sensor Node using Game Theory
Each UAV in n belonging to S_n sends a HELLO message Sensor nodes prioritize UAVs according to the A_{dr} values of each UAV **while (S_k matrix is !=0) or Max $B_n$for each UAV is achieved** Each sensor node k belonging to S_k sends the association request to UAV in S_n from which it get highest A_{dr} Each UAV n in S_n prioritizes in reverse the k nodes in S_k according to the A_{dr} Each UAV n associates the node that receive highest Adr value from it Once the sensor node is associated with a UAV it is removed from the list of nodes in the Sk matrix **End while**

In order to save the energy of the sensor nodes initially establishing the clusters and further selection of the energy centroid the UAVs initiate a HELLO message formation as shown in table 3.2 each entry of the HELLO message is one byte in length. The sensor node use this HELLO message to rank all the UAVs according the their respective A_{dr} data rate.

From line 8 onwards in table 3.1 till the end of the while loop two different phases take place one in which sensor nodes rank the UAVs according to the highest data rate and second in which UAVs also examine the A_{dr} values of the requesting sensor nodes to associate the best candidates and reject the rest. Once each node has been associated a Feed Back reply packet is generated from each UAV as shown in table 3.3 and sent to all associated sensor nodes in one cluster. The feedback reply packet is generated from the servicing UAV which indicates the ID of the servicing UAV. The message is sent to all the nodes within one cluster group that has been generated after the association algorithm is run.

TABLE 3.2: HELLO message format

Message Type	Sender ID	X-Cordinate	Y-Cordinate

With the help of this message all the nodes learn about the current ECN node that will act as the cluster head node for the current round. The servicing UAV will be communicating with the ECN node of that particular cluster only while the member nodes will send data to the ECN node. Servicing UAV-ID will be used for D2D forwarding for network extension. Once the energy centroid node is calculated it will send a join request to all the member nodes to establish link in the cluster.

TABLE 3.3: Feedback reply from UAV

Message Type	Energy-Centroid Node ID	Servicing UAV-ID	Average Energy

Table 3.4 presents the join packet that will be used by the energy centroid node. Once the ECN node has been elected for the new round by the servicing UAV through the feedback reply packet the ECN node generates a join request packet for all the zone members. Each zone member replies with the acknowledgment. It can be seen in the join packet that the ECN node transmit to the zone members

contains a TDMA based time slots that each zone member will follow which means that each ECN node will accept the data from zone member in independent terms.

TABLE 3.4: Join Request from the Energy Centroid Node

Message Type	Energy-Centroid Nod-ID	Servicing UAV-ID	TDMA Based Node Schedule

3.2.2.6 Energy Centroid Nodes ECN

LEECH based hierarchical routing protocols use random variables at the end of each round to identify the cluster heads. This technique distributes the burden of bearing data aggregation and communication with the control center on all the member nodes within one cluster. In real time simulations when the actual cluster head nodes are identified for each round the selection of the cluster head varies in terms of node's position. A node that is positioned at the edge of a cluster can become cluster head based in a round within an iterations based on the probability density function and its residual energy. Due to this some of the nodes with in the cluster in that particular round will not be able to communicate with the cluster head due to location. This problem was identified by Jian Shen et al. in [114] where the authors proposed a unique solution to over this problem faced by all the hierarchical routing protocols. The solution provided by Jian Shen focuses on identifying the center of energy for each round within the cluster. The center of energy steadily changes its location as compared to traditional cluster based approaches in which any node irrespective of its location is chosen to be the cluster head and the change in cluster head location is abrupt. Energy efficient routing protocols can benefit from this concept since the energy dissipation during cluster formation and routing processes is uniformly distributed within the clusters. This is evident if we examine figure 1.1 it can be seen that the concentration of the sensor nodes in each cluster formation is biased having dense deployment at one side and sparse on the other. This concept is used by Jian Shen et al. in [114] in which energy centroid is calculated for each cluster and the node nearest to the energy centroid is taken as the cluster head. This energy centroid cluster head will gather data from the neighboring nodes of same cluster and forward it to the servicing UAV that will route it towards the control center.

$$\overline{x_{ec}} = \frac{\sum_{i=0}^{n} \frac{E_r i}{E_o i}.X}{N} \tag{3.8}$$

$$\overline{y_{ec}} = \frac{\sum_{i=0}^{n} \frac{E_r i}{E_o i}.Y}{N} \tag{3.9}$$

In the equation 3.8 and 3.9 X is the X coordinate of each node and Y is the Y coordinate of each node on the network grid. N is the total number of nodes in a given zone. $E_r i$ is the remaining energy of the ith node which is used for the division with the initial energy of the node denoted by $E_o i$. Once The servicing UAV makes these calculations an coordinate point on the (x,y) plane is identified as labeled by $(\overline{x_{ec}}, \overline{y_{ec}})$ which is considered as the center of energy for a given zone.

3.2.2.7 Gateway Node Selection for D2D Multi Hop Relay

In a UAV assisted WSN selection of gateway nodes can improve the coverage and network throughput. Gateway nodes increase the network connectivity reducing the number of nodes that have failed to develop any association with any of the UAVs after applying game theory model or these can be the nodes have failed to hear any of the broadcast from the UAV i.e HELLO message.

UAV coverage might be partial where some of the sensor nodes are not in the coverage zone due to physical terrain due to which those nodes can only route data towards the control center through gateway nodes as pointed out by K. Ali et al in [91].

Table 3.5: Data transmission and energy centroid rotation for each round

Algorithm for data-transmission & ECN-rotation for each round
Phase-I
for j = 1 : k s.t. k $\in$ to K node set /*each k node having l bits to transmit */
if(j==cluster member)
$E_r l = E_r l - E_T l - \epsilon_{fs} l$ /*residual energy E_r updated at each transmission*/

if(j==gateway node)

$E_r l = E_r l - E_T l - \epsilon_{fs} l$

do { $E_r l = E_r l - E_R l$

$E_r l = E_r l - E_T l - \epsilon_{fs} l$ }

else-if (j==ECN){

do { $E_r l = E_r l - E_R l$

while (data signal is sensed on receiver)

$E_r l = E_r l - E_T l - \epsilon_{fs} l$ }

for i = 1 : k_m

Each node (k_m) send location & residual energy $E_r(k_m)$ to the servicing UAV

end-for

Phase-II

Servicing-UAV calculates average energy of the cluster

for n = 1: k_m $E_o = \sum_{n=1}^{k_m} \frac{E_r[n]}{k_m}$

end for

Servicing UAV updates the energy centroid

for n = 1 : k_m

$\overline{X_{ec}} = \sum_{n=1}^{k_m} (\frac{E_r[n]}{E_o}.X_n)/k_m$ X_n is x-axis of each node n

$\overline{Y_{ec}} = \sum_{n=1}^{k_m} (\frac{E_r[n]}{E_o}.Y_n)/k_m$ Y_n is y-axis of each node n

$d = \sqrt{(\overline{X_{ec}} - X[n])^2 + (\overline{Y_{ec}} - Y[n])^2}$ **end for**

for k = 1 : k_m

if ($E_r[k]$ >E_o **&&** $d[k]$ **is least** $\forall$ k_m **nodes) {**

send Feedback packet to k_m cluster members.**} end-for**

ECN node sends join request to all k_m members.

end-for main loop

TABLE 3.6: Cluster formation by member and ECN node

Algorithm for cluster formation after the feedback packet

Servicing-UAV sends Feedback message to all k_m cluster member

for i = 1 : k_m

each i node examine the node ID

```
if (Node(i).ID == ECN.ID){
        Mark as the ECN & Open receiver antennas
        Send Join request packet to the cluster members
  }
else-if(Node(i).ID != ECN.ID){
        Wait to receive join request packet
        update the ECN-ID for transmission
        send join reply
        data transmission phase
}
end-for
```

Nodes that have not received the HELLO and the Feed Back message from the UAV but overheard the acknowledgment to the join request sent from the centroid node will be connected to the same cluster head using the D2D forwarding in figure 1 the green nodes. D2D routing will help to reduce the rejected nodes thus increasing network connectivity and minimizing rejections. From figure 1.1 each green colored sensor node will send a D2D relay request packet to the neighboring node. In this study one hop relay request will be accepted. D2D schematic flow diagram is presented in figure 3.6.

If the receiver node that receives a relay request packet finds that the hop is greater then 1 it discards since 1 hop relay is considered in this study. Seminal study for energy aware WSN conducted by Heinzelman et al in [54] mathematically proved that direct transmission to the receiver gateway dissipates less energy as compared to multi hop. Similarly if the cluster head id of the energy centroid node is missing then it discards the packet since the receiver is also unaware of the gateway node and is also in search for it thus hop limit will be greater than 1 again. The nodes lying outside the circular grid will use use D2D forwarding techniques such as shortest path routing, flooding neighbouring approach etc. to reach the gateway node which will forward the data collected to the energy centroid node in the respective cluster. The energy centroid node will forward the data to the control center through UAVs.

This study uses the first order energy model proposed by Heinzelman et al in [79]. According to Heinzelman the energy required to transmit l bits of data at d apart

$$E_{Tx,d}(l,d) = E_{Rx,d}(l,d) = E(l,d) = \Big\{ l(e_r + e_t + \epsilon_{fsd^2}) \tag{3.10}$$

In this model l is the packet length in bits, e_r and e_t are energy spend by a node during transmission and receiving over distance d with the UAV and its self.

3.2.3 Data Transmission & Energy Centroid Rotation Phase

Once the optimal deployment of the sensor nodes has been accomplished data transmission begins. Sensor nodes send data to the centroid node (ECN). The ECN forwards the data to the UAV which will relay it to the control center. After each successful transmission the ECN examines its residual energy which if falls below a threshold initiates the ECN transfer request to the servicing UAV. The UAV recalculates the average energy of the cluster to select a new ECN. The ECN sends a new join request to the member nodes. The routing algorithm is presented in table 3.5.

The data transmission round in each cluster is divided into two phases. Initially every node that within a cluster having data to transmit will send the data to the ECN node. During transmission the energy dissipated is equal to the subtraction of the energy required during transmission of l bits $E_T l$,the transmit amplifier energy ϵ_{fsd^2} from the node's residual energy E_r. Similarly for receiving the l bits packets the energy required only subtracts the receive energy $E_r l$ for l bit and the amplifier circuit energy ϵ_{fsd^2} is excluded. In table 3.5 $phase - I$ node residual energy during transmission and the residual energy of the ECN node for accumulating data is calculated. Just before finishing this phase all nodes within a cluster send residual energy and location to servicing UAV for calculating energy centroid node for the next round. In the UAV assisted WSN the energy lost due to computation of the cluster head as done previously involves cluster head calculations to be performed by the existing cluster head which reduces places additional burden on the CH node that results in reduced network lifetime and early dead node detection. However in this study just before the termination of each round the residual energy is sent to the UAV which offloads the existing ECN node for making calculation in the next round. This approach extends the network lifetime and further delays the first dead node reporting.

In the second phase of the algorithm the servicing UAV will calculated the energy centroid for the cluster by considering the residual energy E_r reported by each node from the k_m nodes. Once the new ECN is calculated the the servicing UAV sends feedback packet to the nodes. The new ECN node will send join request to all the cluster members to which the cluster member reply by acknowledging the join packet. All nodes with in the cluster examine the node id with its own id. If the node id matches with the id sent in the feedback message the node marks its self as the ECN node and sends the join request. Otherwise the node with different id waits for the join request from the ECN node to become a member node. The joining algorithm is presented in table 3.6.

3.2.4 Complexity of the EHGR Protocol

In this section we analyze the overall complexity of the algorithms presented in the deployment and routing phases. In the deployment phase after the HELLO packet is broadcast by the servicing UAV the nodes prioritize the UAV's according to the signal values received each node makes an independent decision in given time frame and sends the association request to the servicing UAV from which the highest Adr values are reported. Therefore the we can say that the run time for each node is $\theta(1)$. Since we have made an assumption that there is abundant energy power available on the UAV's side therefore the time complexity of the UAV is not needed since it is not energy constrained. The ECN joining algorithm presented in table 3.6 sends the joining request to the zones member and so if there are n nodes and k number of servicing UAVs then assuming a random time the overall time complexity will be $\theta(nk)$. The overhead being faced during the routing phase of table 3.5 is also $\theta(n)$ since there are n nodes and the cluster head waits for each node to send data that it aggregates over a given time schedule in which each node follows it time table.

The second phase of the routing protocol of table 3.5 has run time $\theta(n^2)$ but however since the calculations are performed by the servicing UAV and not the nodes so there is no penalty in terms of energy drainage for the second stage in phase II. Therefore the overall complexity of the EHGR is $\theta(n)$ in all the phases of data routing as well as deployment for optimized coverage.

3.3 Summary

In this chapter the network setup phase of the EHGR protocol is presented. Since EHGR is a multi phase protocol therefore each phase has been highlighted in detail along with the mathematical modeling used in the deployment phase and the routing phase. A unique feature is that instead of using a traditional clustering algorithm for zone establishment as in the case with most hierarchical routing protocols EHGR uses game theory approach. The objective in the game is to maximize the objective function equations on each side i.e all the players involved. The deployment algorithms and the routing algorithm implemented are presented in table 3.1, 3.5 and 3.6. The algorithms are implemented using matlab and in the next chapter the results of the implementation will be presented. In this chapter we have also presented the limitation that are currently faced by the EHGR routing protocol that currently it is only providing node to node and node to control center coverage. In the future UAV to UAV and UAV to control center modules will be added as an extension to the EHGR. Also time complexity of the overall protocol is calculated to determine its load on the nodes.

Chapter 4

Results and Discussion

In the network setup and implementation phase of chap 3 two important phases have been implemented. First phase addresses the optimized deployment of the nodes. If the deployment of the nodes is not efficient the nodes will drain energy rapidly due to greater distance between the nodes and their cluster heads due to which more energy will be required to transmit the data to over to cluster heads. The cluster heads will dissipate more energy as the transmission will require the cluster head node to keep the receiver antennas for longer duration. Once the data has been gathered from the entire network the cluster head node will use the transmitter antennas to send the data to the control center. If the deployment is not efficient the cluster head node will drain its energy rapidly since it will use more power for transmission while communicating with the control center as compared to the situation in which the deployment of the nodes and the cluster head is optimized. This important aspect is addressed in the first phase of this study.
Optimized coverage is an important module for any network. If the nodes are not deployed efficiently then the rejection rate of valid nodes can reach upto 35% as has been pointed out in the figure 2.5 and figure 2.6. Both the figures have simulated the node associations with the cluster heads.
LEECH and DEEC based hierarchical protocol all suffer from the problem in which the nodes are considered for routing only but their placement is ignored. The objective of these protocols is to provide routing inside a wireless sensor network without considering how the nodes have been deployed. These protocols

are inefficient in terms of optimized deployments for modern day networks where the number of sensor nodes reaches from hundreds to thousands.

In the second phase of this study energy efficient routing algorithm is presented. In the proposed hierarchical routing algorithm the network formation phase in which energy centroid nodes are established and game theory is used to get the nodes associated with the ECN nodes is partially offloaded to the servicing UAVs which performs the necessary calculations and offloads the computationally intensive tasks from the nodes to the servicing UAVs. In the hierarchical routing the network formation takes place in every iteration. Similarly in each round within an iteration ECN nodes are calculated. If the sensor nodes are used to perform these calculations the energy will drain quickly.

The routing algorithm therefore extends the network lifetime by offloading this to the servicing UAVs. During the second part of the routing algorithm the sensor nodes forward the data to the ECN nodes. The ECN nodes communicates with the servicing UAVs to forward the data from the ECN nodes to the control centers.

In hierarchical routing algorithms the cluster heads forward the aggregated data of the member nodes to the control centers directly due to which energy routing holes are created since the cluster head drains its energy rapidly as compared to the rest of the nodes.

In this study the UAVs perform this calculations and the ECN nodes communicate with the servicing UAVs only. Again in the second part of the routing algorithm routing holes are avoided and the entire network dissipates the energy uniformly which again increases network lifetime. Lastly the nodes that use the relay nodes for getting associated with the ECN nodes are also considered in this study. Single hop routing is used as a forwarding strategy.

The energy of the nodes that will be performing the relay functionality will be deducted twice once for forwarding its own sensed data to the ECN node and second the deduction for acting as a relay in which both the transmit and the receiver antennas are used again. Both the energy consumption models have been addressed in the routing protocol.

4.1 Network Extension and Optimized Coverage during Deployment Phase-I in EHGR

The experimental setup is conducted in matlab with parameter values shown in table 4.1. The experimental grid is established after which 200 sensor node are randomly deployed. The grid measure $400m^2$ for case when two servicing UAV's are deployed and $3600m^2$ when nine servicing UAV's are deployed. Location of the control center as from figure 1 is outside the network that can be accessed only the UAVs.

TABLE 4.1: Parameter Values used in Simulation

Simulation Parameters	**Values**
Network area	400 m^2, $3600m^2$
Control Center	Outside network area
Sensor Node	200
ECN Nodes	4, 9
Initial Energy	0.5J
Data Aggregation energy	5 nJ/bit/signal
Transmit Energy	50 nJ/bit
Receive Energy	50 nJ/bit
ϵ_{fs}	10 pJ/bit/m^2
ϵ_{amp}	0.0013 pJ/bit/m^4
Packet size	200 bit
Bandwidth availability per UAV	10 Mbps
UAVs availability	Varies with number of Clusters
α, β	9.61, 0.16

Figure 4.1 presents the results of the mapping of nodes during the deployment phase. Initially 2% of the sensor nodes were assumed to be the ECN nodes. The four ECN nodes can be seen in the first part of the diagram. In the first part of the figure 4.1 simple deployment scenario is presented. The scenario highlights how the

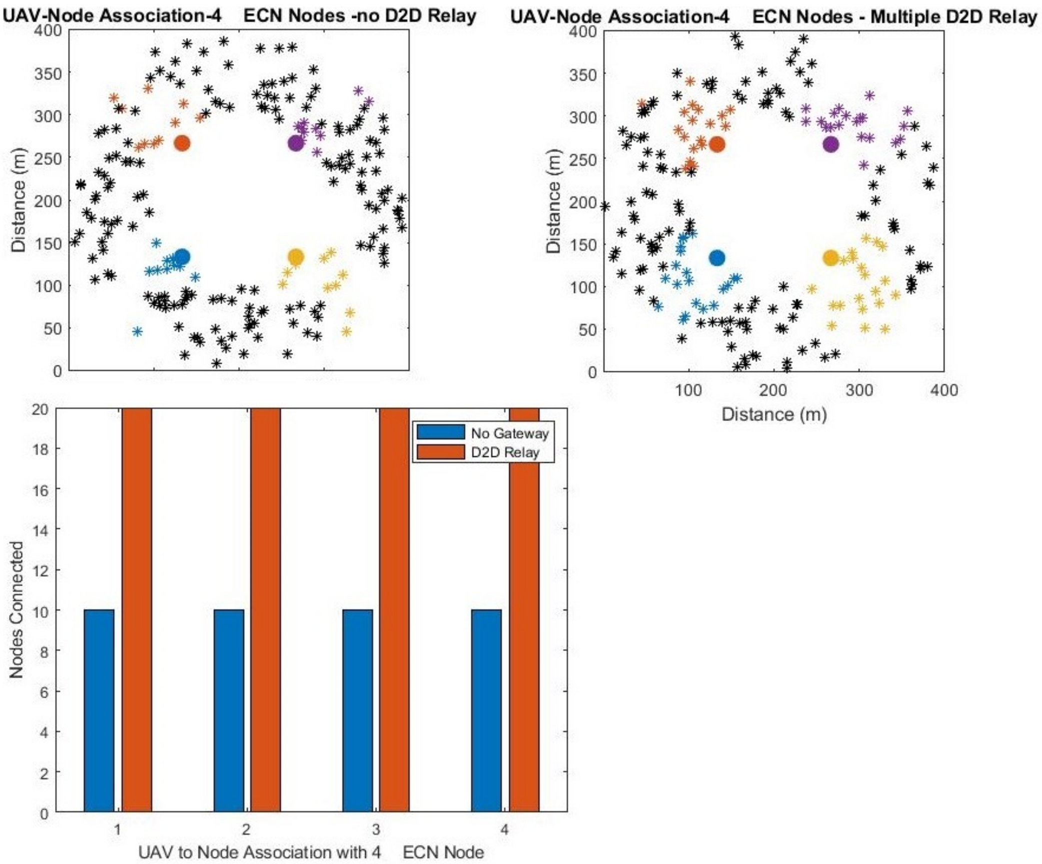

FIGURE 4.1: UAV to Node association with varying ECN node with 2% ECN

traditional hierarchical LEACH and DEEC based protocols map the nodes to the cluster head nodes (ECN nodes in this study). 200 nodes have been deployed on the grid (Examine Table 4.1). The bandwidth of each node is taken to be 1Mbps where as the bandwidth of the servicing UAVs is 10Mbps. Each UAV achieve its maximum capacity however large number of the nodes still remain to be connected. In the second part of the figure 4.1 with the use of gateway nodes it can be seen that this reaches to double. The third part of the figure shows the exact connectivity in bar chart of the nodes for the scenario in which no gateway node was used (in blue) and the scenario in which gateways nodes were used (in orange). The black dotted nodes are the nodes which have failed to be associated with any of the ECN nodes. With the use of gateways nodes the number of black dotted nodes are reduced but have not decreased to zero this is because of the fact that one hop gateway nodes are selected only which means that each node connected to the ECN node is allowed to forward the data of one extra node that have failed to develop association with any of the ECN nodes during the deployment phase. If

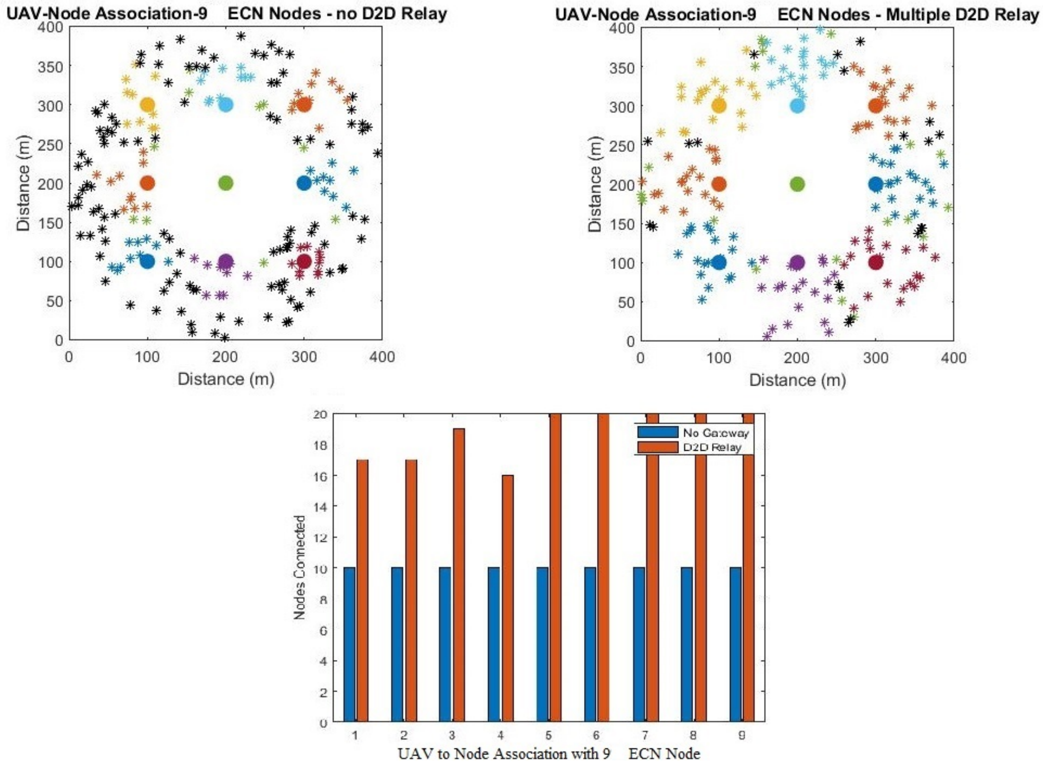

FIGURE 4.2: UAV to Node association with varying ECN node with 4.5% ECN

either the number of one hop contraint is relaxed or the bandwidth requirement of the nodes is reduced the connectivity can further be improved. However for modern day applications bandwidth requirements are increasing. If the number of the ECN nodes are however increased from 4 ECN nodes to 9 ECN nodes i.e from 2% to 4.5% the connectivity can again be increased the fact can bee observed in the Figure 4.2.

In figure 4.2 the same scenario is presented as compared to figure 4.1 however the number of ECN nodes are increased from 4 to 9. With 9 ECN nodes it can be seen that the rejection during network formation phase can be reduced to a great extent when the gateway nodes are deployed. However with the use of extended number of ECN nodes and gateway nodes the number of black dotted nodes can be observed this is again due to the fact that that bandwidth is limited and one hop gateway nodes are allowed to be associated with the ECN nodes.

Both the figure 4.1 and figure 4.2 present and increased coverage from deployments of nodes. The use of game theory for associating nodes with the energy centroid nodes and the energy centroid nodes with the servicing UAVs is shift in the hierarchical domain for mapping in which is inefficient technique such as k means etc. are used for associating sensor nodes. Traditional hierarchical mapping algorithms focus on refining the cluster group of nodes with the cluster heads over repeated iterations. The cluster groups use the Euclidean distance as a technique for performing the clustering function. In each round this activity is performed during the network setup phase. For every round there is an abrupt change geographically with in the cluster in terms of the cluster head's location. The reason is that the LEACH and DEEC based protocols use Euclidean distance algorithm for examining the distance between the nodes and the CHs, the probability value that is generated randomly by all the nodes as shown in table 2.5. The probability value must be greater then a specific threshold for any $1 - p(r \, mod \, p))$ node to be considered as a cluster head node.

$$\text{Cluster head selection } c_i \rightarrow h_i \begin{cases} \text{if } h_i = 1, h \in \mathbb{R} \\ \text{and if } n - randval_{h_i} \leq T(n) \\ \text{where } T(n) = \frac{p}{1-p(r \, mod \, p))} \forall r \; rounds \\ \text{and } c_i \; after \; \frac{1}{p} \; rounds \end{cases}$$

The above equation serves as basis for selection of the cluster heads in different round during the network setup phase. The same equation model with some variations is also adopted by majority of the hierarchical nodes. According to this model every node n chooses a random value between the range of 0 to 1. If the chosen number is less then the threshold $T(n)$ the node becomes the cluster head for the current round. The value for $T(n)$ is always fixed at each round r such that p is the probability that indicates the number of cluster heads overall to be used e.g. in figure 4.1 the p is fixed at 0.002 which indicates that total 4 ECN nodes will be established in the network grid and in figure 4.2 the p is fixed at 0.0045 value which indicates total 9 ECN nodes will be established on the grid. The r value is the current round which keeps on changing within an iteration.

4.1.1 Increase in the Network Capacity

An important aspect of the deployment module is that due to the utilization of gateway nodes the coverage of in the network is increased significantly. Every member node is allowed to act a gateway node for the dropped out nodes. However the restriction of a maximum one hop is placed. The nodes that are randomly deployed farther away from the servicing UAVs such that they are unable to hear the hello packet broadcast or the feedback broadcast are able to communicate with the control center using the gateway node mechanisms. Nodes that are within the coverage zone of a particular servicing uav can also get dropped due to a lower value or A_{dr} reported through the line of sight and non line of sight received signal values. In such scenarios these nodes can obtain benefit form the use of gateway nodes. However an important point should be cleared out that not all the nodes that are deployed will be able to communicate with the control center since a node can get placed randomly on the edge of the network gird in which the node will be unable to hear any broadcast from any servicing uav's or any acknowledgment from the zone member node.

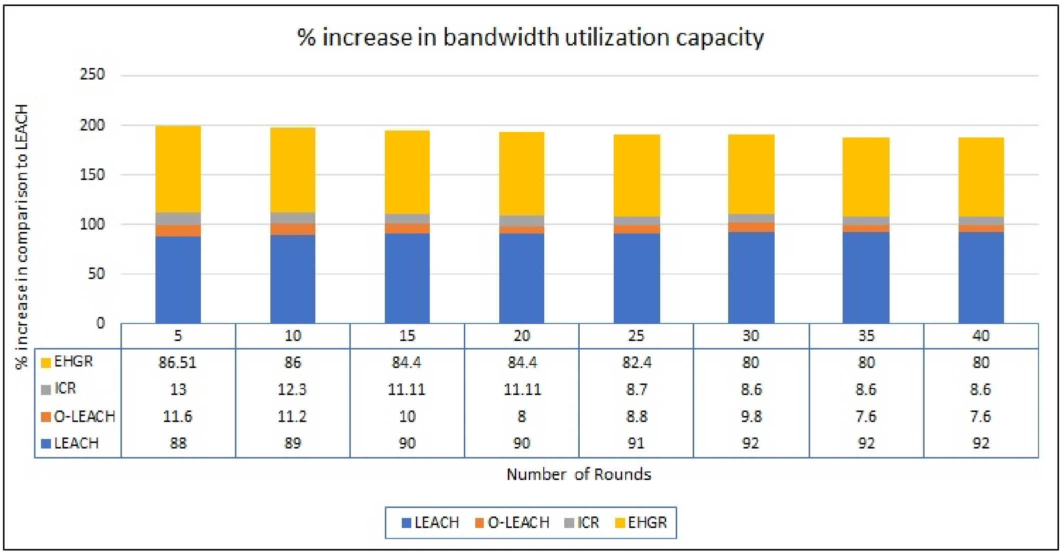

FIGURE 4.3: Increase in the network capacity from the EHGR deployment phase

The figure 4.3 shows the percentage improvement in the capacity of the network in comparison to the traditional LEACH, O-LEACH and the ICR routing protocols. In the figure the increase in the capacity is shown in different rounds and it can be observed that after 5 rounds the capacity of the leach protocol is at 86% which means that 14% of the nodes get dropped during the first five rounds. In a comparison to the EHGR routing protocol it can be observed that there is and improvement of 86% as compared to the traditional leach protocol. As just explained above that due to the gateway node the number of nodes that are connected can be increased to almost double the capacity of the initial coverage. After 5 rounds for a given set of 200 node only 20 nodes were dropped such that these nodes were not able to either transmit data directly or from the gateway nodes.

The increased number of connected nodes increases the resource utilization at the servicing UAV's which increases the network capacity.

4.2 Routing Phase and Data Transmission to the Control Center Phase-II in EHGR

Once the deployment scenario is optimized routing process begins. The first iteration of the routing process uses values passed down from the deployment layer that indicates the initial energy centroid nodes and the servicing UAV's. Each node follows a transmission schedule generated form the energy centroid node. Every round within each iteration calculates the energy centroid node. ECN node calculations.

are performed at the micro controller enabled servicing uav's which offload the computations carried out at round. The energy dissipation model calculates the energy dissipated as presented in the routing algorithm for data-transmission & ECN-rotation during the transmission phase and reception phase, data aggregation phase of the nodes and energy centroid nodes. In the work done by Naseer et al in [87] relay nodes are used to transmit data to the control center to preserve energy dissipation at the cluster head nodes. But this issues generates routing holes rapidly such that the burden placed on the relay nodes doubles since the relay node will receive the transmission from the cluster head node and use its own radio to transmit the data to the control center. This decreases the network lifetime by doubling the ratio of the dead nodes. However in EHGR the data is offloaded by the servicing UAV which limits the use of relay gateway node and again improves the network lifetime.

4.2.1 Improvement in the Energy Dissipation of the Entire Network

In energy efficient routing protocols such as in [115], [109], [87], [85], LEACH and its variants much of the node energy is dissipated towards the end in each iteration when the entire cluster recalculates the new cluster head, member nodes association with the cluster head, cluster head reconfirmation to the joining nodes, which decreases the network lifetime and creates routing hole quickly.

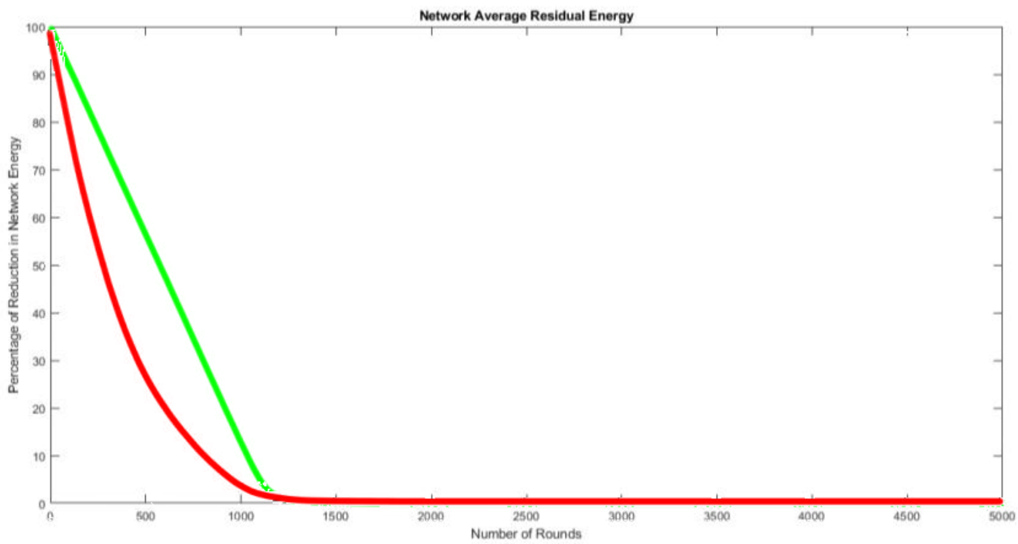

FIGURE 4.4: Calculation in the reduction of energy after each round

Examining figure 4.4 which shows the average residual energy of the entire routing process for LEACH in red and EHGR in green during all the phases it can be observed that the methodology adopted in the EHGR protocol to preserve the network energy is stable and effectively the entire network remain above 50% total average energy even after 500 iterations as compared to the leach protocol. This is due to the fact that computationally intensive calculations in deployment phase, ECN node selection phase, transmission of data to the control center phase are offloaded to the servicing UAV's thus increasing the network lifetime. Therefore it can be concluded that the energy dissipated is reduced by over 100% as compared to leach protocol.

4.2.2 Nodal Life Report

An important measure for a routing protocol is to measure the impact of the routing process on individual network nodes. The EHGR protocol proposed in this study offloads major energy intensive computations to the micro controller enabled servicing UAVs. In the first phase of the EHGR routing process the network formation is established. In various rounds during the routing process energy centroid node calculations of the entire zone are performed by the servicing UAVs which later broadcast this to the member nodes. During the stable phase of the EHGR The member nodes send the data to the ECN node during each round which offloads the data to the servicing UAVs which saves the energy of the ECN nodes which offload the the accumulated data at a closer distance as compared to offloading it at a sink node which is far away and can dissipate energy rapidly. These modifications result in a higher nodal life time such that the first dead node is reported near 1000^{th} round which is by the far the best accuracy reported by sate of the art protocols as reported in the literature.

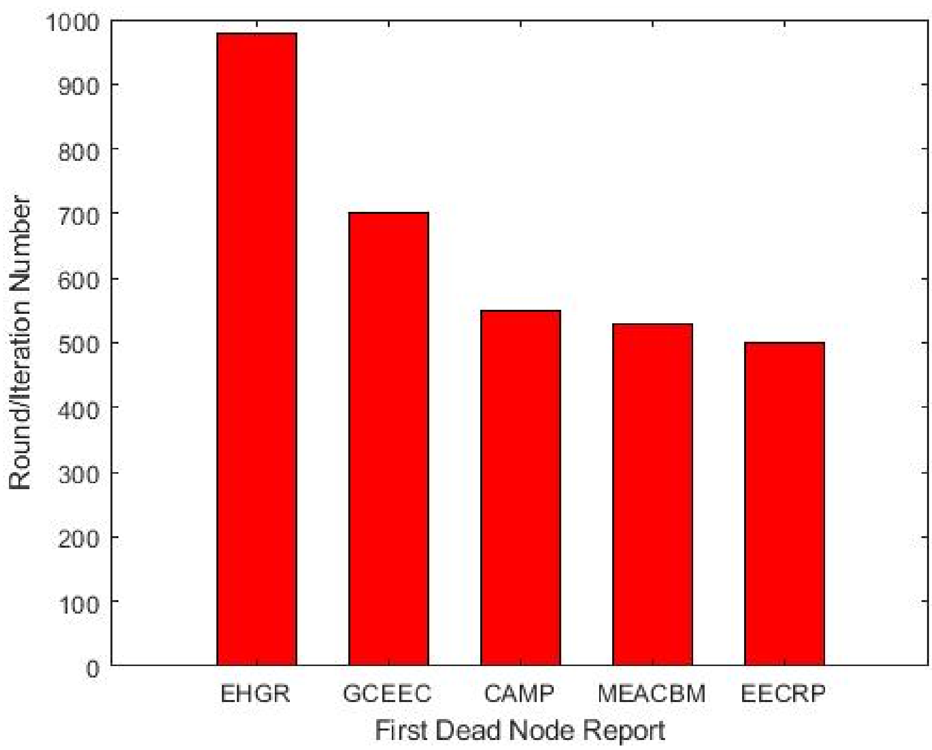

FIGURE 4.5: First dead node report

Figure 4.5 presents the first dead node report graph. The EHGR protocol outperforms most recent routing protocols by significantly reducing the dead nodes. In the GCEEC protocol the first dead node is reported at the 700^{th} round. In the GCEEC protocol the cluster head makes decision in each round weather to forward data directly to the sink node in case the distance is smaller then a threshold or forward it to a gateway node which will relay it to the sink node. In the network formation phase of the GCEEC protocol cluster head selection, gateway nodes selection are all calculated by the member nodes. These computations drain the energy of the member nodes rapidly due to which the GCEEC protocol is unable to extend its network lifetime beyond 1000 rounds during the routing process before either all nodes are dead or significant routing holes prevent further the process of routing. Similarly in the CAMP, MEACBM and the EECRP protocol the dead node report is even earlier then 500 rounds which means that entire network is dead far too.

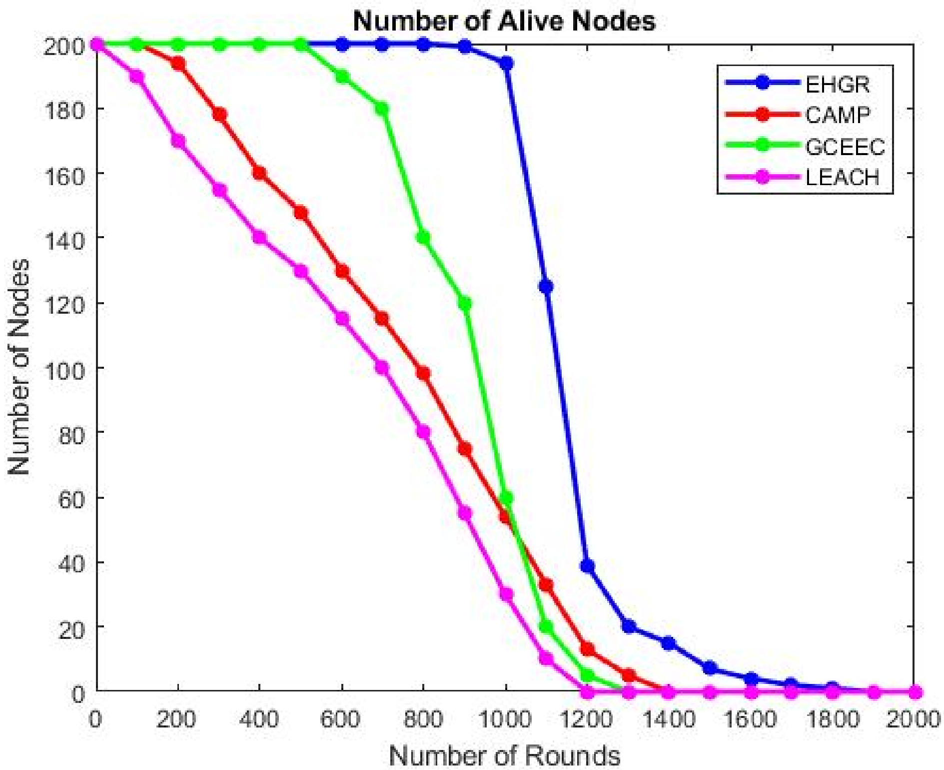

FIGURE 4.6: Reduction in the number of alive nodes

Figure 4.6 presents the reduction in the number of alive nodes as the routing process progresses.

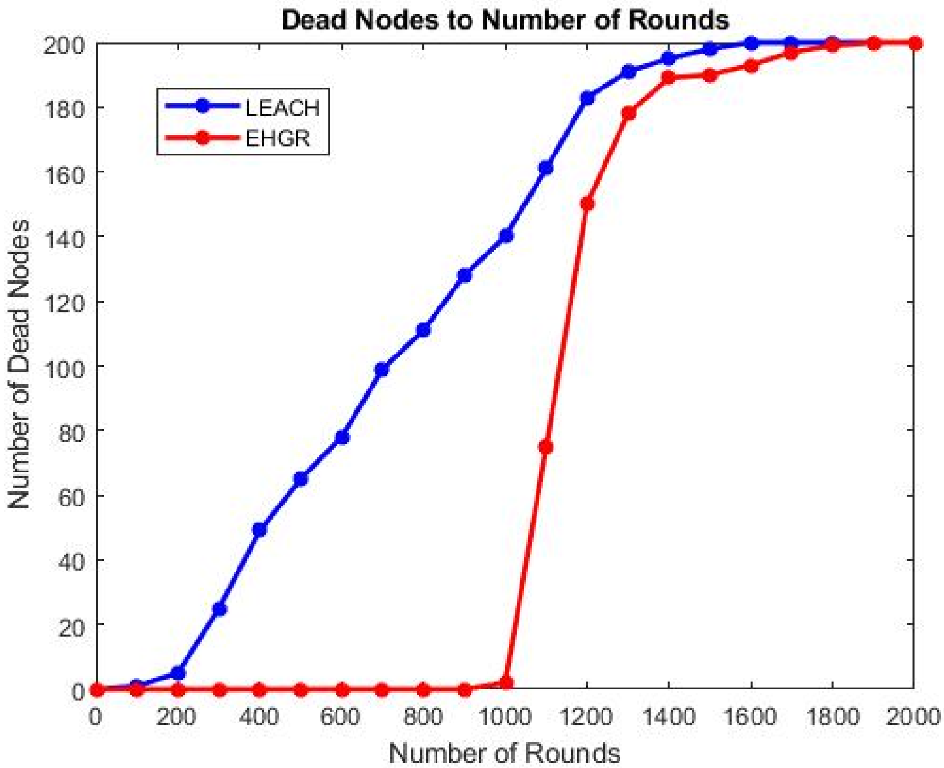

FIGURE 4.7: Increase in Number of Dead Nodes during each Iteration

It can be observed from the figure that the EHGR protocol presented in blue outperforms the GCEEC,CAMP,LEACH protocol due to the unique routing process adopted. Figure 4.7 makes a comparison with the LEACH protocol to examine the number of dead nodes in each round for the entire routing process. It can be seen that the EHGR protocol remains stable till the one thousandth round before the report of first dead node where as 85 percent of the entire network is dead in LEECH protocol. From the figures 4.5, 4.6, 4.7 it can be concluded that the EHGR routing protocol extends the nodal lifetime of the entire network due to improvements in the network formation phase, steady phase and the data offloading phase. The servicing UAVs offload computationally intensive task due to which the network lifetime is improved.

4.2.3 Network Throughput of the Routing Process

Network throughput is an important indicator for an energy efficient routing protocol and it measure the number packets sent to the control center in different rounds. Examining sub-figure 4.8 it can be seen that the benefits of offloading computationally intensive tasks to the servicing-uavs results in a substantial increase in th number of packets sent which approximates to 40000 packets per round with a gradual increase.

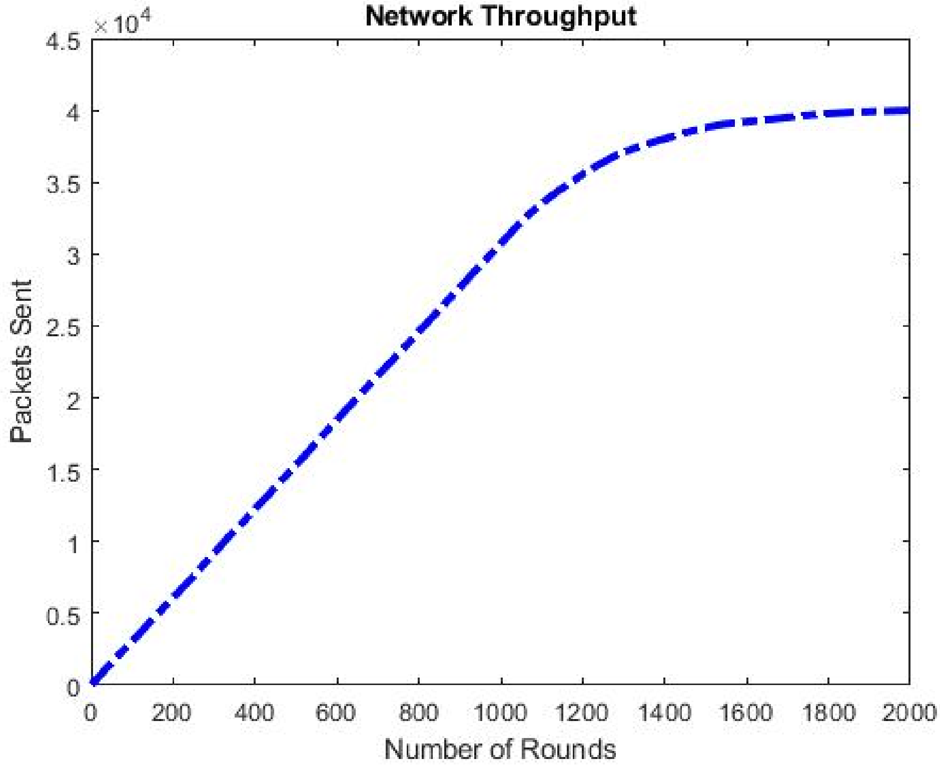

Figure 4.8: Network Throughput of EHGR: Packets Sent by ECN node to Control Center with the servicing UAV

In comparison to the existing routing protocol by observing figure 4.8 it can be seen that for both GCEEC and the CAMP first the throughput increases but after 600 rounds the throughput stables to a much lower values in comparison to the throughput of EHGR. Therefore as expected the EHGR outperform the existing routing protocols in generating higher levels of throughput due to its efficient extension of the network coverage by using gateway relay nodes due to which the network coverage is extended and data offloading capabilities which extend network lifetime along with coverage.

4.2.4 Throughput Comparison

In the fiugre 4.9 we have presented the comparison of the overall throughput per each round of the EHGR protocol in comparison to the existing protocols

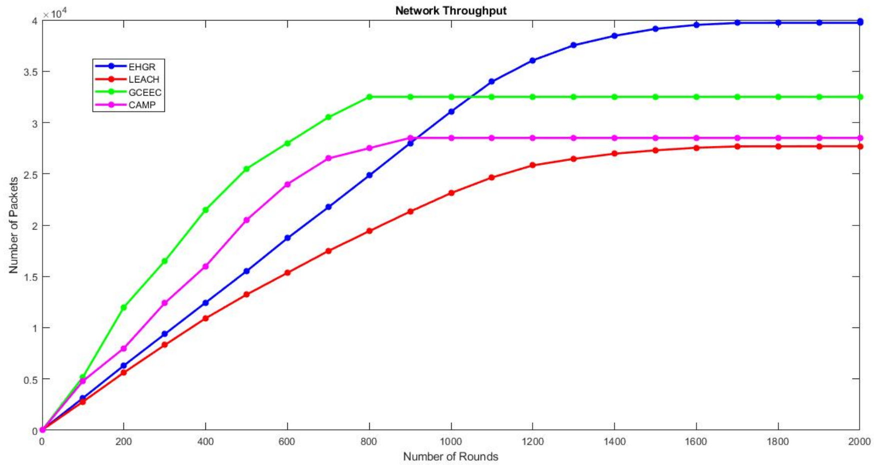

Figure 4.9: Comparison of throughput EEHGR with the rest of the routing protocols

presented in the literature review chpater. It can be observed figure 4.9 that due to extra burden of cluster formation and routing of data packets directly to the sink node by the cluster heads in the LEACH and CAMP protocols results in rapid development of routing holes since major energy is drained during network formation and data transmission phases which results in a low yield in network throughput. The throughput figure shows that initially CAMP and GCEEC send packets with greater throughput achievement as compared to EHGR but after 1000 rounds both the protocols achieve a maximum throughput of 30000 packets per round but however the EGHR achieves a throughput of 40000 packets per round.

4.2.5 Network Lifetime

In section the network lifetime of the EHGR protocol is presented.

The total run time of all the existing approaches presented in this study are mapped against the run time of EHGR in figure 4.10. The EHGR has a higher network lifetime against the existing approached this is due to the battery preservation technique adopted. Nodes that indulge in heavy calculations to support network formation stages as mentioned in existing techniques deplete their battery quickly.EHGR however offloads these tasks to the servicing-uavs due to which nodal lifetime is extended. It can be concluded that the uav-assisted wireless sensor networks that perform load balancing in calculations for network formation, zone

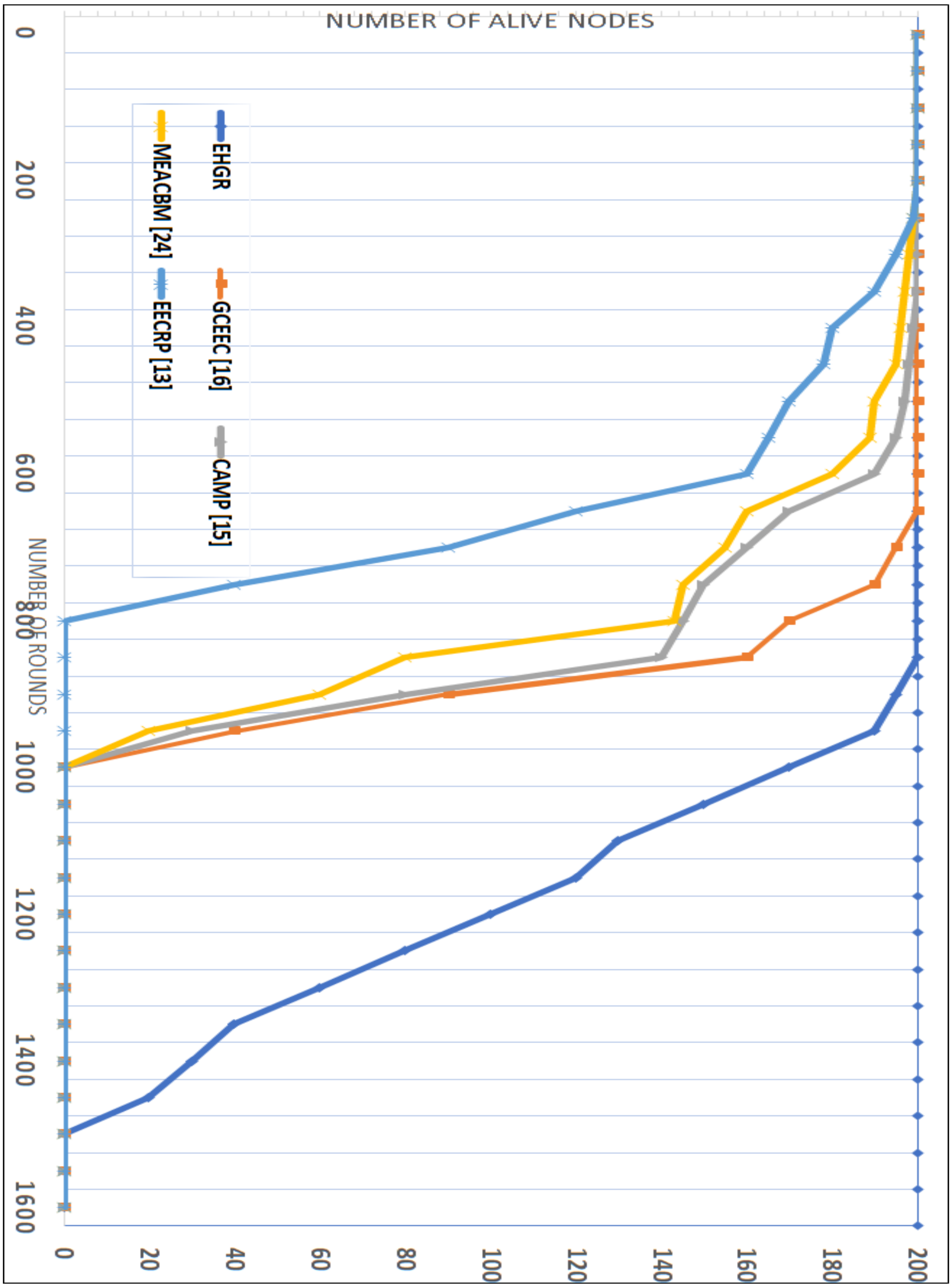

FIGURE 4.10: Total Network lifetime of the EHGR protocol with existing protocol by varying iterations

formations, etc. will enjoy an extended network lifetime as compared to the rest of hierarchical approaches.

The algorithm runs for 2000 iterations and the first dead node is reported at the 97th round see figure 4.5 which is approximately the total life span of the networks established in legacy routing protocols such as LEACH, GCEEC [87], CAMP [98], EECRP [114], MEACBM [116].

Finally the total network lifetime is shown in Figure 4.10 which shows the benefits of the UAV assisted WSN where the UAV are deployed to extend network lifetime by load balancing.

Table 4.2 highlights the conclusion and presents a summary of all the results from chapter 4 in a tabular form as comparison with the study.

Examining table 4.2 we can see that the ICR protocol reaches the network lifetime of over 2300 rounds with 80% of the coverage and similarly in another configuration it reaches to 8000 rounds with the same 80% coverage. In the EHGR routing protocol the coverage is 98% with all configurations and the network lifetime ranges between 1600 to 5000 rounds. The main reason for this is that in the EHGR routing protocol we have kept the initial energy of the sensor nodes E_o to 0.5 Joules where as in the ICR protocol the sensor nodes initial energy is set at 1 Joule which is double to our initial value.

4.2.6 Limitations of EHGR

In the energy efficient hierarchical routing protocol our objective has been to provide optimized coverage of the networks and provide energy efficient routing that network lifetime is increased and at the same time the thourghput is maximized as compared to the existing routing protocols. The servicing UAVs extract data from the ECN nodes and forward it to the control centers. Also the servicing UAVs provide computational offloading of the network setup phase in which the ECN nodes are selected after each round. However it should be noted that UAV to UAV coverage is not considered. In future extension to the EHGR routing protocol we will also examine the UAV to UAV coverage currently node to ECN coverage is considered only. The UAV to UAV and UAV to control center routing is also a challenging task in which multiple hops are also present in case one UAV is far away from the control center.

TABLE 4.2: Final Results of the study of hierarchical zone based routing protocols in comparison to the EHGR protocol

Ref#	**Technique**	**Gateway-based**	**Coverage**	**Multihop**	**First Dead-Node**	**Last Dead-Node**	**Through-put 2%CH**	**IoT/WSN-/Disaster-Regions**	**Network-life-time**
[54]-LEACH	Hierarchical-Zone-base	No	No	No	150-round	700-round	$2.2 * 10^4$	WSN	700
[105]-OLEACH	Hierarchical-Zone-base	Yes	Yes-98%	Orphan-to-member	800-round	1150-round	$2.2 * 10^4$	WSN	1150
[90]-MRP-GTCO	Game Theory with-Penalty	No	Yes	Yes-CH to CH	800-round	1500-round	N/A	WSN	1500
[116]-MEACBM	Hierarchical-Zone-base	No	YES	Yes SUB-clusters	490-round	1000-round	$3 * 10^4$	WSN	1000
[106]-ICR	Hierarchical-Zone-base	No	YES -80%	No	1100 in 1joule	2300	$5.0 * 10^5$in-100nodes	Iot	2300
	2nd Variation in ICR	No	YES -80%	No	2300 in 1joule	8000	$5.0 * 10^5$in-500nodes	Iot	8000

Ref#	Technique	Gateway-based	Coverage	Multihop	First Dead-Node	Last Dead-Node	Throughput	IoT/WSN-/Disaster-Regions	Network-life-time
[87]-GCEEC	Hierarchical-Zone-base	Yes	No	Yes-CH-to ECN	700-round	1000-round	$3.3 * 10^4$	WSN	1000
[98]-CAMP	Hierarchical-Zone-base	No	No	No	500-round	1000-round	$2.7 * 10^4$	WSN	1000
[114]-EECRP	Hierarchical-Zone-base	No	No	Protect-ion based	500-round	800-round	$5 * 10^4$	WSN	800
[117]-EHGR	Game Theory with objective function	Yes	Yes-98%	Yes-D2D	1000-round	1600-round in 2%ECN	$4.0 * 10^4$	IoT-WSN	1600
[117]-EHGR	Game Theory with UAV based objective function	Yes	Yes-98%	Yes-D2D	1800-round	5000-round in 4.5%ECN	N/A	IoT-WSN	5000

Chapter 5

Future Work

5.1 Security and Network Protection

Wireless sensor networks are evolving from being a simple group of static nodes sending data to the nearby control to the point that now mobile networks, IoT based sensor networks and many more fall in the domain of wireless sensor networks. WSN have thus become a dominant part of modern network. WSN's have now become and integral component of IoT based networks. The market share for WSN based IoT networks now exceeds over 126.93 billion dollars with an annual increase of 18% as pointed out by Faris et al. in [118]. A market of such size and the growth rate has attracted tremendous research in all aspects of daily domestic and industrial applications. Due to the tremendous growth of the network security risk and attacks have also increased recently. Sensor networks can be ad hoc, static, under water, aerial the nodes in the network can be redirected by any rouge device and compromise the entire network. Attacks can be launched at all the layers of the TCP/IP stack. Recently firewalls are used to prevent nodes from getting compromised but these approaches are not sufficient. Continuous monitoring of the network to identify any irregular pattern of the nodes and the data traffic movement can be tracked using some kind of intrusion detection mechanism. Traffic pattern of the sensor nodes can become a tricky in situations due to natural conditions the networks gets damaged, nodes are rusted, or unable to transmitt due to torrential rain falls therefore false positives are very common in the intrusion detection systems that monitor wireless sensor networks. Some of the well know attacks on the WSN are

1. Active duty cycle attack: These attacks are commonly launched to keep the node active even during its sleep cycle which keeps the antennas open for traffic monitoring. This attack causes almost 30% reduction in the node's active lifetime. Research in the wireless sensor network is a challenge along this direction to design security protocols to identify attacks that keeps nodes active.

2. Resource exhaustion attacks: These attacks classify as denail of services attacks where rouge devices can inflict routing loops, continuous transmission of network formation beacons can be carried out until a node's battery is dead. Similarly a more serious type of attack that is has been recently identified by Sundararajan et al in [119] is where the data link layer's request to send ie RTS packets and clear to send CTS packets time window is reduced or increased to inflict a server attack to compromise all the nodes communication.

3. Routing black hole attacks: In this type of attack the source node is tricked into selecting a path that it considers to have the minimum cost associated with hence the message is sent ot the attacker node which later discards the packets. Another active area in the routing layer is to identify such attacks. A more serious form of the attack is when for example a health care monitoring setup where the remotely monitored patient send data to a disclosed location thinking that the data is actually being sent to the medical care givers.

4. Traffic Diffusion attacks: Another well know category of attacks that exit at the time of routing data is to spread the information of false source node in the entire network where the traffic updates are bombarded with the false routing information this types of attacks are well know and are considered a form of the denial of service attacks. Since the WSN network setup is always exposed in the environment hence denial of service attacks are more common as compared to other attacks Muawia A. Elsadig in [120] have proposed a

machine learning technique to identify diffusion attacks using the decision tree approach with the ginni selection approach.

5.2 Traffic Prioritization

Wireless sensor networks consists of vast deployment of node that transmit data to the control centers. This massive transmission can cause a problem whereby traffic coming from high priority devices can get blocked due to various issues such as lack of available bandwidth, head of link blocking etc. Routing protocols that are designed to work for disastrous regions must route emergency data with higher level of priority. Existing protocols used for routing emergency traffic for IoT based WSN's are not able to provide efficient routing for such traffic. Well known routing protocols that are used to handle emergency traffic prioritize paths from source to destination by placing a high priority to the routes from which minimum delay is reported between source and destination. However these protocols such as RPL, SPEED and ERGID dont make any changes in the structure of the packet to differentiate it form the normal traffic. The EHGR routing protocol doesnt not handle any emergency traffic.

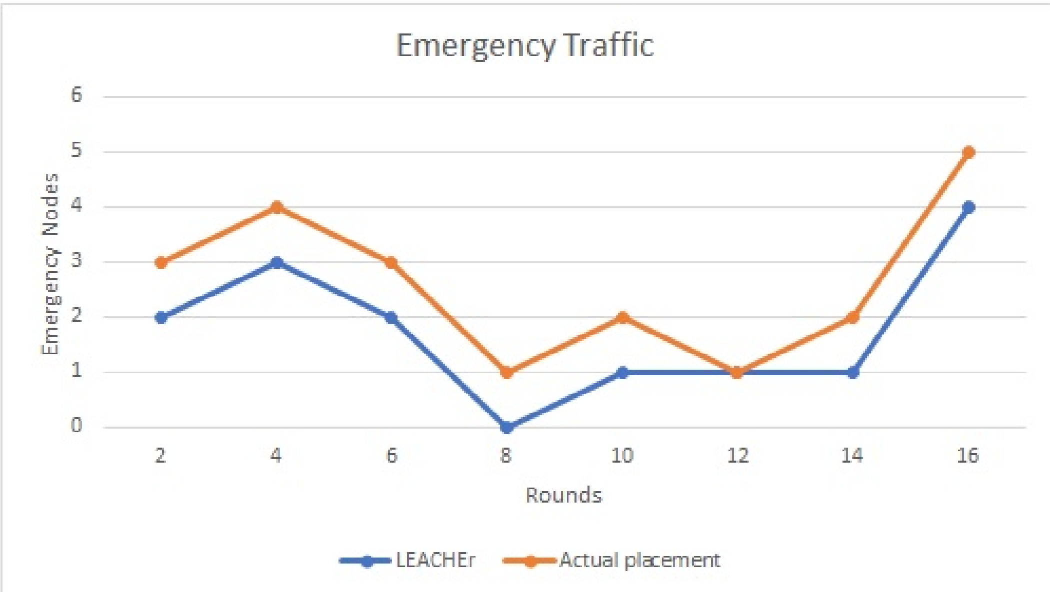

Figure 5.1: Mapping of emergency data in LEACH protocol

However this extension will added to the EHGR in the next version. An experimental study is conducted with only 16 rounds in which LEACH protocol is run over 16 rounds only with 200 nodes. Examining figure 5.1 where in each round the actual number of emergency nodes are shown in orange whereas the experimental study simulation emergency nodes are shown in blue.It can be seen that in each round the leach protocols drops emergency node from even getting connected to the cluster head. This is a small but significant issue highlighted here that will be addressed in the second version of the EHGR protocol.

5.3 Using UAV in Public Safety Networks to Identify Target Regions for Zone Level Deployments

The aerial images taken by a drone a considered as complex images since the images have greater detail about the region. Important information such as target region identification, stranded citizens identification, gesture analysis of individuals seeking help can be extracted from these images. UAVs are deployed accordingly after the desired objective/ target group is identified.
The aerial image analysis beings by segmenting images for useful information extraction. An image contains useful information that needs to be extracted for further processing by various applications that rely on images. Image analysis is therefore rudimentary phase in the image processing domain. The first phase of understanding the image is known as segmentation. Segmentation is also considered as the gap between the low level vision analysis(processing on image to produce another one with highlighting favorable characteristics) and high level vision analysis (object recognition, scene interpretation). Depending on different requirements and characteristics some parts of the image might have more importance as compared to other. Segmentation of images is based on a certain criterion where the input image is divided into a number of same nature categories for extracting the information in which we are interested in. This also serves as the basis for extraction of features from images and for applications such as object detection, object tracking, automatic driver assistance, and traffic control systems, etc. Image segmentation

techniques are ad hoc techniques in which different techniques emphasize on different desired properties to achieve ideal segmentation. The good segmentation technique should identify regions that are homogeneous in characteristic such as gray levels with smooth boundaries such that the regions from different boundaries should be disjoint upon which the region are based.

Chapter 6

Conclusion

In this study a game theory based energy efficient hierarchical gateway routing protocol (EHGR) is presented for ad hoc wireless sensor networks. The study addresses two important challenges for modern uav-assisted wsn's i.e optimized deployment through game theory matching approach with gateway nodes and second energy efficient routing with load balancing between the servicing unmanned aerial vehicles and the energy centroid nodes. The matching algorithm with the help of gateway nodes achieves significant improvement in coverage as compared to state of the art traditional leach based approaches. The use of energy centroid nodes during data transmission process results in gradual energy dissipation due to which the network lifetime is extended. Due to load balancing of computations during all phases of EHGR between the energy centroid nodes and the unmanned aerial vehicles the decrease in energy dissipation is further controlled and the first dead nodes which is reported at 979th round and last dead node report at 1800th round. The simulation figures of the EHGR presented in chapter 4 show a substantial achievement against existing approaches. Overall the EHGR has a remarkable break through at near 1800 rounds for the entire routing process along with energy efficiency such that the total average energy of the entire network remains above 90% for at least 500 rounds. UAV-assisted WSNs are likely to attract more research in the future. This study will be further extended to explore the behavior of the ad-hoc wsn while using multi hop D2D routing with extended coverage. The routing processes must be continuously improved to address the requirements placed by modern day applications all of which require more computation, traffic prioritization, improved load balancing techniques with extended network lifetime. In the section 2.10 two research questions are presented.

Research Question 1 states that how to use deployment algorithm efficiently for the system of UAVs by examining features of stranded user equipment?
Figure 3.4, 3.5 and 3.6 from chapter 3 give the phase wise details about how this research question is addressed. The deployment of nodes in ad hoc Iot based wireless sensor networks is an important aspect through which the throughput and network lifetime can be optimized. This study used the game theory approach for the deployment of nodes. In game theory all the participating game players try to maximize gains. In this study game players are the nodes and the servicing UAVs. The nodes try to maximize their gains against the equations 3.5, 3.6 and 3.7. The nodes receive line of sight and non line of sight values according to the figure 3.1 as presented by Al hourani for low altitude platforms. The servicing UAVs perform similar steps and prioritize the nodes with which they will get associated and the nodes will prioritize their servicing UAVs to whom the request for association will be sent. Once the association between nodes and the UAV's is completed zones are established as a result. The servicing UAV's calculate the energy centroid nodes and broadcast it to the nodes to which the final acknowledgment is sent from the nodes to the ECN nodes for the confirmation. Some of the nodes that fail to receive any association from the servicing UAVs use the second phase of the deployment which is data forwarding through relay nodes. The figure 3.7 indicates mechanisms of a node opting for D2D relay mechanism.

Results Summary of the Research Question 1

The results of the deployment phase are presented in figure 4.1 and figure 4.2. In both the figures the results of the deployment of nodes by simply using game theory are presented on the left side and on the right side the result of node's association using D2D relay nodes. It is noted that the number of rejected nodes is decreased in both the cases with having 2% and 4.5% of the nodes acting as the ECN nodes. However it is observed that not all the nodes in the network can be associated due to constraints that lead to a lower resultant value of the objective function from the game theory.

Similarly in section 2.10 **Research Question 2** states that
How to route data between nodes in an energy constrained environment by optimizing power?

Figure 3.7, 3.8 from chapter 3 present the algorithmic flow of the routing algorithm and the calculation of the energy model. Table 3.5 presents the algorithm used for data transmission and ECN rotation phase for each round in the routing process. The routing process proposed in the EHGR is superior as compared to GCEEC, CAMP, MEACBM, OLEACH, TESEES and MRP-GTCO as the energy calculations of the zone and the ECN node calculations are updated by the servicing UAVs rather then the nodes themselves which saves the battery power of the nodes and extends network lifetime.
In chapter 4 the results of the routing process are presented in the figures 4.3 - 4.10. The energy reduction graph per round is presented in figure 4.4 which depicts that the entire network remains above the 50% threshold even after 500 iterations in the routing process. The first dead node report which indicates the round at which the first node is reported dead is graphically presented in figure 4.5, the reduction in the number of the alive nodes round wise is presented in figure 4.6, increase in the number of dead nodes is presented in figure 4.7 and it is observed that EHGR outperforms these existing protocols. The network throughput of the EHGR is presented in figure 4.8 and a comparison of the network throughput with the existing protocols is presented in figure 4.9 it can be observed the results that the EHGR protocol yields a greater throughput. It is also observed that uptil 900 round the throughput of GCEEC and CAMP outperforms EHGR but after 900 rounds the throughput of the EHGR protocol increases. Figure 4.10 presents the overall run time of all the protocols it is observed that the EHGR reported the last dead node at 1600th round as compared to the EECRP in which the last dead node is reported at 800 round the CAMP, MEACBM and GCEEC reported the the last dead node at the 1000th to 1100th round respectively.

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