Topology Control Algorithm for Fair Energy Distribution of 5G UAV Swarm System

By

Syed Suleman Dawood Bukhari

Department of Electronics
Quaid-i-Azam University, Islamabad.

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بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

هَلْ أَتَىٰ عَلَى ٱلْإِنسَٰنِ حِينٌ مِّنَ ٱلدَّهْرِ لَمْ يَكُن شَيْـًٔا مَّذْكُورًا ١

بیشک انسان پر زمانے کا ایک ایسا وقت بھی گزر چکا ہے کہ وہ کوئی قابلِ ذِکر چیز ہی نہ تھا۔

There surely came over man a period of time when he was a thing not worth mentioning.

(Al-Insan : 1)

Dedicated to my family

CERTIFICATE

It is certified that the work contained in this dissertation is carried out and completed by Syed Suleman Dawood Bukhari under my supervision at Quaid-i-Azam University, Islamabad, Pakistan.

Prof. Dr. Hasan Mahmood
Department of Electronics
Quaid-i-Azam University, Islamabad, Pakistan.

Submitted through:

Prof. Dr. Qaisar Abbas Naqvi
Chairman
Department of Electronics,
Quaid-i-Azam University, Islamabad, Pakistan.

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Abstract

Since the advent of 5G and beyond, the use of unnamed aerial vehicles (UAVs) has increased significantly. Along with that, the issue of energy optimization has arisen. Although the nodes in a UAV swarm network remain stable until they have a sufficient amount of residual energy, 5G and beyond have the potential to support a massive number of devices in a single network. More devices imply more connections between nodes, and more connections signify increased energy consumption and a shorter network lifetime. In order to address this issue, we use statistics to create the ED-Index. This algorithm guides us in developing an algorithm that balances residual energy across the network, such that nodes with high residual energy have a large number of links and vice versa. This increases the network's lifetime, and the algorithm that creates this topology is referred to as the energy distribution topology control algorithm. The results indicate that networks with a higher ED-Index value have a longer lifetime as compared to those with a lower ED-Index value.

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List of Abbreviation

Acronym	**Description**
ACK	Acknowledgment
UAV	Unmanned Aerial Vehicle
MIMO	Multiple-Input Multiple-Output
$ED-Index$	Energy distribution index
EDTC	Energy distribution topology control
MST	Maximum Spanning Tree
EDTC	Energy-degree topology control algorithm
WSN	Wireless sensor network
WAIoT	Wireless Ad-hoc Internet of things network
LTCA	Localized Topology Control Algorithm

Chapter 1

Introduction

A swarm network of unmanned aerial vehicles is classified as an ad-hoc network. The ad-hoc networks are not centralised networks similar to conventional 3G or 4G networks; rather, unlike centralised systems, these networks allow devices to communicate directly with one another. This mode of communication has a number of advantages and a some disadvantages. The advantages of an ad-hoc network include its ease of setup, flexibility, and robustness. In addition to the UAV swarm network, other types of ad-hoc networks include wireless sensor networks (WSNs), wireless ad-hoc Internet of things (WAIoTs), and so on.

The use case for WAIoT is the deployment of UAV swarms in a stadium, or the deployment of nodes in shopping malls, or the communication of security cameras in hotels. The disadvantage of ad-hoc networks is that devices require only a few redundant links. The reason for this is that there is no central base station that receives data from any node and then forwards it to the appropriate node. Instead of communicating directly, if a node wishes to communicate with another node that is outside its transmission range, it will send the data to a neighbouring node, which will then send it to another neighbour, and so on until the message is received by the intended node. If there are no redundant links and only one link fails in this case, the network will be disconnected. For the same reason, nodes that are unrelated to the message will expend energy forwarding data from other nodes. However, it is also true that WAIoT networks are inevitable, as the demand for IoT has increased significantly with the advent of 5G and beyond. In order to overcome this energy constraint, a topology control algorithm is used, which optimises the network's topology in such a way that it conserves the nodes' energy. Conserving node energy results in a longer network lifetime. Typically, two methods of topology control are used-namely neighbour node selection and antenna power adjustment. However, in this thesis, we chose the neighbour node selection method. We use a graph to visualise the network [1]. A UAV is depicted as a node, and the connection between two UAVs is referred to as an edge. If we run the simulation in a graph scenario, the continent is simulated. Once the graph is formed, one method of topology control is to eliminate redundant edges, which equates to removing connections between devices in a geographical network. Not only that, but a good graph topology should avoid disconnecting the graph, i.e., there should be enough edges for each node to have at least one edge or set of edges through which it can communicate with another node. Other metrics that a topology control algorithm should possess are the ability to generate a robust network with a high energy efficiency [2]. If we consider the ideal case for WAIoT, the following conditions apply:

1: All devices have the exact same range of transmission.
2: Node-to-node communication is bidirectional.
3: The Euclidean plane has a two-dimensional configuration.

Taking this ideal scenario into account, the graph used is referred to as a unit disc graph [3]. All devices in this ideal graph have the same communication range and transmit data in a circle. If two nodes appear to be within the transmission range of one another, an edge is formed between them.

However, we did not consider all conditions to be ideal in this research; we use three-dimensional space rather than two-dimensional space because UAV swarms fly; additionally, this work uses dynamic nodes rather than static nodes. Additionally, each node has a unique residual energy value, as this is the case in a real-time geographical network. Even if nodes are deployed with the same power supply, once the devices begin communicating, each node consumes energy differently depending on its distance from other nodes and the number of links to the one it is connected. As a result, it makes sense to distribute energies randomly rather than keeping them constant. Residual energies were distributed in the range from 1 to 10 Joules. As soon as the simulation begins, energy begins to drain as the nodes communicate with one another. When a node runs out of residual energy, all of its links are disconnected because it is no longer capable of receiving or transmitting the signal.

Each simulation changes the location of the nodes because each node is actually a dynamic UAV in our case. As a result, the topology changes each time, but the nodes' energies remain constant, draining in each simulation. Once all simulations are complete, we can determine the number of alive nodes and thus the network's lifetime based on the number of alive nodes.

On the basis of this network, we hypothesised that the network lifetime would be increased if nodes with a higher residual energy had a higher node degree, i.e., a greater number of edges, whereas nodes with a lower residual energy had fewer neighbour nodes.

It makes sense logically, as more the links, the more nodes must communicate, and vice versa. To demonstrate this, we developed an algorithm using statistical methods and named it the energy distribution index (ED-Index). This algorithm is used to evaluate the resulting topology and determine whether our claim is true. Theoretically, a high ED-Index value indicates that nodes with a high energy have a high node degree, and vice versa. And vice versa if the ED-Index value is low. Thus, by comparing the ED-Indexes of various topology, we can determine whether the network lifetime of the topology with a higher ED-Index is greater or not. We propose and named the algorithm energy degree topology control algorithm (EDTC). This algorithm starts with the maximum spanning tree of the original topology, which is obtained using Kruskal's Algorithm, and then reintroduces a few edges under the guidance of the ED-Index, resulting in a prolonged network lifetime. Kruskal's algorithm is also referred to as the greedy algorithm because it eliminates all superfluous links and retains only the necessary ones. Rather than using the minimum spanning tree, we use the maximum spanning tree because we require all the links to remain in the network with high weights. The link's weights are determined by the average of the residual energies of both ends.
If we conclude our research findings, they are as follows:

1. Development of the ED-Index through statistical analysis to determine whether or not our hypothesis is correct.
2. Development of energy distribution topology control algorithm.
3. Verification through the ED-Index that EDTC has a longer lifetime than other advanced algorithms

1.1 Thesis Organization

The organization of thesis is as follows. Chapter 2 discusses the literature review for topology control algorithms, touching basis with state of art algorithms being used in industry for topology control, which gives the idea of present work about this topic. Chapter 3 presents our contribution to enhance the network lifetime of the topology. First, we explain the system model and discuss the problem statement or findings. Finally, we present the approach to solve the issue, where we discuss ED-Index and EDTC. In Chapter 4, we describe simulations results and conclude this thesis in Chapter 5 along with future work.

Chapter 2

Literature Review

With the dramatic adoption of the Internet of Things (IoT) paradigm, the network topology is improved for advancing the traditional ad hoc networks. It is noted that many IoT devices use wireless topology using ad hoc network for advancing in terms of gaining advantage through flexible, improved fault tolerance, and rapid development support. Some commonly reported examples of wireless ad hoc IoT networks includes wireless sensor networks (WSN), UAVs, and smart vehicle networks. Due to the lack of device-to-device communication in conventional cellular networks, this requires the need for using WiFi and Bluetooth for developing WAIoT topology over unlicensed sources. However, a major limitation is reported during this process in terms of service quality. Therefore, the core reason behind the adoption of 5G technology is to connect everything efficaciously along with high data rate. To this end, the devices can be connected through WAIoT over the cellular networks.

Different use cases of device-to-device connectivity in 5G networks is defined by authors in [4], present the development of the scenario, in which the WAIoT is allowed for providing Internet access to the congested areas that include shopping malls and stadiums. Similarly, UAVs have been noted as a solution for developing ad-hoc network along with the flying base stations for communicating using 5G devices [5]. Another interesting research effort performed by the authors in [6] reported that the content-centric paradigm is the future for the WAIoT networks. According to these authors, peer-to-peer ad-hoc networks mainly allows dissemination of the content along with sharing between the devices without any limitation of infrastructure. Generally, mobile devices have reported issues during content sharing in dense regions. For this purpose, these devices adopt a new architectural design, based on self-organizing ad-hoc network, can be perform on the basis of content-centric networking module for WiFi connected mobile devices. A major advantage of this architectural design can be understood from the perspective of achieving power efficiency along with efficiently

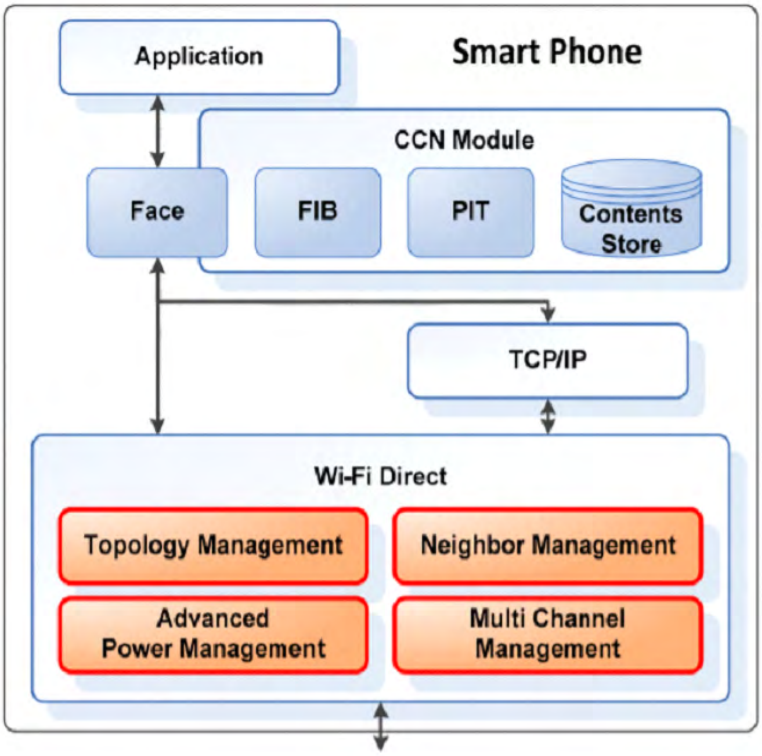

Figure 2.1 Content-Centric D2D Topology

dealing with energy-constrained devices. Following is the architectural topology adopted by these researchers for improving content sharing between devices over WiFi.

The above presented visualization depicts the node model, in which overall components of the architectural model includes the CNN portion that is responsible for data communication through interfaces between the applications. In CNN, three major sub-components include content store, pending interest table, and forwarding information base caching. The forwarding information base caching is mainly responsible for maintaining the routing information for interest and contents packets using Face. The above given WiFi direct module is better than the traditional WiFi AP with certain advance functionalities. For this reason, the topology management module is used for constructing a multi-hop technology based on concurrent operations defined through the WiFi direct module. This module can also help in defining the group based architectural model, in which the highest intent values are listed along with the client information for defining the owner role for developing multi-hop network. This intent value of the client is mainly dependent over the neighbors count along with the distance between the smartphones by a content server. Hence, it can be said that a client with large number of neighbors can have high probability of becoming owner of the system.

Another interesting topology is presented by the authors in [7] that lists multiple challenges in WAIoT nodes connection. The frequently reported issue is defined in terms of explaining that WAIoT contains a limited power source for nodes connectivity. It degrades the performance of the WAIoT nodes based on the limitation in the lifetime for battery recharge. Likewise, another major limitation identified from WAIoT network is the limitation of computing resources, which includes computing power, computing memory, and computing bandwidth for the wireless devices. Hence, they have explained the case scenario of the WAIoT in terms of WSN. It should be noted here that WSN has mainly resource constrained topology. The use of topology control is identified as essential parameter for prolonging network life along with the efficiency improving scheme for the network. The solution for defining topology control scheme is through the use of antenna, which is generally used for power adjustment purpose. Likewise, neighbor selection approach is also noted as a solution for power adjustment for topology control process. Different application is noted in terms of defining the diverse requirements for the purpose of presenting the type of topology control methodology to define the assumptions for design goals. The use of WAIoT can also be observed from the perspective of topology graph, which use graph nodes for representing the wireless devices along with the edges as connected wireless devices. Because of the fact that the original graph may contains different redundant edges with a common goal of presenting topology control algorithm for eliminating the redundancy identified in original graph. The authors in [2] present the benchmarks that are required by a suitable topology control algorithm that can be used for generating a sub-graph which can be use for the purpose connecting the original graphs along with the requirements that are defined for the high energy efficiency controlling process along with the fault tolerance. Likewise, the run time topology of the systems is discussed in [3] that presents the ideal case of the WAIoT in which every device have a constant wireless transmission range and all those devices have an organizational arrangement using Euclidean plane. An important paradigm is reported from the WAIOT in terms of presenting the false assumption in a way that no barriers can be use for impeding the wireless signals. Similarly, this ideal case can be defined for explaining the wireless transmission range in terms of circle radius. The edges of the circle that are between the two devices are presented for the two devices that are in between the range of each other's transmission. For this reason, the common approach is defined in terms of developing the ideal condition that can help in efficaciously transferring the content over WAIoT nodes.

The authors in [8] present an efficient approach that can be used for reducing the irrelevant edges from the connected graph. The purpose behind this processing approach is for reducing the extra cost involved during the weights generation of the models. It can be said that the connected graphs with irrelevant edges are required to address the reduction

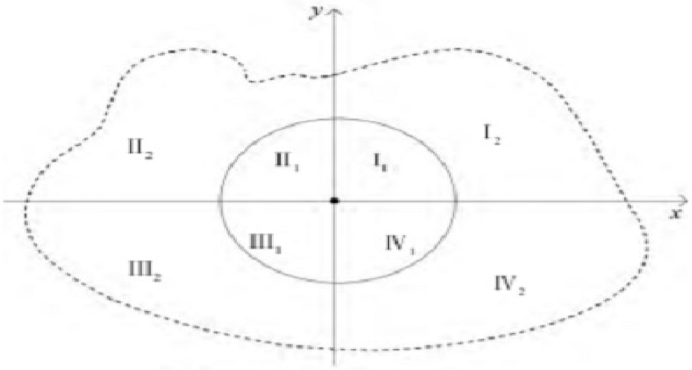

Figure 2.2 CTEF Implementation

of those without affecting the connectivity for generating the min/max spanning tree that can help in defining original graph. For this reason, MST algorithm were inherit from the Kruskal's algorithms that use shortest path finding approach in similar pattern to the Prim's algorithm. The edges that are established through the triangulation impact of the disk is mainly responsible for defining the nodes that are used for communicating the edges between them using Delaunay triangulation scheme. Another algorithm presented by the authors in [9] follows the Gabriel graph algorithm, which can be categorized as a sub-graph of the Delaunay triangulation for addressing the issues related to the removal of the extra edges in the graph topology of WAIoT. The core reason behind this process is the optimization of the energy consumption in terms of reducing interference in the WAIoT networks. The authors in [10] present that the techniques for reducing interference through measuring the interference quality of the structure. Based on the interference issues reported from the WAIoT, the use of handling re-transmission is reported as a solution for improving power consumption of the WAIoT network nodes. A machine learning model is presented by the authors in [11] that have used clustering approach for energy forecasting to develop an efficient topology control algorithm (CTEF). In this algorithm, a clustering based attempt is made for categorizing nodes energy in a way that the nodes that are consuming high energy can be predicted through the algorithm based on which we can compute interference for each node to reduce by following Prim's and Kruskal's algorithm. A visualization of the CTEF workflow is shown in figure below:

According to an assumption based on CTEF, the nodes of each network must need to have a communication control with the base station. Therefore, a major limitation arise during the implementation of CTEF is the lack of connection range between the nodes and base station. For this reason, the development of CTEF is not suggested for developing an energy efficient WAIoT network. From the above given figure, it can be observed that the clustering of the network nodes is defined through the circles in which the nodes is categorized based on the energy usage pattern.

Based on the idea of spanning tree, the authors in [12] preset an architectural design for developing a low-energy adaptive clustering hierarchy (LEACH). The major concept behind the implementation of LEACH is defining a dynamic scheme that can be used for allowing different nodes as cluster heads based on different iterations. These nodes is used as cluster heads based on the prevention of the nodes for running out of the energy quickly. The LEACH follows the distributed algorithm scheme in which every network node is evaluated for defining the condition under which a node can be categorized for use as cluster head or not. For this reason, LEACH is recognized as an efficient solution based on which the model can be developed for presenting grouping of the nodes. However, a major limitation reported from the LEACH algorithm is that during the process of clustering head selection, the residuals energy is ignored that may degrade the performance of the clustering scheme. Another important issue reported from the architectural design of LEACH algorithm is the biasness in the distribution of the cluster heads. Generally, a heuristic approach is defined for presenting the distribution count of the cluster heads. However, in LEACH algorithm there is no heuristic behind the distribution of the clusters head that makes the distribution uneven [13]. The authors in [14] preset an energy balanced topology in a way that the energy balance control topology (EBTG) can help in managing the nodes energy distribution in WAIoT networks. This EBTG approach follows game theory concepts that helps in measuring the inequality of energy distribution between nodes. The use of game theory helps in developing a competition between the distributions of energy among different nodes. This concept is further explained through the authors in [15] that have presented a local minimum spanning tree topology control scheme (LMST). The basic concept is inherit from the Prim's algorithm to define a model for power transmission between the nodes pair in the form of weights for each edge. Hence, it is noted that the results reported through the LMST are suitable enough for defining a flexible architectural model based on which the network topology can be presented without any future maintenance. Generally, it is noted that the nodes given in the development of the LSTM are selected through a random selection approach that have redundant paths eliminated by the LSTM. Hence, in case of losing any of the node in the network, the issue of malfunction can arise that may degrade the performance of the network. Different authors have reported this issue of malfunction in LSTM based topology. For this reason, the authors in [16] have noticed that the topology control algorithm that presents energy efficient network models have a major limitation in terms of lacking optimization of capacity between the nodes. Hence, they have proposed a solution through the inclusion of the multi-objective topology control algorithm (ECTC). The presented algorithm is works for

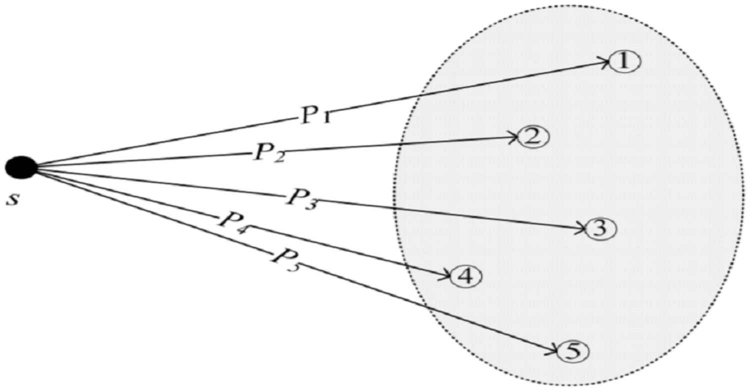

Figure 2.3 PDRsn Module

optimizing the network capacity for the energy efficient network modeling. The architectural design of the ECTC is based on the localized minimum spanning tree; hence, a major drawback reported from this algorithm is the inaccurate grouping of the nodes based on global position system (GPS).

For handling the previously reported issue, the authors in [17] have presented a topology control based opportunistic WSNs routing algorithms (ERTO). According to the presented algorithm, a packet delivery ratio is defined between source node and candidate set calculation model (PDRsc), which use the network interference for defining the topology control pattern. The concept of ERTO can be defined in terms of explaining multi-objective optimization scheme that helps in optimizing PDRsc. The expected energy ratio is defined through the degree of relay nodes that explains the geolocation of the nodes connected over the network. Based on the optimization algorithm, an efficient improvement is observed in the state of the art model of WAIoT. Because of the fact that ERTO have performed efficaciously for optimizing the energy consumption in network nodes of WAIoT, a detailed discussion is presented for explaining the workflow through PDRsc. The packet delivery ratio shared between the sender and candidate set is perform through opportunistic routing pattern. The source node is responsible for sharing data packet to all the connected nodes of the candidate set [18]. The relay nodes have transmitting process that works through the relying of the priorities for sharing data packets. For this reason, the PDR is divided into two modules. The first module is consist of sender and rely node with PDR that controls the transmitting pattern of the data packets. The architectural design for this module is shown below:

The above given figure depicts that the sender node architectural design have access for multiple distributions of the data packets based on the priorities defined by relays. Similarly, another model defined for data packets sharing is second module of PDR which follows a

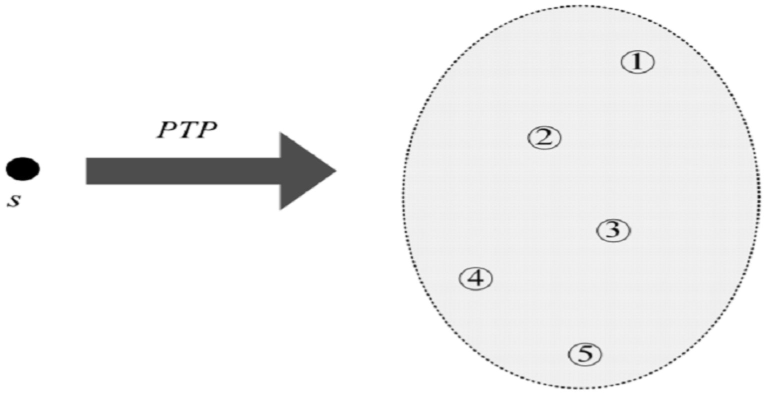

Figure 2.4 PDRsc Module

PDR development between the sender and candidate set. The architectural design of PDRsc is shown in figure below:

The authors in [19] have presented a suitable solution that presents an efficient form of previously presented ERTO. They have developed a localized topology control algorithm (LTCA) that use node ids based on which presents low data packet sharing pattern for improving energy consumption. It is identified from the LTCA that the limitation over the packet sharing between the nodes can help in improving the energy consumption of the nodes for conserving energy. This topology use an undirected graph which may not be able for preserving the connection between the nodes. Hence, a high risk of connectivity loss is reported from the LTCA. To this end, the authors in [20] have presented a solution through non-cooperative game based algorithm EFTCG that is developed for implementing energy-efficient topology in the WSNs. The concept for developing EFTCG is dependent over game theory that develops a competition game between nodes of the network as players. Here, the common goal of the competition is the reduction in energy consumption. The EFTCG is reported as a solution that use dedicated functions for the balancing of energy transmission along with the consideration of the residual energy and network connection. To this end, this approach is noted as a suitable scheme that can improve the traditional topology of WAIoT.

Currently, different researches has also been reported on developing the topology control of wireless network that is categorized using the following groups:

It can be observed that the topology control scheme is consist of multiple scheme that is discussed in the forthcoming sections: Power Adjustment: The process of power adjustment is mainly refer to as a scheme through which the energy consumption can be reduced based on the transmission of the data. Here, a major adjustment is reported in the power nodes that are responsible for defining the transmitting of data with a threshold based energy. The purpose

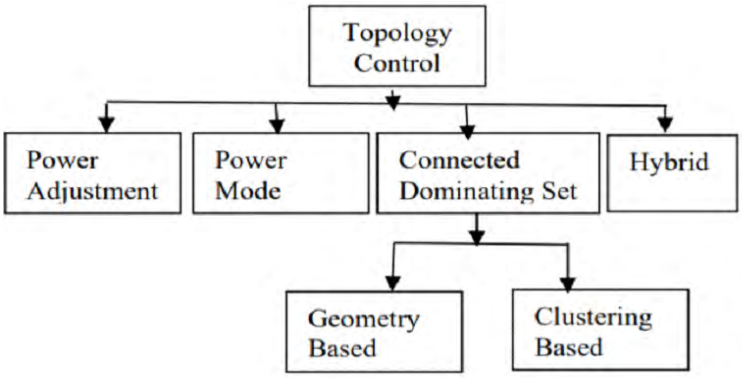

Figure 2.5 Topology Control Approaches

behind the power adjustment is to develop a module, which the nodes can cooperate with each other for adjusting the power for the sake of presenting a suitable energy transmission pattern between the connected network nodes. Hence, it is noted that a limited number of power values is defined per node that can be used for adjusting the power transmission. Based on the limited power values, it is possible for defining a solution that can adjust the power consumption of each node for optimizing the total energy consumption in the network connectivity. These approaches are responsible for improving the throughput of networks along with the management of energy cost reduction using single interference.

Power Mode: A scheduling approach is noted as a solution for establishing a method that can be used as a feature by the wireless node networks interface that presents power modes for energy saving. These nodes consist of four power modes including sleep, monitor, receive, and transmit. Based on these different energy consumption, a pattern is reported that defines the distribution of the energy with highest values in transmit and receiving mode. Hence, it is noted that the energy consumption control is required over the monitoring nodes that are responsible for planning the energy control flow and receive pattern process. This feature is used in different topology control scheme for improving the energy optimization pattern without affecting the network capacity and connectivity. The authors in [5] preset a solution through GAF approach that can be used for conserving energy by reporting nodes that have an equivalent distribution from the routing node and it has the ability of turning off the irrelevant nodes with a constant level of routing fidelity. The STEM algorithm presented by the authors in [6] also follows the similar approach for defining the pattern through which the distribution of the tasks between the network nodes is performed for presenting a user given query along with the conserving of the power in the idle state process. The ASCENT model presented by the authors in [21] shows that a minimal set of nodes are enough for developing a routing forwarding backbone. Hence, the ASCENT follows the pattern of assessing the connectivity of each node over the network along with the adoption in multi-hop network topology.

Connected Dominating Set: A scheduling approach is noted as a solution for establishing scheduling method that can be used as a feature by the wireless node networks interface to present power modes for energy saving. According to the authors in [21], the dominating set depicts the graph that satisfies the major conditions including the connection constraint that every node is associated outside the subset must contains a neighboring set to relate domination set. Based on following the condition, a graph can be said to be a connected dominating set (CDS). The purpose behind the implication of the condition over a normal graph to develop CDS can be understood in terms of reducing communication energy and load. The usage of wireless networks can be related to the graphs based on which the topology model control problem can be defined for converting the minimum connected dominating set. However, this problem is categorized as NP-hard problem because of which the development of clustering approach is presented for inclusion of clustering based topology for improving node set selection process. The common goal behind the implementation of this topology is the development of an optimized solution that can be used for presenting topology control scheme. The authors of [7] present a clustering based approach called PACDS for developing a computational power aware approach that can be used for developing a dominating set of topology control scheme. The use of PACDS improves the energy consumption process by enhancing the technique flow of the model. Another enhancement can be observed in [18] that developed the ECDC approach. This scheme is reported as an energy efficient scheme for developing a distributed dominating set algorithm. The core purpose behind the implementation of this algorithm is to present a mechanism for prolong network lifetime to enhance energy balancing techniques. This distribution technique is also adopted by the researchers in [1] that use a backbone topology for defining a minimal dominating set (MDS). Hence, using MDS a significant improvement is observed in comparison to the traditional approaches used for the WAIoT networks. Moreover, TMPO by [22] presents the topology management approach that can be used for constructing previously presented backbone algorithms using MDS. Based on TMPO, the connected nodes can determine the membership of the MDS based on one-hop neighbors along with the two-hop neighbor details.

The use of geometry based topology control schemes has also been reported from the literature. These techniques mainly adopts WSNs and ad hoc networks for implementing the topology control algorithm [22]. The core purpose behind the development of the module is understood from the perspective of defining family structure named as k-localized minimum spanning tree. The use of such trees is clear from the perspective of defining topology control process to enhance the broadcasting techniques in wireless ad-hoc networks. The authors from different research articles such as [23] [9] define the use of topology control process through prediction based DTN. The use of time-evolving network topology can be observed in the process that can be predicted through the structural components of the model. The core reason behind the implementation of the topology control scheme is to present a sparse structure that can help in developing a space-time graph. This network graph can be developed through the use of connections based time support DTN routing process. Hence, the advance version of the DTN is named as PDTNs that use probability factors in spanning tree along with the defining of NP-complete problem.

Hybrid Approaches: This category of topology control schemes is presented for defining a cluster based approach with the ability of power adjustment to reduce energy consumption efficaciously. The SPAN approach presented by [13] presents the power saving technique for developing a multi-hop ad hoc network. The reason behind the development of the SPAN approach is to establish a clustering based technique to cope with the process of developing significantly suitable approach that can have energy consumption process with suitable connectivity of the network nodes. Using a similar clustering approach, the authors in [14] present the use of randomized rotation technique that can be used for developing local clusters. These clusters are defined with the head name for reducing the impact ration of the process in terms of energy load balancing. For handling the energy consumption issue in WAIoT, the authors from [21] preset the use of energy-aware platforms. These models can help in presenting the information processing approach along with the communication protocol for the sensor collaboration. The core focus of this research work is over the exploring of the techniques that is adopted for developing the optimized WAIoT networks. They have observed the use of environmental energy harvesting approaches for the energy optimization process during sensing technique. This research also presents different solutions that can be used for eliminating the energy consumption issue from the WSNs. The use of sensor nodes is defined for improving the existing topology of the models by energy efficient nodes processing. For this reason, they extend their research effort in comparing different MAC protocols as well. Another interesting research effort conducted by the researchers in [7] presents that the use of energy management process can help in reducing power need in wireless networks. However, they have also mentioned certain issues related to the power management from the perspective of cost. Generally, allocation of resources for defining constraints management can increase the cost for management. For this reason, the topology management module is use for constructing a multi-hop technology based on concurrent operations defined through the WiFi direct module. This module can also help in defining the group based architectural model in which the highest intent values are listed along with the client information for defining the owner role for developing multi-hop network. This intent value of the client is mainly dependent over the neighbors count along with the distance between the smartphones by a content server. The authors in [18] present that for handling energy distribution in WSNs, it is important to use a systematic and comprehensive classification technique. The process of classification mainly involves the interactions between the protocols of the system along with the cross-layer interactions. They present a classification protocol scheme, in which each part can be defined for presenting in the solution to define the assumption associated with the energy consumption with higher data sampling for preprocessing consumption. Different applications are observed with greater power consumption process over the network nodes that requires the handling over the energy filtering process. Hence, real applications is reported with transmission control protocols for developing energy conversion process. The authors conclude the findings of their research work by explaining the increasing need of MAC in the WAIoT networks. They relate this fact with the mobility of the nodes that may become a major challenge for energy consumption in topology control. Some machine learning based approaches are also reported from the literature that mainly focus over the development of the prediction models. These models can help in identifying the particular nodes with high probability of energy consumption. Hence, the use of node classification has the ability for dealing with the identification scheme in terms of presenting the graph based approach for the WAIoT networks. These approaches are mainly responsible in terms of automating the conventional approach of detecting energy consumption. Hence, adjacency matrix is commonly developed during the machine learning model implementation for defining the process flow of the data. This topology model reported by the authors in [24] mainly focus over using semi-supervised classification technique. The core purpose behind the adoption of semi-supervised classification technique is to relate the scenarios for presenting the information over the graph structure. This configure is depicted in the figure shown below to explain the working of the machine learning models with graph convolutional network and multi-layer graph network through classification approach.

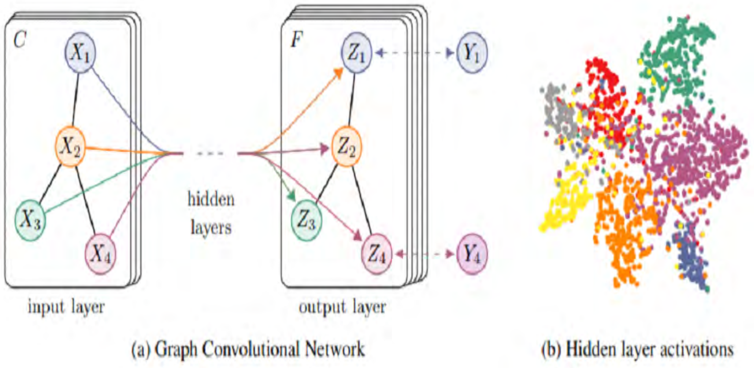

Figure 2.6 Visualization for Semi-supervised Classification Topology

A brief discussion from machine learning based graph based classification models is presented in the referenced paper. These details are provided for discussing the classification attempt for handling energy consumption in WAIoT networks.

Graph-based Semi-Supervised Learning: From literature, numerous researches are obtained over the development of graph based semi-supervised learning topology. These approaches are presented by explaining the graph representation approaches by categorizing the process into two groups: these methods are mainly responsible for defining explicit graph regularization approach along with the graph embedding based approaches. Hence, authors in [25] present the prominent scheme for defining a manifold regularization approach. The purpose behind the implementation of the defined approach is for the defining a deep-learning embedding scheme to learn graph embedding. An advancement in the development of the approaches is presented in terms of defining different models that can help in learning graph based embedding for the skip-gram model. The authors present DeepWalk approach in [26] that use random walk based graph development technique. It helps in presenting the approach that can be used for showing prediction approach along with the local neighborhood of nodes. The sampled nodes that is presented through the random walk process can be explained by showing a LINE method over nodc2vcc scheme that extends the deep walk process in terms of showing sophisticated random walks along with the inclusion of the breadth-first search scheme. In this process, the model is developed by explaining the optimization process through which each node can have separate energy utilization process. This technique can improve the conventional energy utilization process by optimization. A visualization of the presented approach is presented in the figure given above.

MST based Topology Control Algorithms: In this section, the minimum spanning tree (MST) based topology control algorithms is summarized for presenting the solution

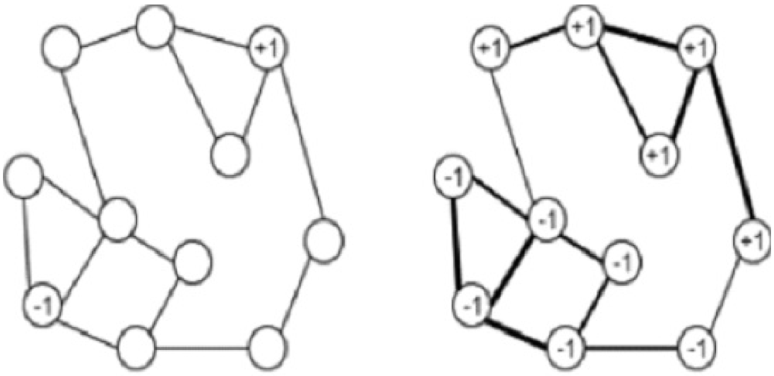

Figure 2.7 Graph-based Semi-Supervised Approach

of optimizing energy conservation scheme in WAIoT. The energy efficiency and network capacity is reported as a major issue in WAIoT. Another major limitation identified from WAIoT network is the limitation of computing resources, which include computing power, computing memory, and computing bandwidth for the wireless devices. Hence, they have explained the case scenario of the WAIoT in terms of WSN. It should be noted here that WSN has mainly resource constrained topology. The use of topology control is identified as essential parameter for prolonging network life along with the efficiency improving scheme for the network. The use of topology control approaches is recorded as a solution for maintaining the network connectivity along with the handling of energy consumption of network nodes. The common idea behind the development of the topology control algorithms is to define a structural model based on which the neighbor relation can be reported for defining node based data transmission. During the process of data sharing, a major issue related to the energy consumption is defined for explaining the maximal power consumption. For this reason, a detailed analysis over the MST is presented to explain the use for handling mobility of the wireless networks. For this reason, an approach introduced by the authors in [15] presented that the local minimum spanning tree (LMST) can be used as multihop wireless network that can deal with the mobility of the models. For this reason, the topology development can be performed by connecting each node with the local MST structure. These nodes of the network can be presented for showing different hops over the tree nodes. Likewise, different features of the LMST is presented by these authors in terms of topology developed through LMST, node degrees for generating the LMST topology, and generating of bidirectional links for presenting resulted topology. The design guidelines of the MST algorithms presented by the authors in [15] depicts that there is a need for preserving the network connectivity along with the minimal power consumption. Likewise, a distributed algorithm has to be presented for defining the multihop network architecture. Similarly,

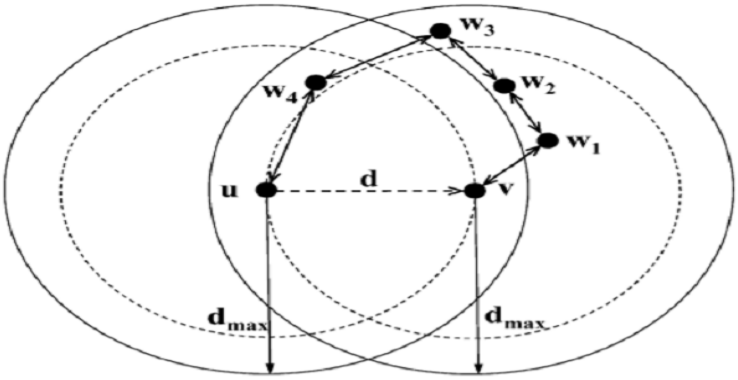

Figure 2.8 MST Connection Architecture

MST models have a less mobility connection in terms of depicting the dependency of the algorithm over local information with less delay and overhead in message. Moreover, a required functionality in MST is the inclusion of the bidirectional links based on which reserve paths can be presented for showing proper working of RTS/CTS scheme. Moreover, the node degree must need to be small in topology based on which a small node degree can provides mitigation of several terminal related issues. Hence, suitable communication channel can be developed through MST topology.

Chapter 3

Making the topology control algorithm for fair energy distribution

The nodes used in this study are classified as MIMO UAV swarms. Because the network is dynamic, nodes' locations will constantly change. Three-dimensional Euclidean space is used for the simulation. The graph of nodes and vertices is undirected. The model is position agnostic. The swarms of UAV can communicate with one another via automatic dependent surveillance-broadcast (ADS-B). Once the location is determined, the node calculates the distance between itself and the other node.

3.1 System Model

Due to the fact that the graph is undirected and each node has multiple antennas, each node can communicate with all of its neighbours by transmitting the required amount of power. The graph is represented by

$$G = \left(V, E \right) \tag{3.1}$$

where V represents the nodes and E represents the edges between nodes. We consider the worst case where all nodes are communicating with each others using the edges.

If two nodes v_i and v_j are within each other's maximum communication range γ, an edge v_{ij} is established between them.

E = [e$_i \dots e_n$] is the set containing all edges while V = [v$_i \dots v_n$] is the set with all the nodes. The residual energy of all nodes are stored in the set denoted by ε.

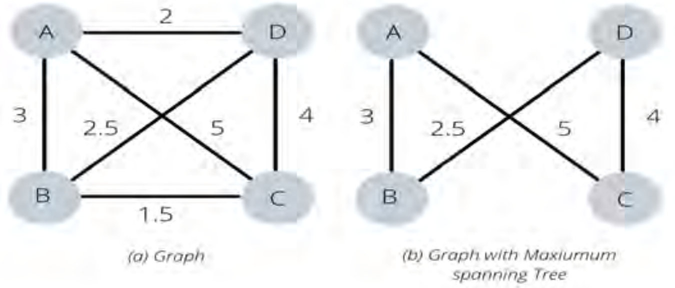

Figure 3.1 Depiction of the original topology with all links available and maximum spanning tree in which links are removed using Kruskal's algorithm. Letters showing nodes and numbers showing weights of the links

Each node uses ADS-B to determine the location of its neighbor nodes . Once the location is determined, node v_i uses the following equation to determine the distance from node v_j:

$$d_i j = \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2 + \left(z_i - z_j\right)^2} \tag{3.2}$$

3.1.1 Calculations and estimations

The term "node degree" refers to the number of nodes connected to a single node. In other words, the node degree of v_i defines the number of edges it is connected with. The condition for establishing a link between two nodes is that both nodes are within each other's maximum transmission range. Node degree D_{vi} equals the number of adjacent nodes N_{vi} for a node v_i. Two nodes can communicate with one another if they share an edge. For a node i and j, If p_j denotes the transmission power, PL_{ij} denotes the path loss between v_i and v_j, and g_{ij} denotes the channel's direct gain, then $c_{ij} > 0$ denotes the receiving signal's power [**?**].

$$c_{ij} = g_{ij} log\left(1 + \frac{p_j}{10^{P^L ij/10\sigma^2}}\right) \tag{3.3}$$

σ is a Gaussian noise with zero mean.

In order to optimise communication efficiency, we can estimate the power of the received signal by fixing the data transmission rate. Once the received signal power is received, we can calculate the sender's transmission power using 3.3

$$p_j = log(\frac{c_{ij}}{g_{ij}})log(PL_{ij}/10\sigma^2) \tag{3.4}$$

s represents the size of data, using which the transmission time can be measured using:

$$t(s) = \frac{s}{r_{tx,rx}} \tag{3.5}$$

As the minimum data transmission rate is fixed for the sake of communication assurance,it is straightforward to calculate the transmission time [**?**] by **??** Finally, we determine the amount of energy consumed by the sender while transmitting the signal using 3.4 and **??**

$$J(s) = p_{tx} \times t(s) \tag{3.6}$$

3.2 Problem Statement

The primary goal of topology control algorithms is to extend the life of the network by eliminating redundant edges. This is because a large number of edges forces a node to communicate with a greater number of nodes, draining their energy in the process. We accomplish this goal by carefully removing redundant edges to prevent the network from collapsing. The resulting graph is referred to as a minimum spanning tree or a maximum spanning tree, depending on the method used to satisfy the requirement. There are several algorithms for generating a maximum or minimum spanning tree, but we will use Kruskal's Algorithm.

3.2.1 Kruskal's Algorithm

In graph theory, Kruskal's Algorithm[**?**], also known as the "greedy algorithm," is used to eliminate redundant weighted edges in order to obtain the least possible links. It adds a weighted edge in each iteration without creating a loop or redundant link, resulting in formation of spanning tree in which all nodes are connected but there is no redundant path between them. The resultant graph of $G'_{MST} = (V, E'_{MST})$ obtained from the original topology $G = (V, E)$ contains all the nodes with less number of edges i.e. E'_{MST} ⊆E.

Maximum Spanning Tree

In a maximum spanning tree, the Kruskal's algorithm continues to add edges based on the maximum available weight, eliminating redundancy while maintaining the graph's connectivity. As a result, it returns the graph with all nodes and $n-1$ edges, where n is the number of nodes in connected graph. Between two edges that do not create redundancy in the connected graph, the algorithm chooses the edge with greater weight.

Minimum Spanning Tree

In a minimum spanning tree, the Kruskal's algorithm continues to add edges based on the minimum available weight, eliminating redundancy while maintaining the graph's connectivity. As a result, it returns the graph with all nodes and $n-1$ edges, where n is the number of nodes in connected graph. Between two edges that do not create redundancy in the connected graph, the algorithm chooses the edge with low weight.

3.2.2 Distribution of nodes based on residual energy

Decreasing the number of edges in an undirected graph indeed increases the network's lifetime because nodes with a large number of links must communicate more. However, nodes with a small number of edges must communicate less. As a result, nodes will be able to conserve their residual energy, extending the network's lifetime. However, we discover that simply removing edges to form a spanning tree is insufficient. Additionally, the energy distribution should be such that nodes with low residual energy have fewer neighbours, whereas nodes with high residual energy have a large number of neighbours. Based on the type of network, the distribution node's residual energy is different. For this reason, we cannot create a standard for the topology. However, with a sufficient number of nodes, we can use a statistical approach to improve the network topology in terms of lifetime.

3.3 The Proposed Approach

We assume that the algorithm implemented in this work is used in a way that the greater the node residual energy the larger should be the degree of node and vice versa. i.e. for a node vi, $\varepsilon_{vi} \propto D_{vi}$. However, we require strong evidence to verify our assumption, which is why we require a metric to quantify our claim. For this purpose, we use the energy distributed index (ED Index)[**?**]. After establishing the metric for evaluating our claim, we propose the energy distribution topology control algorithm (EDTC)[**?**]. As the name implies, this goal is accomplished through the use of the maximum spanning tree and the ED Index. After converting the original topology to a maximum spanning tree, the number of edges is reduced, which may affect the network's robustness. We use the ED Index as a guide to reintroduce a

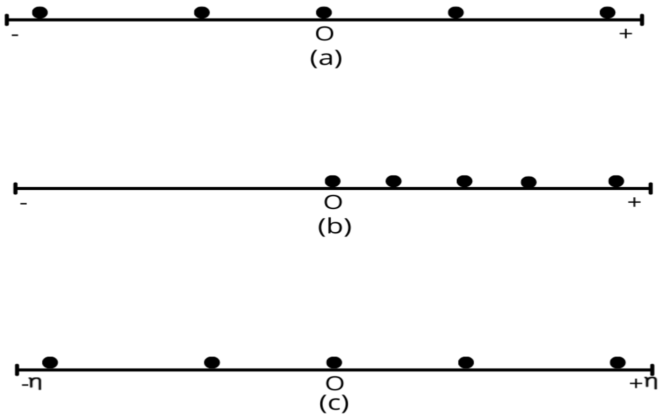

Figure 3.2 (a) shows original values of sample, (b) shows values of sample after first normalization while (c) shows sample values normalized in range [-$\eta, +\eta$]

few edges into the maximum spanning tree to increase network robustness while ensuring that they do not interfere with the nodes' energy drainage, which is the primary objective.

3.3.1 Energy distribution index

Statistics are critical in areas that require estimations. The use of the mean and normalisation enables researchers to concentrate on the concept rather than on large numbers and calculations. This is similar to how we use graphs to represent real-time networks. We consider UAV swarms to be the vertices of a graph and the communication links between these swarms to be the edges of the graph. Using the same methodology as previously described, we used statistics to create a metric for our research known as the energy distribution index. We hypothesize that if nodes with higher residual energy have higher node degrees and vice versa, this should increase the network's lifetime; however, we must have sufficient evidence or results to demonstrate the network's vitality. The ED Index is used in the same way, acting as a matrix to verify our assumptions when simulating our network in various scenarios. The simulation is performed in MATLAB, which is described in the following section. We cannot use actual values for various parameters because these values will change over time in various networks and topologies. Each network will have a unique number of nodes and will have its own unique set of residual energies and other parameters (maximum communication range, Data rate etc.). Statistics assist in this case by normalising the values, which facilitates data manipulation and handling. Simply by having the maximum and minimum values for all available samples for a particular set, we can use the formula to normalise these values.

Table 3.1 Mean values of residual energy and node degree to determine network's lifetime

Residual Energy	Node Degree	ED Index value	Network's lifetime
+	+	Large	Large
-	-	Large	Large
+	-	Small	Small
-	+	Small	Small

$$z(x, x_{min}, x_{max}) = \left(\frac{x - x_{min}}{x_{max} - x_{min}} \right) \tag{3.7}$$

Using 3.7 We normalise two times. It is normalised to the range [0,1] in the case of residual energy. However, we do not want 0 here because if the value is exactly zero, we have no idea where it lies on either side of the number line. As a result, [0,1] is further normalised to [-1,1]. This second-degree normalisation is obtained by subtracting the value of the node's residual energy from the initial normalised value. Finally, we use scale coefficient $\eta > 0$ to get the values in our desirable range. Values can be shrink or extended by multiply with $-\eta$ or $-\eta$. The same process is repeated for node degree to normalise the values of each node. Normalization is showing in 3.2. If we enlist the complete normalization it can be stated as:

1. Normalize the value in range [0,1].
2. Calculate the mean from normalized values.
3. Subtract each sample's value by mean.
4. Select the value for scale coefficient
5. Multiply each value obtained after step 3 with the scale coefficient

The scale coefficient value η is irrelevant; however, when comparing different network topology, it is prudent to use the same scale coefficient value throughout. When we normalize both the residual energy and the node degree, then for node v_i we have $\widetilde{D_{v_i}^*}, \widetilde{\varepsilon_{v_i}^*} \subseteq [-\eta, \eta]$.

After we have normalised the residual energy and node degree values, it is straightforward to obtain the value that will determine whether or not our assumption is correct. To obtain this value, we multiply the node degree and residual energy values, which yields the following four conditions.

1. $\widetilde{D_{v_i}^*} \in \eta \wedge \widetilde{\varepsilon_{v_i}^*} \in \eta$.
2. $\widetilde{D_{v_i}^*} \in -\eta \wedge \widetilde{\varepsilon_{v_i}^*} \in -\eta$.
3. $\widetilde{D_{v_i}^*} \in \eta \wedge \widetilde{\varepsilon_{v_i}^*} \in -\eta$.

4. $\tilde{D_{v_i}^*} \in -\eta \wedge \tilde{\varepsilon_{v_i}^*} \in \eta$.

The first condition indicates that if both the values of residual energy and node degree are positive, then the product will be large. Similarly, if both the values are negative, the product will be large. In contrast to the last two conditions, where if any of the values of either the node degree or residual energy is negative the product is comparatively small. This value helps us while we are comparing different topology with each other. If the simulation shows that the life time of network having this mean value is more then the network having this mean value smaller it means our assumption is correct see the table 3.1.

The final step in obtaining the actual ED Index is to remove extreme values from the obtained mean value to obtain a more normalised value from which we can more accurately estimate the result. This is accomplished through the use of the *Sigmoid* function. When the mean value is passed to the *Sigmoid* function as an input, a value in the range [0,1] is returned.

3.3.2 Energy-degree topology control algorithm

Assuming our assumption is correct, we want our topology to be such that nodes with a high energy have a high node degree and vice versa. This is the balance of energy distribution within a network in its simplest form. Along with removing redundant links, we want to reintroduce a few edges using the ED Index as a guide. Thus, the first step in developing this algorithm is to construct a maximum spanning tree using Kruskal's algorithm; once this tree is constructed, the second step is to further improve lifetime by introducing few edges. This is because eliminating all redundant edges may result in a disconnected graph, i.e. even if a single node is drained, the network may become disconnected.As discribed above, the algorithm is distributing the energy in the maximum spanning tree of the original graph that's why it is named as Energy-degree topology control algorithm.
We begin by assigning weights to the edges before constructing the maximum spanning tree. These weights are averages of each link's residual energies. We want to keep all edges in the spanning tree if they connect nodes with a high residual energy. The equation is used to calculate the average residual energy.

$$\omega(e_{vi}, e_{vj}) = \left(\frac{\varepsilon_{vi} + \varepsilon_{vj}}{2} \right) \tag{3.8}$$

We use Kruskal's algorithm to create the maximum spanning tree after we have weights for all edges. Kruskal's algorithm removes all redundant edges in the original topology one by one based on their weights. Spanning tree is created using following steps.

1. Arrange edges in descending order as per their average weights obtained from 3.8
2. Select the maximum weight or the first entry arrange from descending order set, and insert that edge in the graph. If two edges have same weights select any of those weights.
3. Repeat the step 1 and step 2 for all of the next steps and keep inserting only if the edge is not creating the loop

The resulting graph $G'_{MST} = (V, E'_{MST})$ is the spanning tree of the original graph $G = (V, E)$ where nodes remain the same in both graphs and $E \subseteq E'$. Maximum spanning trees have the fewest possible edges in a connected graph, which means that each node has only one edge, and no node can communicate with another node via more than one edge. That is the point at which a problem may manifest itself and become a massive one. If the energy of a single node is depleted, the edges of nodes connected to it are removed, effectively disconnecting the entire network; instead of a single connected network, there will be multiple disconnected networks. Swarms of UAVs will retain their ability to communicate, but only with the nodes to which they are directly connected. To address this issue, we employ the factor of $0 \leq \vartheta \leq |E| - |E'_{MST}|$. It tells the number of edges to be re-introduced. We take the guidance of the number of edges to be re-introduced from ED Index value. The number of edges cannot exceed this factor; it must be less than or equal to this number, choice of which is made as per the network topology. The EDTC algorithm is complete after reintroducing these edges.

Algorithm 3.1 Algorithm of ED Index

```
Require: Degree matrix, array of residual energies, number of nodes, scale coefficient.
Ensure: ED Index of the topology ED(G,$\eta$)

$\varepsilon \leftarrow$[1xN]                                        ▷ N is the number of nodes
$D \leftarrow$[NxN]

1. 1st degree Normalization | [0,1]

$\varepsilon_{min}, \varepsilon_{max} \leftarrow$ minimum and maximum energy of node V

$D_{min}, D_{max} \leftarrow$ minimum and maximum node degree of V

for $v_i \in V$ do                                                  ▷ For each $v_i$
    $\hat{\varepsilon} \leftarrow \varepsilon_{min}, \varepsilon_{max}$
    $\hat{D} \leftarrow$ D$_{min}, D_{max}$
end for

2. 2nd degree Normalization | [-1,1]

$\hat{\varepsilon}_{mean} \leftarrow$ mean of $\hat{\varepsilon}$

$\hat{D}_{mean} \leftarrow$ mean of $\hat{D}$

for $v_i \in V$ do                                                  ▷ For each $v_i$
    $\hat{\varepsilon} \leftarrow \hat{\varepsilon}_{mean} - \hat{\varepsilon}$
    $\hat{D} \leftarrow \hat{D}_{mean} - \hat{D}$
end for

3. Extend/shrink the value ranges | [-$\eta, \eta$]                 ▷ scalar coefficient


$\hat{\varepsilon}_{mean} \leftarrow$ mean of $\hat{\varepsilon}$

$\hat{D}_{mean} \leftarrow$ mean of $\hat{D}$

for $v_i \in V$ do                                                  ▷ For each $v_i$
    $\hat{\varepsilon} \leftarrow \hat{\varepsilon} \times \eta$
    $\hat{D} \leftarrow \hat{D} \times \eta$
end for

4. Getting ED-Index
$output \leftarrow 0$

for $v_i \in V$ do                                                  ▷ For each $v_i$
    output$\leftarrow$output + $\hat{\varepsilon} \times \hat{D}$
end for
output$\leftarrow$output / number of outputs
return $sigmoind(output)$
```

Algorithm 3.2 Algorithm of EDTC

```
Require: Degree matrix, array of residual energies, number of nodes, scale coefficient and number of edges to be re-introduced ($(\vartheta)$).
Ensure: Energy distributed graph of original topology with greater ED-Index

  1. Construction of maximum spanning tree from original graph

  $G_{MST} \leftarrow$ Kruskual's algorithm applied on original graph G

  $D_{EDTC} \leftarrow$ create copy of degree matrix of MST ($D_{MST}$)

  $EDIndex_{MST} \leftarrow$ calculate ED-index of maximum spanning tree using [3.1]

  2. Storing and sorting weight matrix

  $\omega_{MST} \leftarrow$ weights of all edges in MST

  $\hat{\omega}_{MST} \leftarrow$ Arrange weights in descending order

  3. Reintroducing edges

  $D_{RI} \leftarrow$ D$\backslash DMST$

  $\hat{D}_{RI} \leftarrow$ Arrange the link matrix as per descending order weights ($\hat{\omega}_{MST}$)
  count=0
  for $e_{vi} \in \hat{D}_{RI}$ do                                   ▷ For each $e_{vi}$
      if $count \leq \vartheta$ then
          $D_{EDTC} \leftarrow D_{EDTC} \bigcup e_{vi}$
          $count = count + 1$
      else
          Break;
      end if
  end for
  $G_{EDTC} \leftarrow (V, D_{EDTC})$
  return $G_{EDTC}$
```

Chapter 4

Simulations and results

We use MATLAB to conduct extensive simulations to validate our hypothesis. We cap the simulation area at $80x80_{m2}$. We distribute data points randomly as nodes in that area. All devices have the same transmission range in all simulations, which is 10_{m2} square. Each simulation produces the original graph, the LTCA graph, and the EDTC graph. Each graph has its own link matrix, referred to as the degree matrix, which dictates how the links are established for each topology. We calculate the ED-Index for each topology to determine whether or not our claim is correct, and we discover that the ED-Index is maximum for EDTC. The ED-Index of the original topology is minimal, approaching LTCA. Nonetheless, LTCA has a higher ED-Index than the original topology.Following that, we determine the number of alive nodes in each topology following a specified number of simulations.

4.1 ED-Index

In various simulations, we map the ED-Index of three topology: original, LTCA, and EDTC. We discover that the ED-Index of EDTC is greater than the ED-Index of the other two topology in all simulations, whereas the ED-Index of LTCA and the original topology is nearly identical. This is because, while LTCA eliminates links, it does not account for the energy distribution we are following, i.e., the greater the residual energy, the higher the link degree should be, as determined by maximum spanning tree. The simulation is shown by graphs given below from Fig. 4.1 to Fig. 4.4. The ED-Index is computed by simulating all three typologies multiple times to obtain the mean ED-Index values when the number of nodes was 20, 30, 40 and 50. The graph of ED-Index goes does with simulations as the energy is depleting in nodes for each simulation. When nodes for any node energy is depleted completely that node is removed as well as the edges attached with that node is also removed which results in lower value of ED-Index.

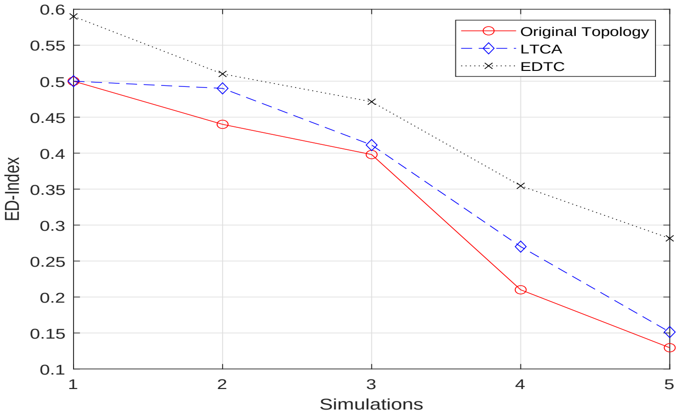

Figure 4.1 $ED - Index\ vs\ Simulations\ when\ N = 20$

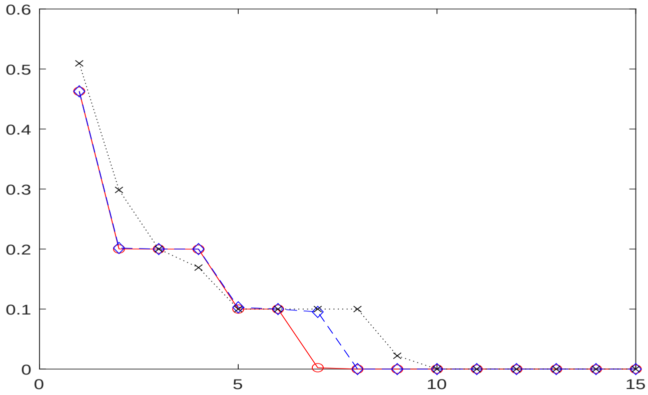

Figure 4.2 $ED - Index\ vs\ Simulations\ when\ N = 30$

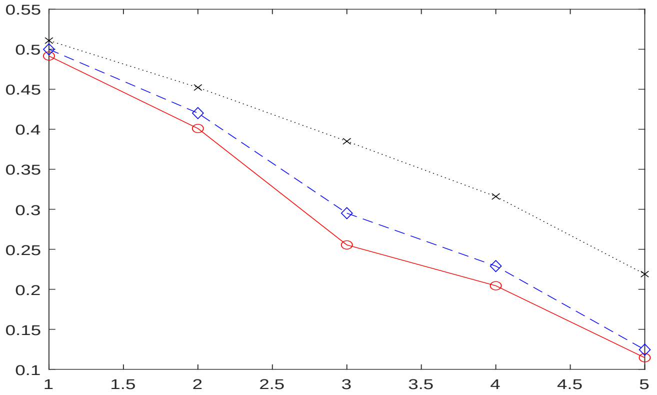

Figure 4.3 $ED - Index\ vs\ Simulations\ when\ N = 40$

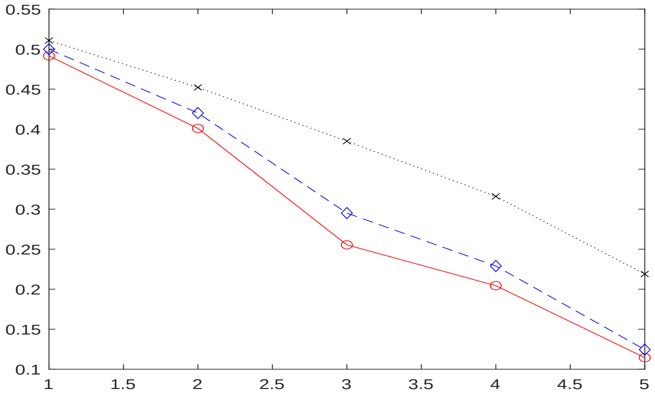

Figure 4.4 $ED - Index\ vs\ Simulations\ when\ N = 50$

4.2 Comparison of network lifetime in different topology

After ED-Index is known for different topology we now simulate these topology in different scenarios to see if there is any difference in number of alive nodes for these topology when simulate in different time steps.
We simulate for nodes $N = 20, 30, 40, 50, 60$ *and* 70 with simulations $S = N/2$. Each network is simulated fifty percent as many times as its nodes. In the example of 30 nodes, the network is simulated 15 times to determine the number of surviving nodes after 15 simulations. This is done for all three topology so that we could compare the number of alive nodes in each after identical simulations. Also, the process is repeated 100 times for each network taking number of nodes constant obtain the mean values in order to ensure that the trend of the results will remain the same.

Fig.[4.5] to fig.[4.10] demonstrates our findings that the number of alive nodes in EDTC is the highest in all instances, whilst the number of nodes in Original topology is the lowest, and LTCA falls in the middle. The simulations were run in parallel for all of these topology, which meant that all nodes started with the same energy and gradually depleted with each simulation.

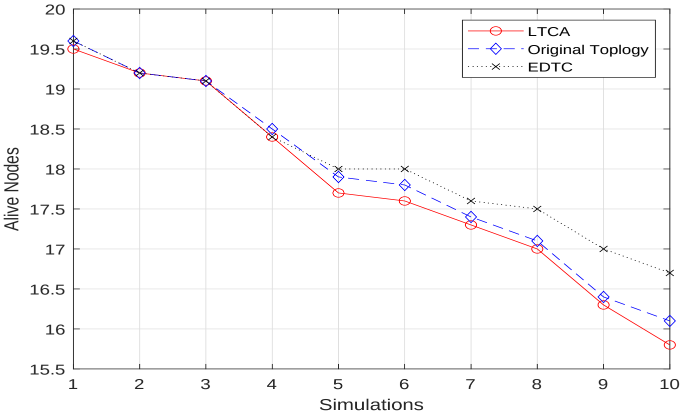

Figure 4.5 *AliveNodes vs Simulations when* $N = 20$

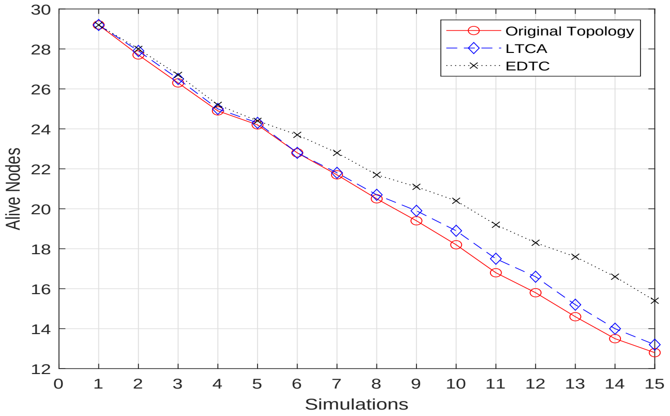

Figure 4.6 *AliveNodes vs Simulations when* $N = 30$

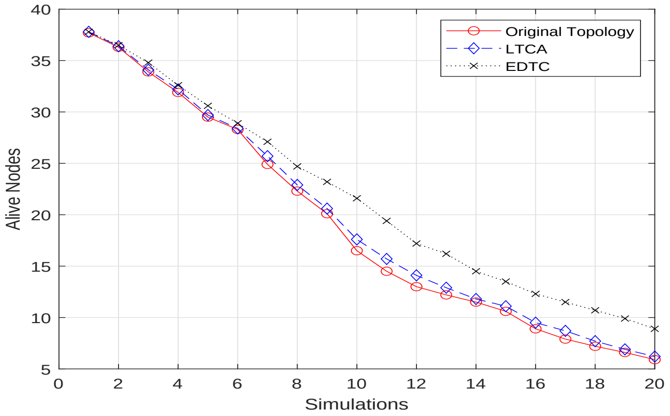

Figure 4.7 *AliveNodes vs Simulations when* $N = 40$

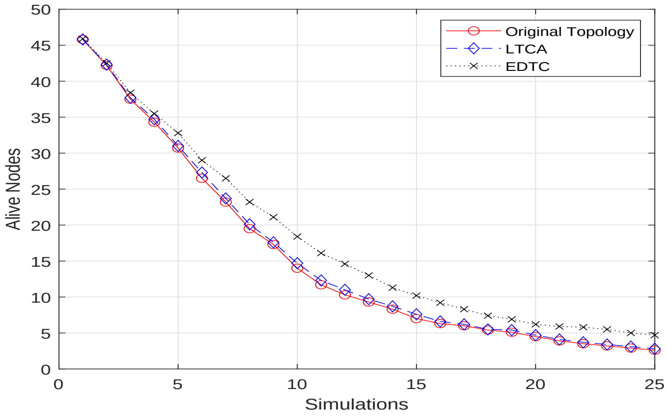

Figure 4.8 *AliveNodes vs Simulations when* $N = 50$

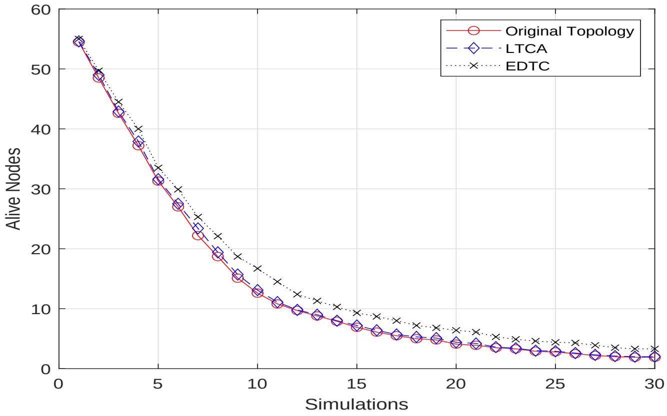

Figure 4.9 *AliveNodes vs Simulations when* $N = 60$

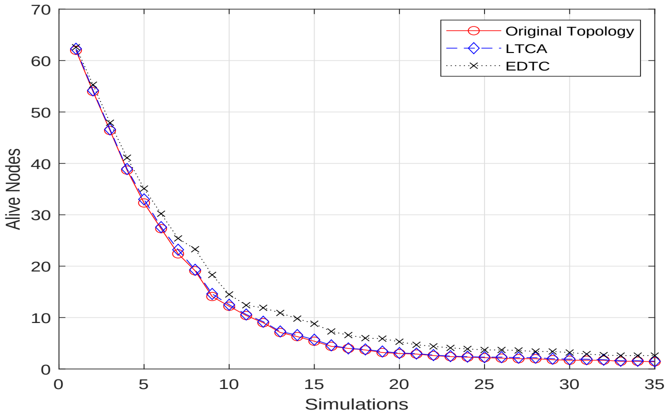

Figure 4.10 *AliveNodes vs Simulations when* $N = 60$

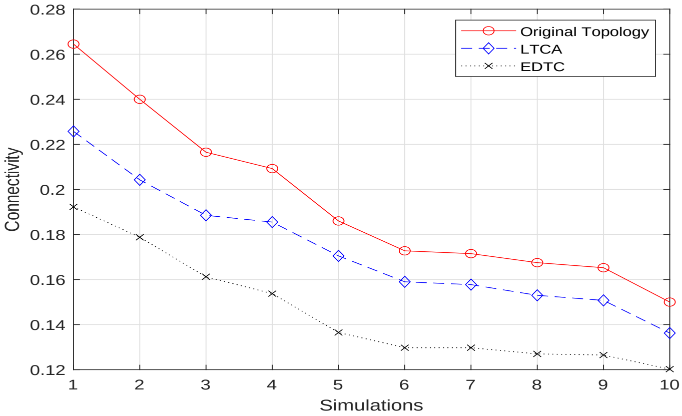

Figure 4.11 *Simulation vs Connectivity when* $N = 20$

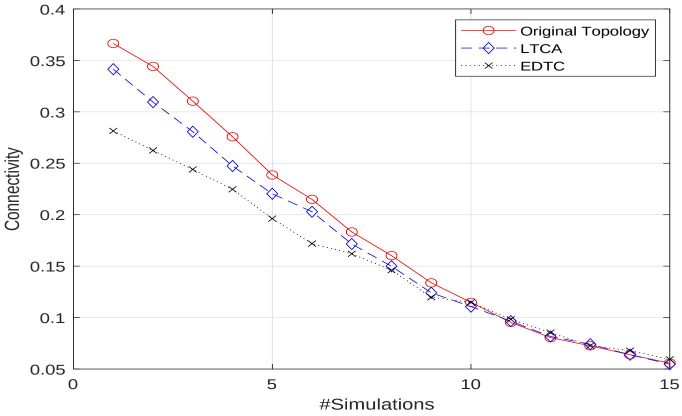

Figure 4.12 *Simulation vs Connectivity when* $N = 30$

4.3 Comparison of connectivity in different topology

We utilise the MST to develop the EDTC algorithm, therefore, connection can be a major concern. In MST, redundant links are eliminated based on weights, which in our case are the average residual energies of the nodes to which the edge is attached. After MST has been applied, a few edges are reintroduced with guidance of ED-Index. In order to solve the issue of connectivity, we develop a connectivity statistic. If the connection value falls below 0.1, the network is disconnected, and vice versa. Which means that a number above 0.1 has no relevance, however a value below 0.1 indicates that the network is disconnected. We discover that EDTC connectivity falls below 0.1 last, while Original topology and LTACA connectivity falls below 0.1 before EDTC. Hence connectivity is sustained in EDTC as opposed to low.

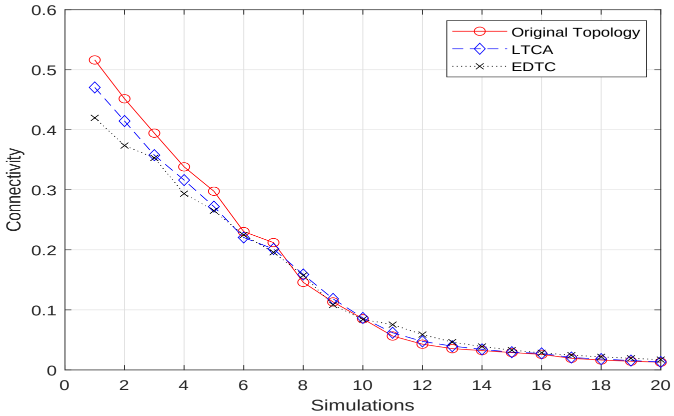

Figure 4.13 *Simulation vs Connectivity when* $N = 40$

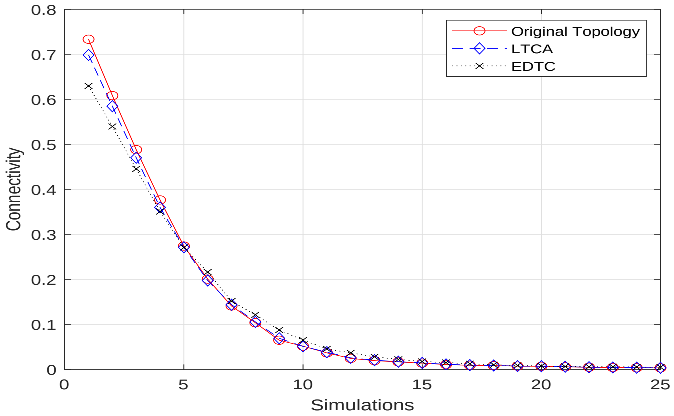

Figure 4.14 *Simulation vs Connectivity when* $N = 50$

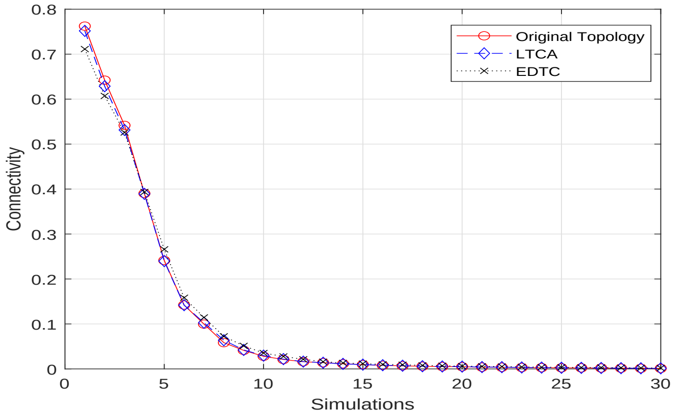

Figure 4.15 *Simulation vs Connectivity when* $N = 60$

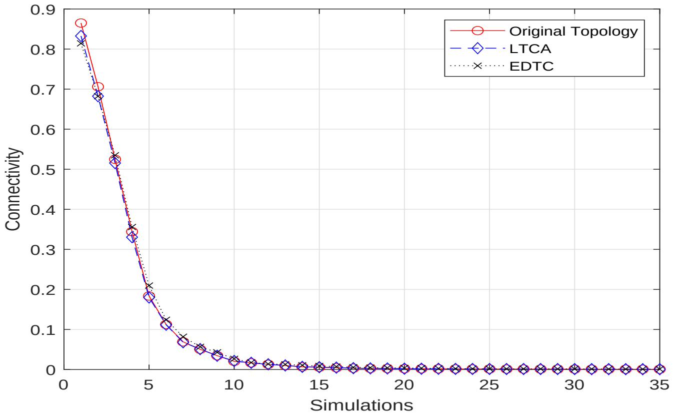

Figure 4.16 *Simulation vs Connectivity when* $N = 70$

4.4 Results

The graphs from Fig. 4.1 to 4.4 demonstrates that the EDTC consistently has the highest ED-Indices across all simulations. While LTCA and original topology have similar ED-Indices, LTCA is not a topology control algorithm in the same way that EDTC is. Although it eliminates some redundant links based on neighbour node IDs. The graphs from Fig.4.5 to 4.10 demonstrate that EDTC has the longest life span of any network topology. Extensive simulations in MATLAB are used to validate this with a variety of different node counts. Similarly to the ED-Index values, the difference in lifetime between the original and LTCA topology is not significant, but LTCA performed better than the original. EDTC outperformed both the original topology and LTCA in terms of lifetime due to its balanced energy distribution. EDTC is created by introducing a few edges into MST under the direction of the ED-Index. While reducing edges to extend lifetime, we must also ensure that the network remains connected. The graphs from Fig. 4.11 to 4.16 demonstrate the connectivity comparison of the three simulated topology. We are not interested in values more than 0.1, as values greater than 0.1 indicate redundancy. If the value is equal to 0.1, the network is MST, and if it is less than 0.1, the network is unconnected. EDTC maintains connectivity in more simulations than the other two topology, or at least its connectivity does not degrade to a lesser degree.

Chapter 5

Conclusion

We improved the network lifetime of an ad-hoc network composed of UAV swarms in our research. The concept of lifetime enhancement was through balanced energy distribution.

We assumed that if we allow energy to be distributed in such a way that nodes with relatively high energy have a greater number of connected edges and nodes with low residual energy have a lower node degree, the network lifetime will be prolonged. We used statistical techniques to develop an algorithm that calculated the degree to which energy is distrusted in accordance with our hypothesis, which we termed the energy distribution index (ED-Index). We then used this ED-Index to substantiate our claim.

We used Kruskal's algorithm to create a maximum spanning tree and then reintroduced a few edges for the sake of robustness, as the ED-Index value increased. The resulting algorithm was dubbed the topology control algorithm for energy distribution. When simulated in Matlab, the EDTC outperformed all other modern algorithms in terms of network lifetime enhancement.

5.1 Future Work

We developed the EDTC algorithm which is also a time-consuming process; while it extends the network's life. The use of a convolutional neural network can reduce the time required to construct the network's topology, thereby optimising the entire network. Utilizing CNN for network configuration optimization can reduce the amount of time required to develop a network. CNN can identify the optimal settings for a given network deployment scenario by learning from a large dataset of network configurations. This may involve optimising transmission power, data rate, and network frequency, among other parameters. EDTC can also be used with other algorithms to make the newtwork more efficient.

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