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R & D Project Report

Academic Year- 2022-23

On

"TOPOLOGY CONTROL IN WIRELESS SENSOR NETWORKS"

Submitted by

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CERTIFICATE BY SUPERVISOR(S)

This is to certify that the present R&D project entitled "**Topology Control in Wireless Sensor Networks"** being submitted to NIIT University, Neemrana, in partial fulfilment of the requirements for the award of the Degree of Bachelor of Technology, in the area of CSE, embodies faithful record of original research carried out by **Pragya Arora (BT19GBT022), Uday Som (BT19GCS145) & Ashwin Yadav(BT19GCS073).** They have worked under my/our guidance and supervision and that this work has not been submitted, in part or full, for any other degree or diploma of NIIT or any other University.

Place: NIIT University

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Date: 28/05/2022

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DECLARATION BY STUDENT(S)

I/We hereby declare that the project report entitled "**Topology Control in Wireless Sensor Networks"** which is being submitted for the partial fulfilment of the Degree of Bachelor of Technology, at NIIT University, Neemrana, is an authentic record of my/our original work under the guidance of **Dr. Shweta R. Malwe**. Due acknowledgements have been given in the project report to all other related work used. This has previously not formed the basis for the award of any degree, diploma, associate/fellowship or any other similar title or recognition in NIIT University or elsewhere.

Place: NIIT University
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Acknowledgement

"It is not possible to prepare a project report without the assistance and encouragement of other people. This one is certainly no exception."

At the very outset of this report, we would like to extend our sincere & heartfelt obligation toward all the people who have helped us in this endeavor. Without their active guidance, help, cooperation & encouragement, we would not have made progress in the project.

We are extremely thankful and extend our gratitude to **Dean Research Dr. Ratna Sanyal** for advising and mentoring us at each step of this journey.

We are ineffably indebted to our **Dr. Shweta R. Malwe** for moral guidance, encouragement, and for her valuable guidance in the accomplishment of this project.

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3. Introduction

In this paper, we address the problem of topology control in a heterogeneous network of wireless sensor nodes. Consider 2 types of nodes, one with a restricted amount of resources and energy to function (WSN) and the other being a resource rich and non-restrained sensor node (Super node). WSN's are deployed randomly in the desired area and supernodes are placed strategically in set locations and in much lower numbers as compared to WSN's. The supernodes provide better Quality of service as they can collect data from the wireless sensor nodes, store them and do some amounts of necessary processing before sending the data to the gateway (Sink).

We have modeled our topology control mechanism on the basis of efficient supernode assignment, we bring upon an algorithm based upon deploying a supernode based on certain criterion and making the deployment process as efficient as possible to facilitate minimization of the power and resource used by every sensor node while maintaining K-Disjoint paths from the sensor to supernodes. These paths help in tolerating failure of up to K-1 sensor nodes. If a node dies out or is disconnected due to exhaustion of resources our optimized topology can adapt and reduce the chances of failure. Some similar work on K-Disjoint paths and K-atc problems is done in [1] and another algorithm based on disjoint path vectors is discussed in [2]. While framing and testing the algorithm we also took care of minimizing the number of supernodes that will get deployed in the region or the network area so that we don't use resources not required to be used.

The Paper is organized in the following manner: In Section 2 we talk about the Problem statement, followed by the Literature review. Section 3 discusses the Literature review followed by the proposed Methodology in Section 4. Finally we discuss the results of our algorithm and the optimized topology thus created.

4. Problem Statement

A sensor network is constructed for studying remote data which is to be collected with precision, like temperature, soil moisture reading, weather readings etc. For deploying this network we use wireless sensor nodes. It becomes infeasible to transmit data from hop to hop to the sink in a flat network of these WSN's.

The wireless sensor nodes or sensors are capable of doing the assigned work but are limited in terms of:

1. Power of the sensor node: In terms of battery capacity each node has.
2. Range of the sensor node: In this range is dependent on power level of the sensor node so range is affected if power is affected.
3. Total resources available with each sensor node: This is the general resources in terms of power and processing capacity.
4. Low duty cycle.

These problems cause a network topology to be inefficient as data that needs to be collected and sent to the sink and if a sensor node uses most of its resources or is not in the connectivity range it can either die out or disconnect from the network respectively, also leading to a topology that is less fault tolerant and more susceptible to disrupt the flow of information. In topology control we have to increase the (NETWORK LIFETIME) of the topology and decrease the interference in the flow of data from the sensor to the sink and these are the problems that we faced considering every other point discussed above. In our method we have one more layer of nodes having the supernodes which have more capabilities than normal wireless sensor nodes. The communication between supernodes is considered to be fast and reliable with higher data rates and needing fewer nodes to carry out the function.

There is the problem of connectivity between the sensor nodes also as the range of the sensor node and their subsequent deployment in the network is random at the lower level of wireless sensor nodes. K-Disjoint paths from WSN's to the supernode are a probable solution to this problem. A sensor node communicates to a super node or another peer sensor node if the Euclidean distance between the respective nodes is less than or equal to the transmission range of the particular sensor node. Using our algorithm which takes care of efficiency in deployment of super nodes relative to sensor nodes and fault tolerance in terms of K-disjoint paths helps us improve the overall topology of the network thus created.

5. Literature Review/RelatedWorks

Wireless sensor networks are being more and more widely used now for deployment at locations to collect data and make use of it. These help in many applications which involve remote data collection where it's difficult to physically go and do it, like collecting water level samples in an area or measuring moisture of a landscape at different points precisely etc. A fundamental benchmark that measures performance of these networks of wireless sensor nodes is topology control which helps us to monitor how a sensor field is mutually connected to the peer wireless sensor and how fault tolerant it is. Topology control can be classified into two broad categories that are homogeneous and heterogeneous. In homogenous approach transmission range is kept constant and in heterogeneous approach it varies. Topology control is also based upon network coverage issues and network connectivity issues, these cover all parts in them to properly evaluate a network topology. Similar things are discussed by Mo Li, Zhenjiang Li and Athanasios V. Vasilakos in [4].

5.1. Topology Control Strategies

There are algorithms developed to address architecture of the WSN networks and its topology control and addressing a well-known sub problem K degree anycast topology control problem which states that in a heterogeneous WSN with M supernodes and N sensor nodes with restrained resources that are able to adjust their range , determine a range of transmission for each sensor node such that k-vertex connectivity is maintained and power consumption is minimized over all the sensor nodes.These algorithms include a global anycast topology control algorithm (GATC) to solve K-atc problem and a distributed version of it Distributed anycast topology control (DATC) as an enhancement and a feasible option. The aim of both GATC and DATC are to provide K-vertex supernode connectivity for the network of sensors by incrementally adjusting the transmission range of WSN which are more discussed in [1,3]. There have been improved versions of above algorithms too focusing on making the topology fault resilient by taking account of missing links between the sensor nodes and disconnected sensor nodes in [5].

Other approaches differ from these and focus more on the super node and sensor node relation. Supernodes are unrestrained, resource rich nodes deployed to aid in making data travel easy, fast and also to facilitate fault tolerance by giving a middle option for data to pass through. These approaches involve creating K-Disjoint paths which are paths from source node to the destination node without having any node in common for two or more such paths. Here we take source as resource limited sensor nodes and destination as resource rich (Supernodes). Disjoint path vector algorithm is one such approach in which we use this architecture of sensor nodes and supernodes where supernodes first establish their presence to lower tier sensor node and then the sensor nodes carve out a disjoint path towards the supernodes in order to send their collected data to the supernode. In the process path finding algorithms and neighbor finding algorithms are taken help of. This approach is discussed in detail in [2].

Another creative approach handles the topology control on the basis of minimum drone placement algorithm (MDP) which involves two steps of UAV based supernodes. Firstly, the algorithm assumes that all the present nodes in the network are capable of becoming a supernode and treats every node as a candidate for UAV-Bs. Secondly, the algorithm chooses the minimum number to be UAV-BS so that the network thus formed becomes k-vertex connected. This algorithm and all its merits are greatly discussed in [16].

Some more work in this field is done in [21] explaining and discussing topology control in great detail. On the topic of optimizing topology [23, 24, 25] where the effects of energy constraint in topology control and how to monitor and optimize it to get a better topology is discussed. Finally on making the topology some work is done in [22] based on active and sleep cycles of WSN in order to minimize energy resources and create an efficient topology.

5.2. Network Lifetime

Increasing network lifetime is a parameter that is the prime objective of topology control as we would like to use minimal resources of our components and have data transmission with ease through the sensors of the network. Network lifetime depends on several factors some of them are:

1. Balancing the load amongst the deployed sensors: The sensor nodes deployed should have proper balancing of load. It may not be the case that nodes near sink use all their resources and die off or there may be disruption in data travel due to
2. Conservation of sensor resources: As sensor nodes have limited resources in terms of battery capacity, processing as compared to supernodes, conserving and using these resources properly is important for network lifetime.
3. Coverage of a sensor node: What range is covered by a sensor node or a supernode is important to see and assess network lifetime as it shows if a sensor is getting left out without any connection for data relay
4. Fault tolerance of the network etc.

A lot of work has been done in the field of network lifetime both in order to quantitatively assess it or to maximize it so that the sensor network becomes more and more efficient. To evaluate network lifetime much work has been done in [10, 11, 15].On the basis of coverage there is work done to evaluate and maximize network lifetime [7, 9] and for maximizing network lifetime [14, 18] are the works that use techniques and algorithms to evaluate, assess and maximize the lifetime of sensor network.

6. Proposed Methodology

The new proposal is for fault tolerant topology control in two tired heterogeneous wireless sensor networks.The lower layer of the architecture consists of randomly distributed sensor nodes whereas the upper layer is made up of supernodes whose transmission range is far greater than the transmission range of the deployed sensor nodes.

r	Transmission Range
k	Number of Hops (k =1, 2, 3)

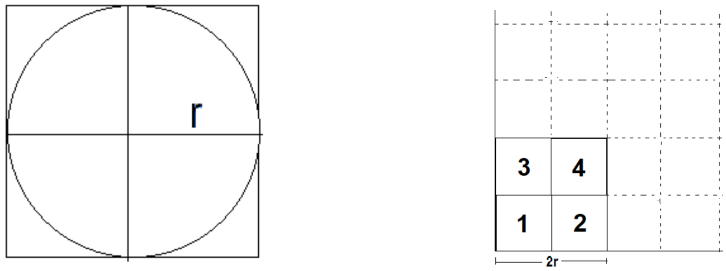
Table . 6.1 : Generic Parameters

6.1. Circumscribed Grid based Topology Control (CGTC)

Deployment of sensor nodes and supernodes has always been done randomly uptill now. The previous algorithms for the two tiered architecture focused upon the intra communication of the lower layer only. On the contrary to this, we aim to have a well structured two staged architecture where the sensor nodes are deployed randomly and based on the deployment of these sensor nodes we try to efficiently deploy the supernodes and eventually also expect to minimize the number of supernodes.For the efficient deployment of supernodes factors such as density of sensor nodes, transmission range of supernodes are taken into consideration.

Our enthusiasm to take this problem forward was based on a simple mathematical relation, where we consider transmission range as ‘r’. The problem of supernode placement grew as we discovered that as we consider a circumscribed circle with transmission ‘r’, the grid size is equivalent to ‘2r’ and hence all the sensor nodes deployed in this area will always be 1 hop connected and some of the sensor nodes might as well be connected via 2 hops.

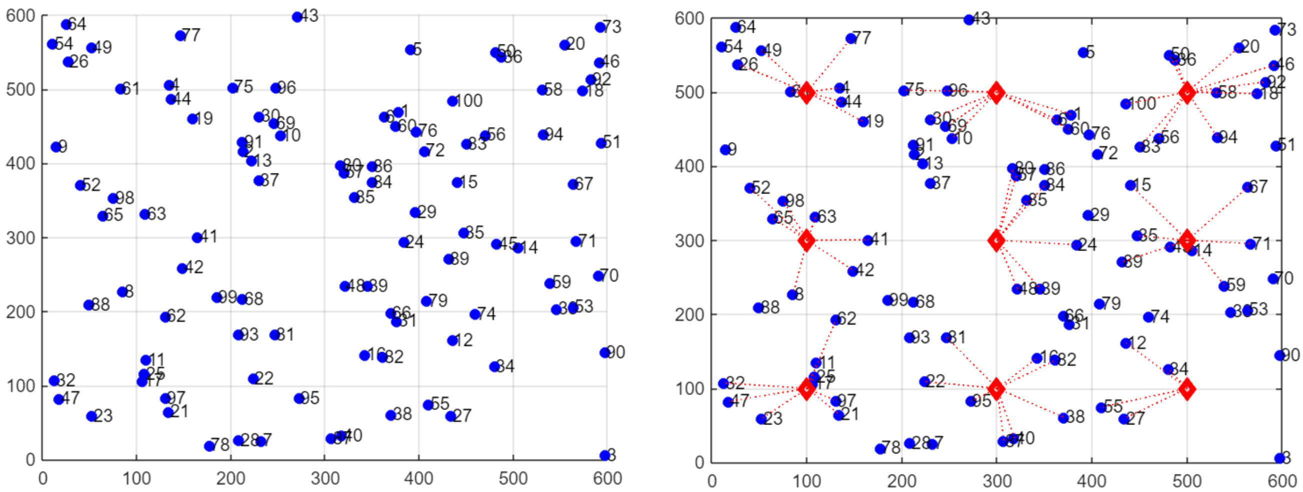
For further ease a matrix Aij of size rXr was established, where each element of the matrix represents the total number of sensor nodes present in each grid cell. The algorithm for supernode placement is applied on this matrix.



(a) (b)

Fig.6.1. : Circumscribed; (a) Unit Structure, (b) Grid Structure

To deploy the super-nodes efficiently we target to divide the field into grids and keep a count of the total no.of sensor nodes inside each of those grids as explained in Fig.6.2 (b) .This data is then stored in an easy to access tabular form. Furthermore, Fig.6.3. represents the primary simulation scene of the CGTC algorithm.



(a) (b)

Fig.6.2. : CGTC : Simulation Basic; (a) Sensor Nodes, (b) With Supernodes

Initially the supernode will be placed at the center of the 4-cell cluster as shown in Fig.6.2 (b), and eventually once the positions of randomly deployed sensor nodes are identified the supernodes will be correctly positioned following the algorithm given below.

Algorithm :

```
for i=1:9
   if nnz(A(:,:,i)) == 4;
      plot at center of 4-cell structure
   elseif nnz(A(:,:,i)) == 3
     plot at center of 4-cell structure
   elseif nnz(A(:,:,i)) == 2
      plot at the center of 2 cells with sensor nodes
   elseif nnz(A(:,:,i)) == 1
      plot at the center of the cell  with sensor nodes
   end
end
```

Further based on this information we deploy our super-nodes efficiently so that no sensor node is left idle or uncovered. This will result in reduction of the total power consumption of the network, hence the network lifetime will be increased drastically.

Fig.6.3 depicts the entire procedure implemented to execute k - Static Circumscribed Topology Control.

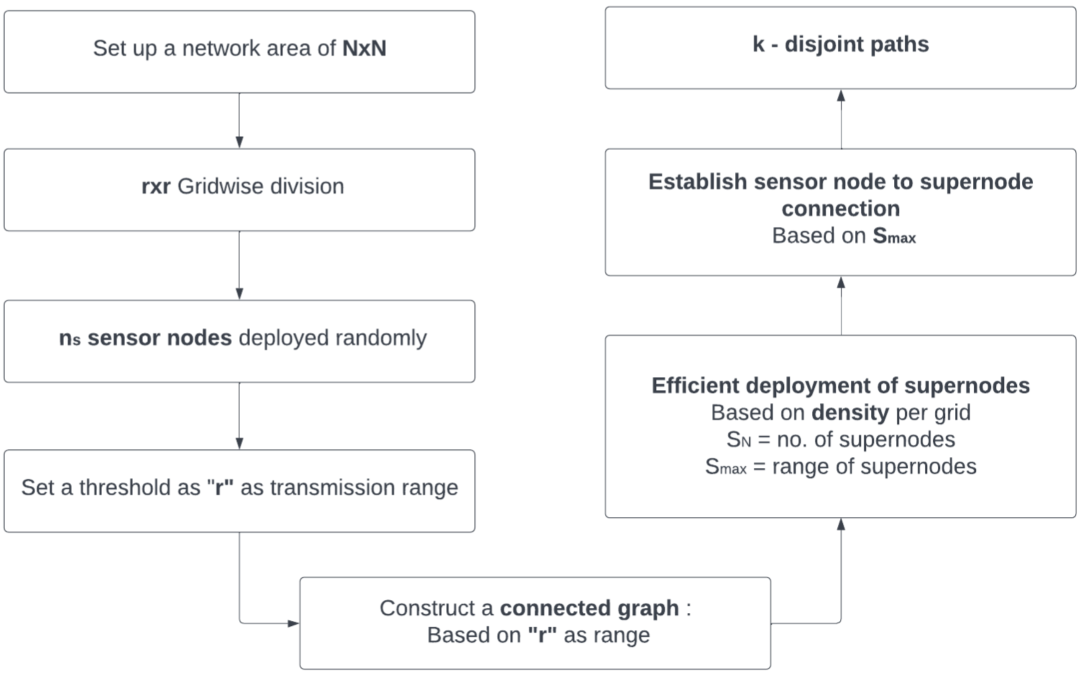


Fig.6.3. : CGTC Approach

For every sensor node transmission range is considered as "r" and the entire network area is divided into smaller grids of r x r. Since the grid size is constant, therefore this proposal is considered to be static where any further advancements are hard to incorporate.

6.2. Proposal : Inscribed Grid based Topology Control (IGTC)

As discussed above the k-SITC method is solving the purpose of efficient deployment of supernode placement but at the same time has its demerits. The approach is independent of the consideration of values of 'k', making the algorithm only viable for k=1 & 2. Moreover the placement of supernodes is not entirely dynamic in nature. Earlier approaches of kATC, first construct a topology considering maximum range, then deploy supernodes and then eventually decrease the transmission range till the topology is k-hop connected.

Contrary to this and modifying the static approach our proposal follows the reverse engineering process, where topology creation initiates with the minimum transmission range of sensor nodes, and the network is maintained with k-hop connectivity using efficient deployment of supernodes.

Considering the values of k, i.e. to maintain k-hop connectivity at all times.

We look at Fig.6.2 (a) & (b) where we can see that the diagonal of the right angle triangle = 2r.

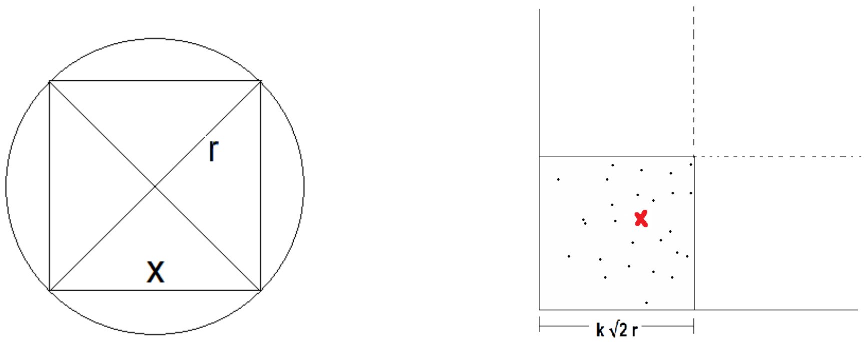
$$(2r)^2 = x^2 + x^2$$

$$4r^2 = 2x^2$$

$$2r^2 = x^2$$

$$x = \sqrt{2}\, r$$

$$x = k\sqrt{2}\, r$$

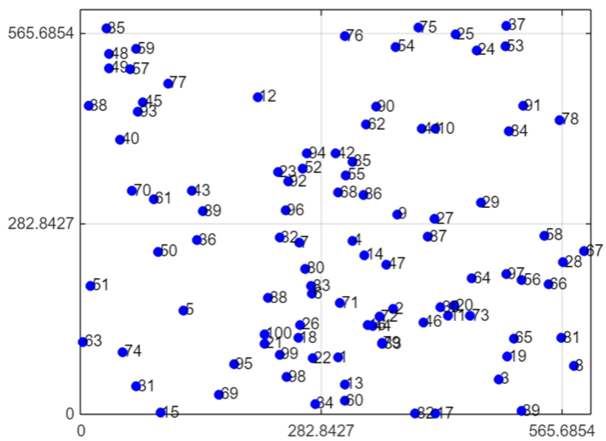


(a) (b)

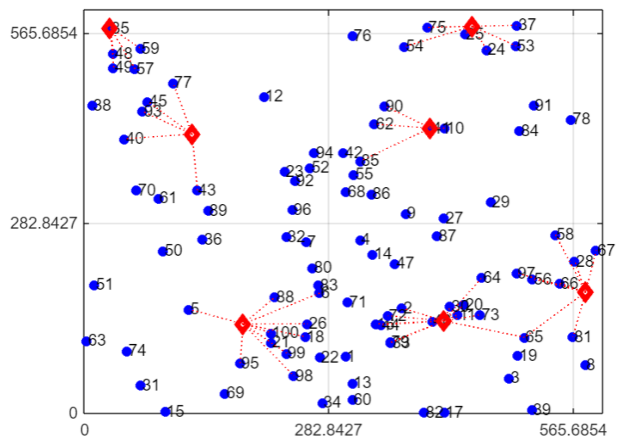
Fig.6.4. : Inscribed ; (a) Unit Structure, (b) Grid Structure

This approach is more dynamic and at the same time ensures a well connected topology with k-supernode connectivity. The subsequent step of deployment of supernodes is done by extracting the standard mean of the x and y coordinates of sensor nodes. Fig. 6.4 (b) depicts a scenario where certain sensor nodes have been randomly deployed in a grid size of $k\sqrt{2}\,r$ and then the placement of a supernode at the mean position of all the sensor nodes present in that grid.

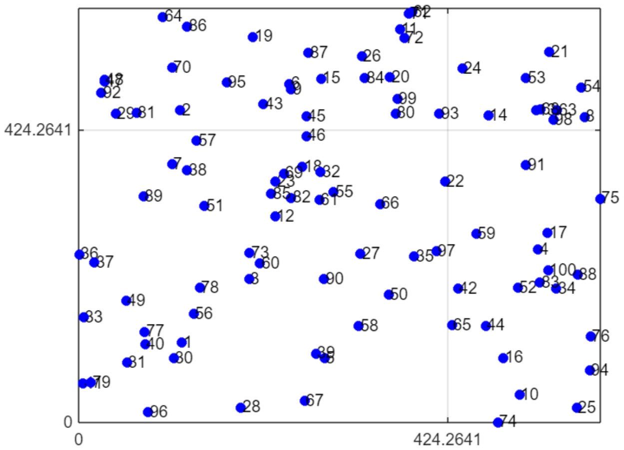
Furthermore, Fig.6.5. represents the primary simulation scene of the IGTC algorithm.



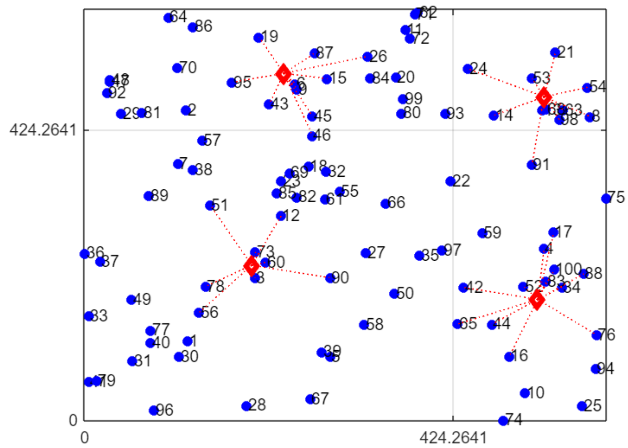
(a).1.



(a).2.



(b).1.



(b).2.

Fig.6.5. : IGTC : Simulation Basic; (a) for k =2 (a).1. Sensor Nodes, (a).2 With Supernodes; (b) for k =3 (b).1. Sensor Nodes, (b).2 With Supernodes

Fig.6.4 depicts the entire procedure implemented to execute k - Dynamic Inscribed Topology Control.

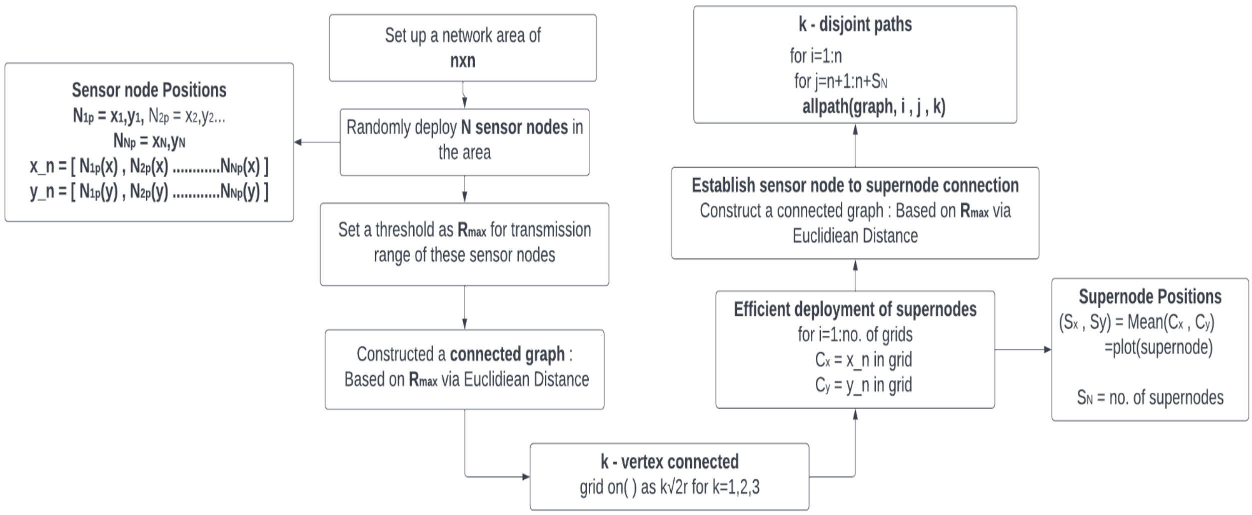


Fig.6.6. : IGTC Approach

With this technique the value of ‘k’ is taken into consideration and at the same time the network is well connected for k=1, 2 as well as 3.

6.3. Software Requirements

The implementation of the entire research was carried out on a 3rd party software Matlab A computing environment by MathWorks.

System Requirements for MATLAB r2013a

OS : Windows 8 and above

Recommended Processor: Any Intel or AMD x86-64 processor with four logical cores and AVX2 instruction set support

RAM: Minimum 2GB

7. Simulation Results

7.1. Simulation Scenario

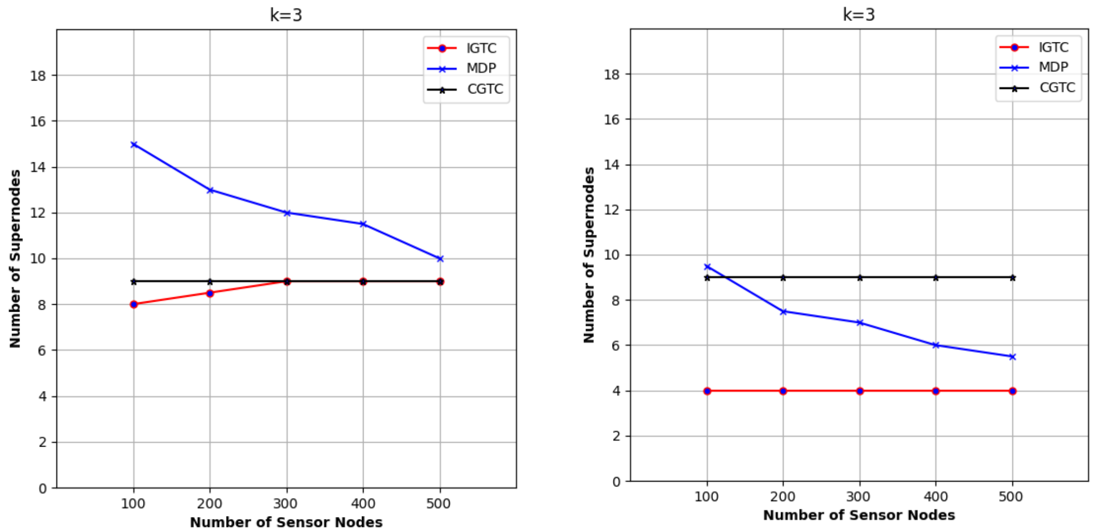
The simulation results show outstanding performance by the algorithms proposed in this paper. Table 7.1 shows all the parameters used for experiment. A constant field size is taken as 600m X 600m for the network area and number of sensor nodes for each set of iterations is taken from 100 to 500 sensor nodes. Number of hops are taken 3 and 5 for k=2 and k=3 respectively. A total of 15-25 iterations are done in order to get the best possible simulation result. The simulation results are divided into 2 subsections where we have compared our proposed algorithm with some existing well known algorithms.

- Section 7.2.1 discusses the number of placement of supernodes vs number of sensor nodes, CGTC and IGTC shows some remarkable performance measures during the simulation.
- Section 7.2.2 discusses the fault tolerance % of sensor nodes.

Field Size	600 x 600
Initial Transmission range of Sensor nodes	Rmin = 100m
Number of Iterations	15-25 times
Number of Sensor nodes	N = [100....500]
Degree of Disjoint paths	k = 2 and 3
Number of Hops	h = 3 and 5

Table . 7.1 : Simulation Scenario

7.2. Performance Results

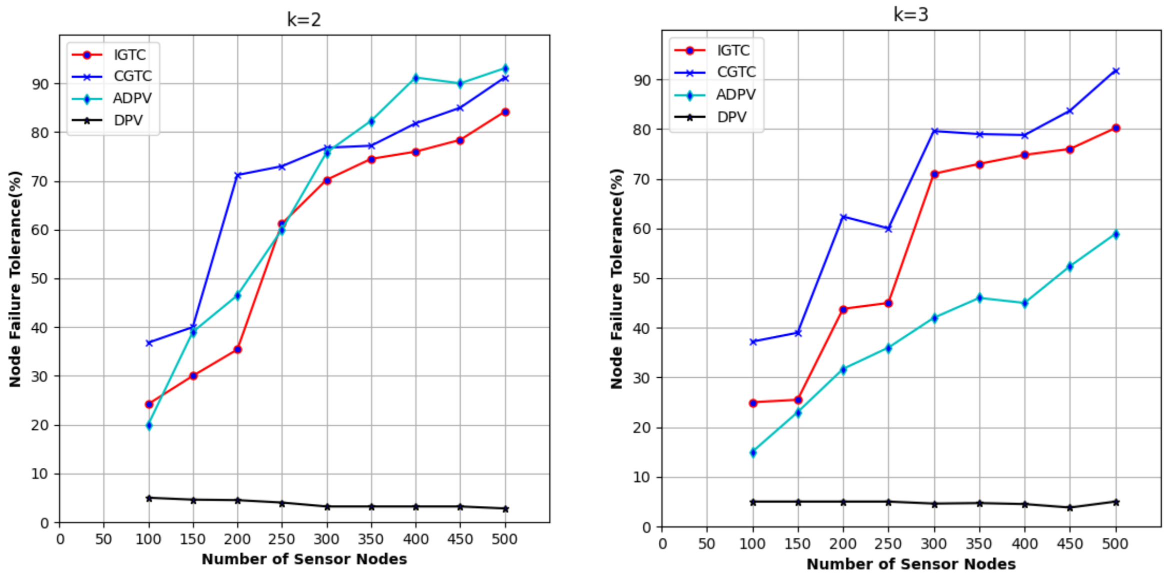


(a) **(b)**

Fig 7.2.1. Comparison of number of supernodes required in our algorithm with respect to MDP; for k=2, (b) for k=3

In Fig 7.2.1, we can observe the distribution of supernodes corresponding to the number of sensor nodes deployed in a 600 x 600m field size. Simulation results show that our algorithm uses less number of supernodes corresponding to sensor nodes deployed when we compare with MDP results. In figure 7.1 (a) i.e the CGTC shows a straight line because the number of placement of supernodes does not depend upon the value of k. In the static approach grid size is taken to be Rmax and supernodes are placed while analyzing the density of sensor nodes in each grid. Figure 7.1(b) shows two results for k=2 and k=3. For k=2, the number of supernodes gradually increases and then remains constant, because as the density of sensor nodes increases, more number of nodes will be deployed in the grids, hence more number of supernode will be deployed until it reaches its threshold value.When k=3, the simulation shows a straight line because the grid's size of our network becomes big and number of grids decreases and only one supernode is sufficient to cover a whole grid. This result can be attributed to our proposed algorithm becoming more effective and efficient for deployment of supernodes. For example, for k=2 and sensor nodes=300, IGTC algorithm would deploy only 9 supernodes in order to make the graph supernode-connected whereas according to the MDP algorithm 12 supernodes will have to be deployed in order to achieve supernode connectivity. For k=2 and 100 sensor nodes IGTC algorithm deploys 7% less number of supernodes.

Considering all experimental results for k=3, our algorithm is on average 2.45% more efficient than the MDP. Similarly, for k=3 for the sets of number of sensor nodes(100..500), the number of supernodes deployed remains constant i.e. 4 which is still less than the MDP result as it monotonically decreases from 9 to 5. For k=3, on average our proposed work is again 1.61% more effective.



(a) **(b)**

Fig 7.2.2 : Failure Tolerance(%) of sensors, up to which the network is supernode-connected; (a) for k=2, (b) for k=3

Fig 7.2.2 shows that, as the network density increases, our algorithms keep the network supernode-connected for a longer period of time. For example, if we consider the scenario of where sensor nodes=400 for k=2 and field size=600 x 600 m, we can see that the network IGTC implemented network can take up to 76% of node failure tolerance i.e. the threshold percentage up to which the network is still supernode-connected. Results for k=2 shows DPV always has a low failure node tolerance of about 1%. For each simulation we measure performance in terms of fractions of dead sensor nodes when the network gets k-vertex supernode disconnected. If every sensor is connected to at least one supernode over h hops then the network is said to be k-connected. For k=3, IGTC and CGTC outperforms both ADPV and DPV algorithms and generates the highest percentage of sensor node failure tolerance for similar simulation scenarios. In both the cases for k=2 and k=3 the results limit using DPV as a fault-tolerant alternative. On the other hand, ADPV and our algorithm shows a remarkable improvement tolerance threshold up to 90% which is a remarkable result.

Fig 7.2.2, compares major parameters with well developed algorithms. These parameters are essential for measuring network lifetime of a heterogeneous WSN.

7.3 Root Length with and without Super-nodes

Since sensor nodes already have such a short lifetime therefore it is very much inefficient to send data to the sink through such long hops. Multi-hop communication may decrease overall energy consumption of the network, however some nodes can be overloaded and drain their energy quickly

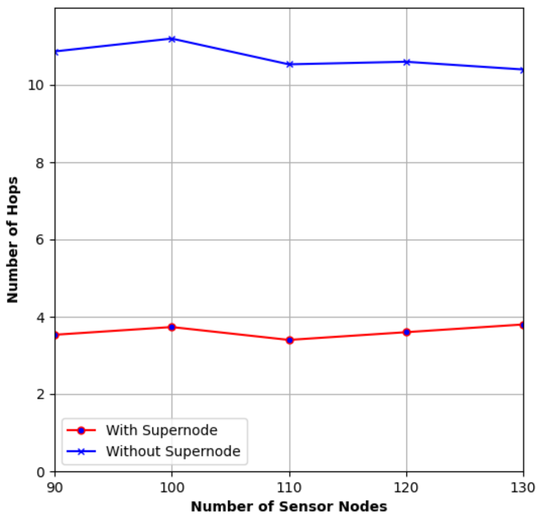


Fig 7.3 Root length with and without Supernodes

Fig 7.3, we can observe the total number of hops required for a sensor node to send data to the sink with and without supernode. The simulation is done for 20 iterations for different numbers of sensor nodes deployed and in each 20 iteration a particular sensor is considered in order to have a proportional testing environment. Without a supernode which is the blue line, the number of hops is very high around 10 and 11 hops with respect to the simulation with supernodes which is between 3 to 4 hops only. Therefore, using supernodes is a very energy efficient and wise decision.

8. Conclusion & Future Scope

Topology control is a process of optimizing and efficiently utilizing the network of sensors formed for a particular application. In order to implement topology control we have proposed Circumscribed Grid based Topology Control (CGTC) & Inscribed Grid based Topology Control (IGTC) which is based on efficient deployment of Super nodes on the upper tier and deployment of normal wireless sensor nodes on the lower tier of our two tier architecture. Also for considering fault tolerance and efficiency of data transmission we made sure connectivity is maintained by implementing K-Disjoint paths between sensor and supernodes. We have used two approaches: a static approach the goal is to deploy a minimum number of supernodes such that the network stays supernode connected. Therefore, to do so use of static grid size is used which is equal to the maximum transmission range of a sensor node. Hence, accordingly no. of supernodes are deployed in each grid corresponding to the density of sensor nodes in each grid and another a dynamic approach In ITC (inscribed topology control) we use a dynamic approach where the the grid size depends on the value k (disjoint path) so, as the values k changes grid size also changes which eventually changes number of deployment of supernodes.

The proposals have been implemented and compared with the existing tech in terms of parameters:

1. Number of super nodes
2. Field size
3. Fault tolerance%
4. Node Failure tolerance%

The future scope of this Research and development project lies in the advancements of topology control strategies. With new ways like ours being developed and researched upon we can further improve our algorithm to be better in ways such as better connectivity, further improvements can be done on the fault tolerance aspect of the project. This project can also be tested on real life networks in order to test out if the simulations done stand and what are the differences there and necessary improvements can be done to the algorithm. This algorithm can help users to be in control and modulate the factors according to their requirement and set the right topology and control it as per need and so more efforts in future can be given to make it more versatile.

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