Topology Control in Homogeneous Wireless Sensor Networks using K-Means Clustering

Chinmaya Gautam

Department of Computer Science and Engineering
National Institute of Technology Rourkela
Rourkela-769 008, Orissa, India

Topology Control in Homogeneous Wireless Sensor Network using K-Means Clustering

Thesis submitted in

May 2013

to the department of

Computer Science and Engineering

of

National Institute of Technology Rourkela

in partial fulfillment of the requirements

for the degree of

Bachelor of Technology

in

Computer Science and Engineering

by

Chinmaya Gautam

[Roll: 109CS0322]

under the guidance of

Prof. Bibhudatta Sahoo

Department of Computer Science and Engineering
National Institute of Technology Rourkela
Rourkela-769 008, Orissa, India

Department of Computer Science and Engineering
National Institute of Technology Rourkela
Rourkela-769 008, Odisha, India.

Certificate

This is to certify that the work in the thesis entitled ***Topology Control in Homogeneous Wireless Sensor Networks using K-Means Clustering*** by ***Chinmaya Gautam*** is carried out by him under my supervision and guidance in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in the department of Computer Science and Engineering, National Institute of Technology Rourkela.

Place: NIT Rourkela
Date: 10 May 2013

Bibhudatta Sahoo
Professor, CSE Department
NIT Rourkela, Odisha

Acknowledgment

No thesis is created entirely by an individual, many people have helped to create this thesis and each of their contribution has been valuable. My deepest gratitude goes to my thesis supervisor, Mr. Bibhudatta Sahoo, Asso. Professor, Department of CSE, for his guidance, support, motivation and encouragement throughout the period this work was carried out. His readiness for consultation at all times, his educative comments, his concern and assistance even with practical things have been invaluable. I would also like to thank all professors and lecturers, and members of the department of Computer Science and Engineering for their generous help in various ways for the completion of this thesis. A vote of thanks to my fellow students for their friendly co-operation.

Chinmaya Gautam

Abstract

A wireless sensor network consists of many wireless nodes forming a network which are used to monitor certain physical or environmental conditions, such as humidity, temperature, sound etc. Some of the popular applications of sensor network are area monitoring, environment monitoring (such as pollution monitoring), and industrial and machine health monitoring, waste water monitoring and military surveillance.

Topology control in WSNs is a technique of defining the connections between nodes in order to reduce the interference between them, save energy and extend network lifetime.

The Objective of my Thesis is to Maximize the network lifetime. The algorithm proposed is a modification to the CLTC framework: first we form clusters of nodes using K-Means, in second phase we do intra-cluster topology control using Relative Neighborhood Graph, and in third phase we do inter-cluster topology control ensuring connectivity. The simulations were carried out using Omnet++ as a simulator and Node Power Depletion and Node Lifetime as parameters.

Contents

List of Abbreviations

WSN	Wireless Sensor Network
CLTC	Cluster Based Topology Control
TC	Topology Control
RNG	Relative Neighborhood Graph
GG	Gabriel Graph
NPD	Node Power Depletion
NL	Node Lifetime

List of Figures

List of Algorithms

Chapter 1

Introduction

A sensor network is a network of sensor nodes which are capable of sensing, computing and communicating elements and it gives an administrator the ability to measure, observe and react to events and phenomenon in a specific environment.
Sensor networks are typically applied to the area of data collection, monitoring surveillance, military applications, and medical telemetry.
Recent advancement in wireless communications and electronics has enabled the development of low-cost, low-power, multi-functional miniature devices for use in remote sensing applications. The combination of these factors has improved the viability of utilizing a sensor network consisting of a large number of intelligent sensors, enabling the collection, processing analysis and dissemination of valuable information gathered in a variety of environments. Instead of sending the raw data to the nodes responsible for the fusion, they use their processing abilities to locally carry out simple computations and transmit only the required and partially processed data.
Sensor networks are predominantly data-centric rather than address-centric. So sensed data are directed to an area containing a number of sensors rather than particular sensor addresses. Aggregation of data increases the level of accuracy and reduces data redundancy. A network hierarchy and clustering of sensor nodes allows for network scalability, robustness, efficient resource utilization and lower power consumption.

1.1 Topology Control in Wireless Sensor Networks

Topology control can be defined as the process of configuring or reconfiguring a networks topology through tunable parameters after deployment. There are 3 mazor tunable parameters for topology control in WSN are:

- **Node mobility**: In WSNs consisting of mobile nodes, such as robotics sensor networks, both coverage and connectivity can be adapted by moving the nodes accordingly.
- **Transmission power control**: In WSNs with static nodes, if the deployment density is already sufficient to generate the required level of coverage, the connectivity properties of the network can be adjusted by tuning the transmission power of constituent nodes.
- **Sleep scheduling:** In large scale static WSNs deployed at a high density, i.e. over deployed. In this case the appropriate topology control mechanism that provides energy efficiency and extends network lifetime is to turn off nodes that are redundant.

Topology control problem has been proved to be an NP-Complete problem[1]

1.2 Literature Review

1.2.1 Effects of Power Control on Connectivity

On varrying the transmission power of the nodes, it's number of neighbors can be varried. Assuming the disk graph model, we study the effect of varying the transmission power, and hence he transmission range on the size of the maximum connected component in randomly deployed wireless sensor network. A flat network topology is assumed.
On simulating a randomly deployed sensor network, with 5000 nodes in a 1500 x 1500 unit are with maximum transmission range of 100 units, the following plot was obtained:

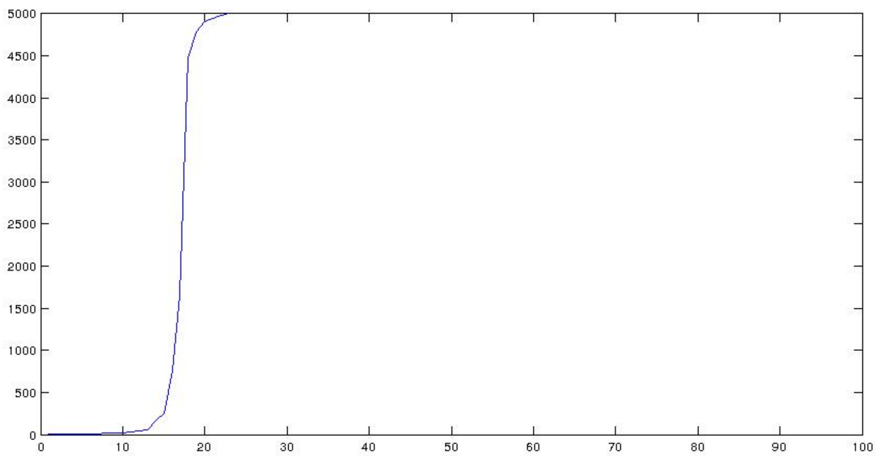

Figure 1.1: Effect of power control on connectivity: number of connected nodes vs transmission range

Clearly, in the case of dense deployment, 100 % connectivity can be obtained at relatively small transmission range. Therefore, by reducing the transmission range (by power control) can effectively achieve full connective. Also the size of the maximum connected component does not gradually increase with transmission range, but increases sharply from 0 to maximum no. of components. Thus a phase transition and existence of a threshold can be seen.

1.2.2 Relative Neighborhood Graph (RNG)

Andreas and willig presented a distributed approach to topology control in their book "Protocols and Architechtures for Wireless Sensor NetworksProtocols and Architechtures for Wireless Sensor Networks". Sparsing a topology can be efficiently done locally if information about distance between nodes or their relative position is available, first we study the Relative Neighborhood Graph.

The Relative neighborhood graph T of a graph G = (V, E) is defined as T = (V, E') where there is an edge between nodes u and v if and only if there is no other node w (a witness) that is closer to either u or v than u and v are apart from each other formally,

$$\forall u, v \in V : (u, v) \in E' iff \nexists w \in V : max\{d(u, w), d(u, v)\} < d(u, v)$$

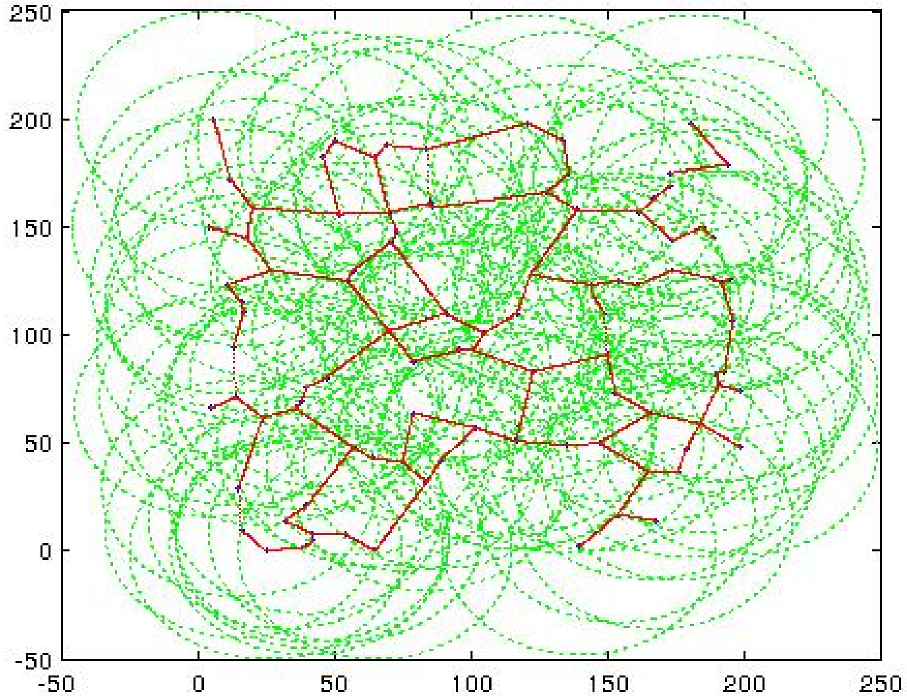

Figure 1.2: Relative Neighborhood Graph

where d (u, v) is the Euclidean distance.between two nodes.

But a this algorithm does not guarentee a strong connectivity.

1.2.3 Gabriel Graph(GG)

Another algorithm presented by andreas and willig was the gabriel graph for sparsing the topology. The Gabriel Graph (GG) is defined similarly to the RNG; the formal definition for it's edges is

$$\forall u, v \in V : (u, v) \in E' iff \nexists w \in V : d^2(u, w) + d^2(v, w) < d^2(u, v).$$

The nodes were randomly deployed in a 250 x 250 unit square area. Each node having a transmission power of 100 units. Both RNG as well as GG sparse the topology. In case of RNG, for some nodes which are only a few hops apart in the original graph becomes very distant. Even though this algorithm has a stronger connectivity than RNG, its quantitative value cannot be determined.

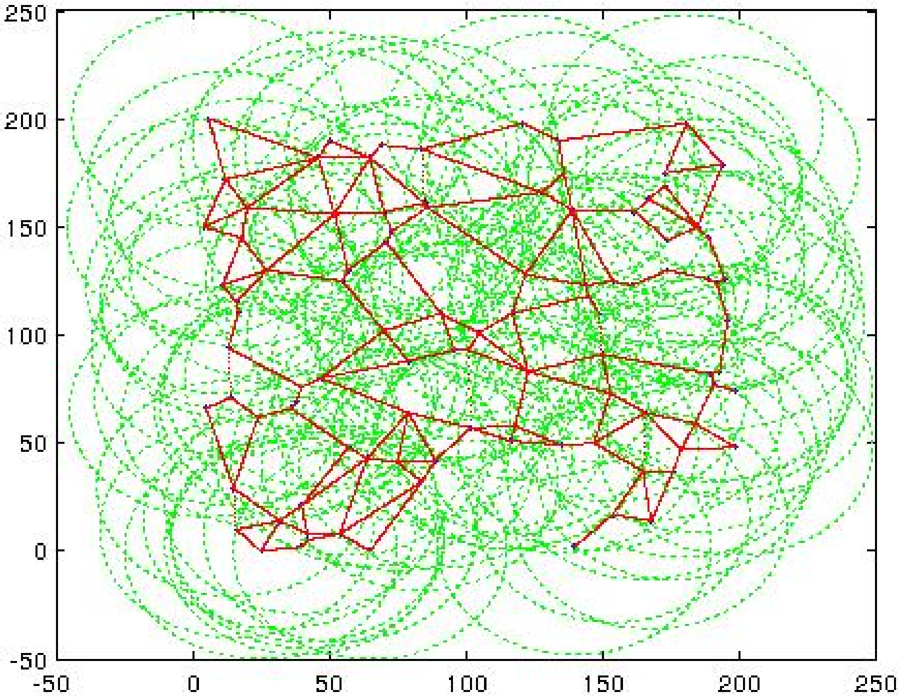

Figure 1.3: Gabriel Graph

1.2.4 CLTC

CLTC stands for Cluster Based Topology Control. It was proposed by Shen et. al. It is a hybrid topology control framework that achieves both scalability and strong connectivity. The framework proposes dividing the Topology configuration into three phases:

- Cluster Formation: In the first phase clusters are formed from the nodes using a suitable clustering algorithm
- Intra Cluster Topology Control: In the second phase a centralized topology control algorithm is used to define the topology of each cluster as a sub-network.
- Inter Cluster Topology Control: In the third phase the clusters are connected to each other to form the final topology of the network.

The authors present one implementation of this framework: CLTC-A which analyzes the message complexity of the network. The energy of the network was not dealt with in this paper.

1.3 Motivation

Saving energy is a very critical issue in wireless sensor networks (WSNs) since sensor nodes are typically powered by batteries with a limited capacity. Since the radio transmission is the main cause of power consumption in a sensor node, transmission/reception of data should be limited as much as possible. In wireless sensor networks, energy is considered a scarce resource:

- The sensor nodes are battery operated.
- Nodes and hence the wireless sensor network has a limited lifetime.

If transmission power is controlled, the network lifetime can be optimized.

1.4 Objective

In a Sensor Network Deployment, if the topology of the network is not controlled, all nodes transmit data at their maximum energy and hence, the lifetime of the network is considerably reduced. Many popular methods exist to modify the topology and prolong the network lifetime, these include distributed topology control mechanisms, centralized mechanisms and cluster based methods amongst others.
The Objective of my work is to maximize the network life time of a Wireless Sensor Network. This can be achieved by minimizing the transmission power of nodes while maintaining connectivity.
The idea is to minimize the average transmission power of nodes:

$$E_{avg} = \frac{\sum_{i=1}^{n} E_i}{n}$$

where,

E_i = transmission power of node i

n = number of nodes

E_{avg} = average transmission power

The overall energy of the network is given by[2]:

$$E(z,t) = \lim_{|S| \to 0} \frac{1}{|S|} \sum_{sensor_i \in S} e_i(t)$$

where,

z = location of the node,

t=time,

S = connected area in the network,

$e_i(t)$ = residual energy of node i at time t

1.5 Outline of thesis

In this chapter, we present the Topology Control Problem in Wireless Sensor Networks, The problem statement and objectives of our work are discussed briefly. The organization of the rest of the thesis and a brief outline of the chapters in this thesis are as given below.

Chapter 2:Topology Control

We discuss the topology control problem and present the various parameters used for analysis of wireless sensor networks, and the options for topology control. We further present taxonomy for the topology control problem.

Chapter 3:CLTC using K-Means

We present our implementation of the Cluster Based Topology Control Framework using K-Means Clustering to minimize average transmission power.

Chapter 4: Simulation and Results

This chapter presents the simulations, results and analysis of the implementation of CLTC:K-Means.

Chapter 5:Conclustion and Future Work

This chapter summarizes the thesis and presents the future directions for this work.

Chapter 2

Topology Control

2.1 Introduction

Topology control can be defined as the process of configuring or re-configuring a network's topology through tunable parameters after deployment.[3]
Let V denote the set of wireless sensor nodes and G(V,E) denote the subgraph on V that contains all possible edges if each node transmits at its maximum transmission power. The edge set E of G is constructed in such a manner that there is a directed edge from u to v if and only if u can reach v using its maximum transmission power. Graph G sets an upperbound on the maximum connectivity that a wireless network can have. The topology control algorithm returns a topology T constructed from G, i.e., T is a subgraph of G on V.[4]
A wireless sensor network should fulfill the following connectivity requirement:
For any pair of nodes u and v, if there is a path from u to v in G then there is also a path from u to v in T.[4]

2.2 Metrics for WSN

Wireless environment are unreliable, with error rate high that introduce burst errors. Various parameters that are used to measure the efficiency of wireless sensor networks are[1]:

- **Throughput:** The throughput of the most important parameter to analyze the performance of the network. It is the amount of data transmitted per unit time.

Throughput is measured in bits/sec. Throughput T in a network is given by:

$$T = d/t$$

where,

d = data transmitted in bits,

t = total time

- **Packet delivery ratio:** It is the ration of number of packets received to no. of packets generated. Packet delivery ratio is given as:

$$P_{dr} = \frac{N_{recd}}{N_{gen}}$$

where,

P_{dr} = packet delivary ratio,

N_{recd} = number of packets received,

N_{gen} = number of packets generated

- **Packet loss:** It is the number of packets lost in transmission. Packet loss is distinguished as one of the three main error types encountered in digital communication. Packet loss is given by:

$$P_{loss} = P_{gen} - P_{recd}$$

where,

P_{loss} = number of packets lost

- **Bit error rate/bit error ratio:** It is the number of received bits that have been altered due to noise, interference and distortion, divided by total number of transferred bits during a particular time interval. The bit error rate is given by:

$$BER = \frac{1}{2}\sqrt{erfc(\frac{E_b}{N_0})}$$

where,

BER = bit error ratio

erfc = error function

E_b = energy per bit

N_0 = noise power

- **Energy consumption:** It is important parameter, as each sensor node has a limited amount of energy, which depletes on re-transmission. The energy of a network is given by[2]:

$$E(z,t) = \lim_{|S| \to 0} \frac{1}{|S|} \sum_{sensor_i \in S} e_i(t)$$

where,

z = location of the node,

t=time,

S = connected area in the network,

$e_i(t)$ = residual energy of node i at time t

2.3 Options for Topology Control

To compute a modified graph I out of a graph G representing the original network G, a topology control algorithm has a few options:

The set of active nodes can be reduced ($V_t \in V$), for example, by periodically switching off nodes with low energy reserves and activation other nodes instead, exploiting redundant deployment in doing so.

The set of active links/the set of neighbors for a node can be controlled. Instead of using all links in a network, some links can be disregarded and communication is restricted to crucial links. When a flat network topology is desired (all nodes are considered equal), the set of neighbors of a node can be reduced by simply not communicating with some neighbors. There are several possible approaches to choose neighbors, but one that is obviously promising for a WSN is to limit the reach of a node's transmission typically by power control, but also by using adaptive modulation (using faster modulation is only possible over shorter distance) and using the improved energy efficiency when communicating only with nearby neighbors.

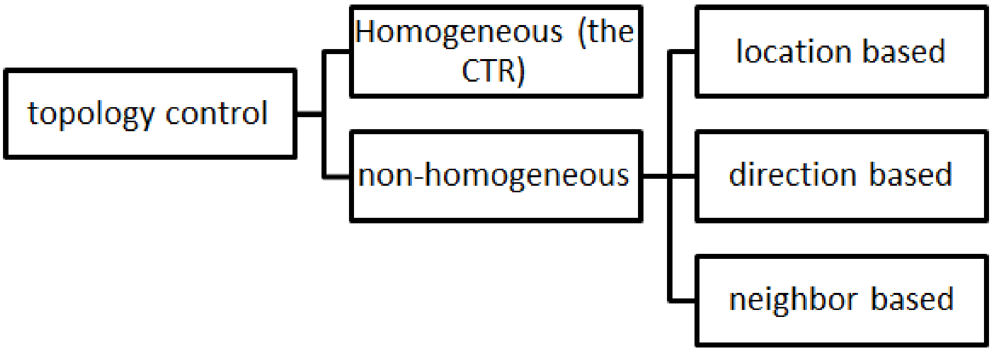

Figure 2.1: taxonomy of topology control problem

Active links/neighbors can also be rearranged in a hierarchical network topology where some nodes assume special roles. One example is to select some nodes as a "backbone" (or a "spine") for the network and to only use the links within this backbone and direct links from other nodes to backbone.[5]

2.4 Taxonomy of Topology Control Problem

The topology control problem can be broadly divided into two types based on the type of nodes deployed [6]:

- homogeneous approach
- heterogeneous approach

We discuss both types of approaches in subsequent subsections.

2.4.1 Homogeneous approach

In case of homogeneous approach, nodes are assumed to use the same transmitting range, and the topology control problem reduces to the one of determining the minimum value of r (range) such that a certain network wide property is satisfied (the Critical Transmitting Range).

Our work follows the homogeneous approach to topology control.

2.4.2 Heterogeneous approach

In this case, nodes are allowed to choose different transmitting ranges (provided they do not exceed the maximum range).

Nonhomogeneous topology control is classified into three categories, depending on the type of information that is used to compute the topology. In location based approaches, exact node positions are known.

This information is either used by a centralized authority to compute a set of transmitting range assignments which optimize a certain measure (this is the case of the Range Assignment problem and its variants), or it is exchanged between nodes and used to compute an almost optimal topology in a fully distributed manner / this is the case for protocols used for building energy efficient topologies for unicast or broadcast communication).

In direction based approaches, it is assumed that nodes do not know their position, but they can estimate the relative direction of each of their neighbors. Finally in neighbor-based techniques, nodes are assumed to know only the ID of their neighbors and are able to order them according to some criterion (E.g. distance, or link quality).[7]

2.5 Network and Communication Model

We present the network and communication model used for the CLTC framework as initially proposed by shen et. al:

M= (N, L) is a mulithop wireless network where $N = \{m_1, m_2, m_3, , m_n\}$ is a set of nodes and L is a one-to-one mapping from N to planar coordinates. Each node is able to obtain its coordinate by some means (e.g. GPS). Further each node u is able to adjust its transmission power level p_u within the range $0 \leq p_u \leq P_{max}$, where P_{max} is the maximum transmission power (we assume this value is the same for all nodes).

For a node u to successfullycommunicate with another node v, the signal received at v must exceed the receive sensitivity S. Recall that signals lose their power as a function of distance when propagating through a communication medium. Here, the path loss propagation function is (in dB) $\gamma(l_u, l_v)$, where the signal travels from u to

v andl_u, l_v are the coordinates of nodes u and v, respectively.
In order to guarantee a successful reception at v, it must be that $p_u \geq S + \gamma(l_u, l_v)$. We assume that γ is monotonically increasing function of the distance between u and v and the function $\lambda(d)$ maps the distance d to the minimum. Transmission power required for successful communication at the distance. Thus, a node u is able to determine its minimum transmission power to reach v from $\lambda(d(l_u, l_v)) = S + \gamma(l_u, l_v)$.
Given this framework, a network M= (N, L) can be represented by an undirected graph G= (V, E), where$V = u_1, u_2, , u_n$ and vertex u, corresponding to node m_i, in M. There is an edge in G between a pair of vertices if their corresponding distance in M enables a successful communication. That is,

$$E = \{(u_i, u_j)\}, u_i, u_j \in V$$

and

$$S + \gamma(m_i, m_j) \leq P_{max}$$

[6]

2.6 Path Loss Model

When nodes communicate, they loose their energy. The power required to communicate to a node is related to the distance of communication using path loss models. We use the path loss model presented by Ebenezer et al. which is presented here:
Two nodes, seperated by a distance 'x' can communicate with each other only if the strength of the signal received is greater than the receiver's sensitivity threshold. As the signal propagates through the channel, its power density is reduced. The relation between the power P_x required to communicate at a distance x is given by:
The energy P_x required to communicate at a destination x is given by

$$P_x = P_0(\frac{x}{d_0})^{\alpha}$$

where P_0 is the energy required to communicate at a distance d_0 [8].

2.7 Conclusion

In this chapter we presented the topology control problem as an optimization problem. We discussed the various parameters for the study of topology control problem, its classification and various options for topology control. We also saw the network and communication model and the path loss model for WSN.

Chapter 3

Implementing CLTC using k-means

3.1 Introduction

CLTC stands for Cluster Based Topology Control. It was proposed by Shen et. al. It is a hybrid topology control framework that achieves both scalability and strong connectivity. By varying the algorithms utilized in each of the three phases of the framework, a variety of optimization objectives and topological properties can be achieved. In this thesis, we present the implementation of CLTC framework for minimization of transmission power using k-means clustering.
The framework divides the TC problem into 3-phases:

- Cluster formation
- Intra Cluster topology Control
- Inter Cluster topology Control

We divide the construction of the network topology into the three aforementioned phases.
In The first Phase, we use k-means for forming k distinct clusters out of the total N nodes in the network. Moreover, a cluster head is selected for each cluster. We assume in this phase that all nodes are transmitting at their maximum power and only connections possible are those within the cluster.
Once clusters have been formed, each cluster modifies its topology using the relative neighborhood graph to further optimize the transmission power. These new transmission powers are stored with the nodes. The nodes do not start transmitting data

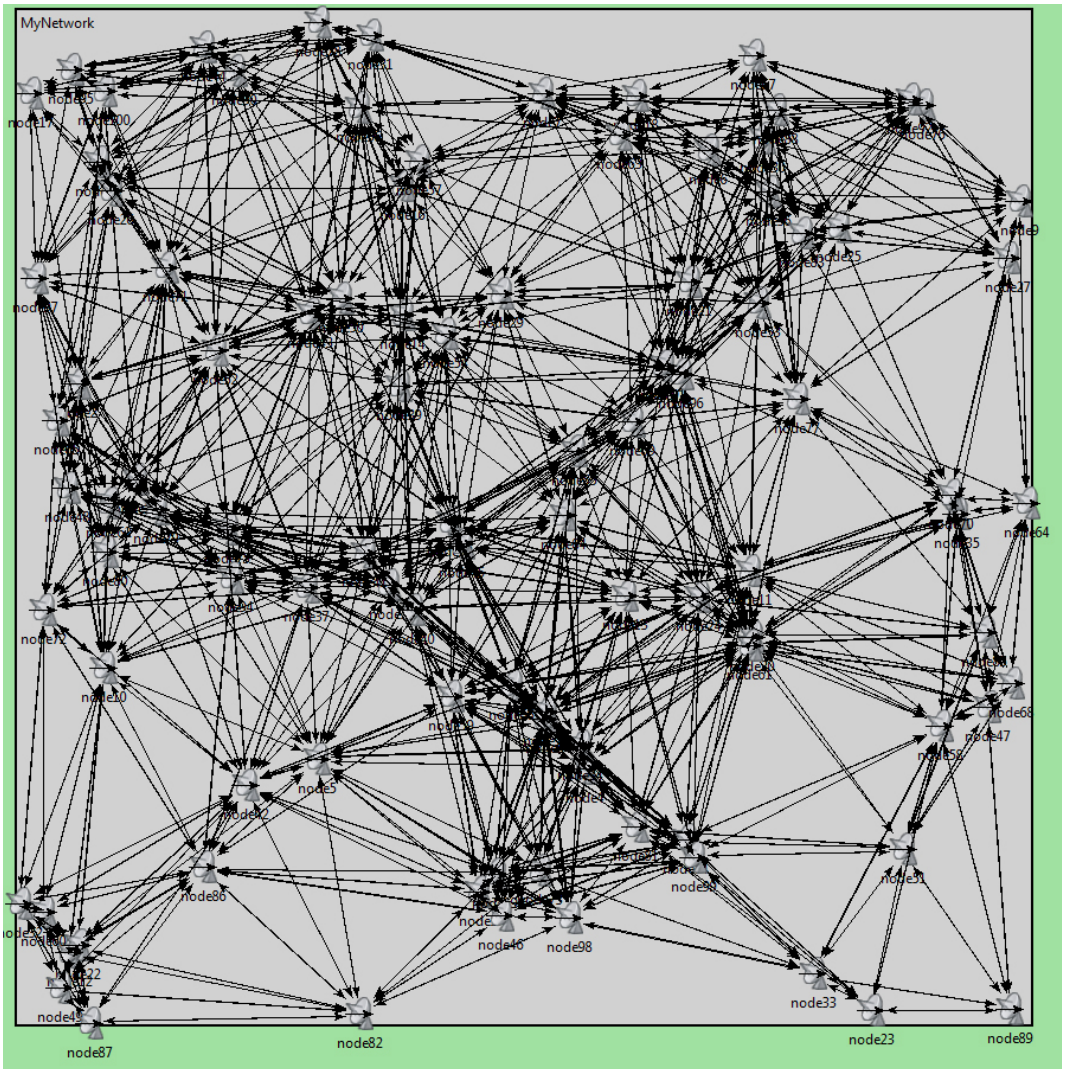

Figure 3.1: A network without any Topology Control implementation

at this point of time.

In the third phase, all pairs of clusters u_i, u_j try to connect to each other if the maximum transmission range of the boundary nodes of u_i can contact any boundary node of u_j . For all such successful connections, the transmission power of boundary nodes are set to the maximum of its present transmission power and the new value required to communicate with other clusters.

3.2 Phase I: Cluster Formation

In the first phase, in a distributed fashion, clusters are formed and cluster heads are selected. Note that the operations in the subsequent two phases are independent of the specific clustering algorithm used in this phase. Any distributed clustering algorithm that can form non-overlapping clusters and select cluster heads can be applied. We use K-Means Clustering to form the clusters from the node deployed in the network as follows:

At first we select K random nodes from the set of nodes N, these form the initial set of cluster heads then for each node ui, we find the closest cluster (using Euclidian Distance between nodes) head and label ui with the nodeID of this cluster head. Once all nodes have been assigned a label, we find the centroid of each cluster and label the node closest to the centroid as the new cluster head for the cluster. This process is repeated for R (= N/10) number of times, to form the clusters.

Algorithm 1 Clustering nodes for Phase I

```
for i=1 to N/10 do
  clusterHeads[i] = rand()%MAX_NODES
end for
for i = 1 to 10 do
  for j = 1 to N do
    minDist = ∞
    for k = 1 to N/10 do
      newDist = distance(nodes[j], nodes[clusterHeads[j]])
      if newDist <minDist then
        minDist = newDist
        nodes[j].label = k
      end if
    end for
  end for
  clusterHeads = newMeans(nodes)
end for
```

The algorithm to find new means is preseneted further:

Algorithm 2 Finding new mean nodes for K-Means Clustering

```
for  j=1 to K do
   totalx=0
   totaly=0
   entries=0
   for  i=1 to N do
      if  nodes[i].label = j  then
         totalx = totalx + nodes[i].x
         totaly = totaly + nodes[i].y
         entries++
      end if
   end for
   clusterHeads[j].x = totalx/entries
   clusterHeads[j].y = totaly/entries
end for
for  j= 0 to K  do
   for  i = 1 to N  do
      minDist = ∞
      if distance(nodes[i], clusterHeads[j] < minDist  then
         minDist = eucledianDistance(nodes[i], clusterHeads[j])
         nodes[i].label=clusterHeads[j]
      end if
   end for
end for
```

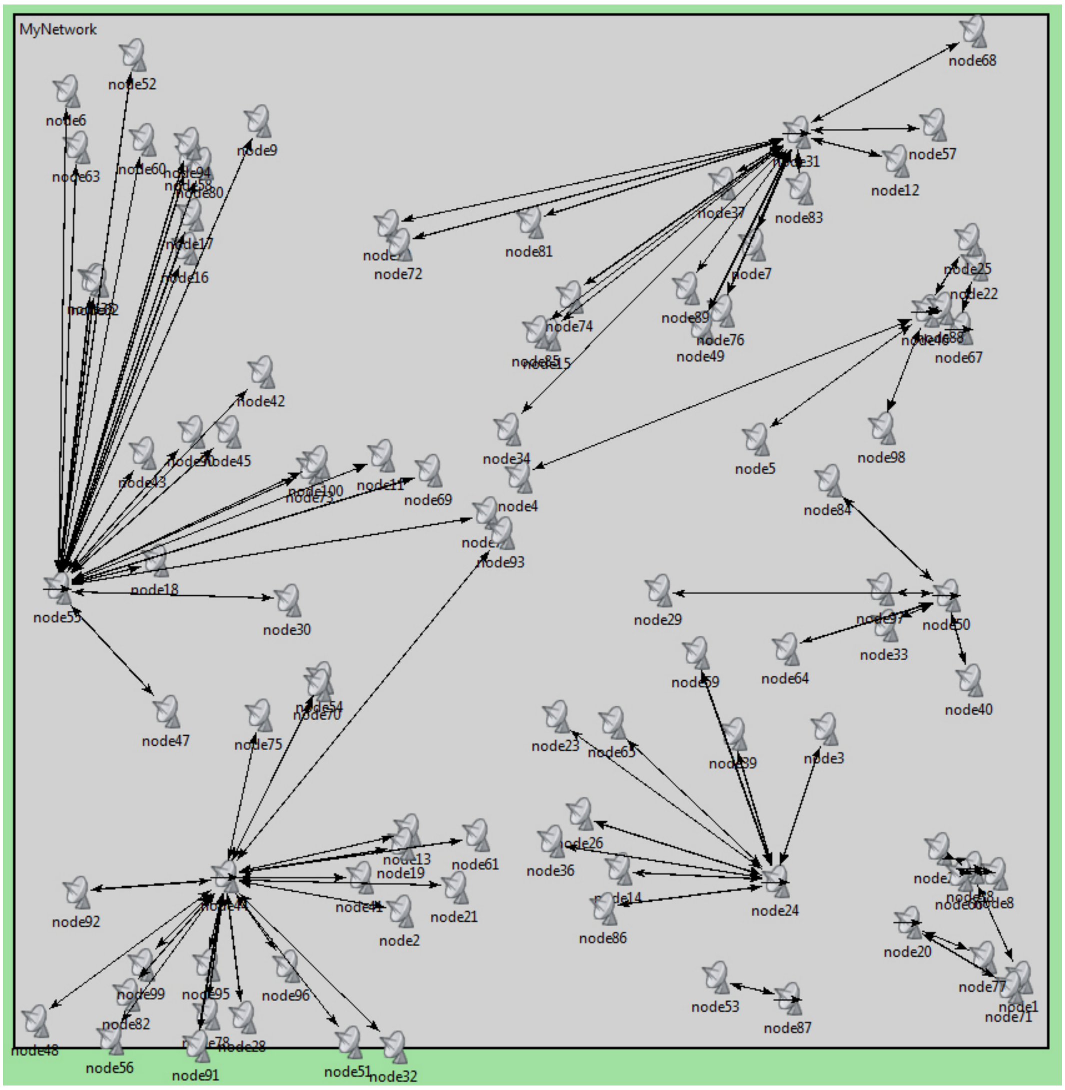

Figure 3.2: Clustering of 100 nodes spread in a 1000 x 1000 area

3.3 Phase II: Intra Cluster TC

In Phase I, all the nodes have been partitioned into distinct clusters, in this phase we modify the topology of each the network by considering each cluster as an isolated sub-network.

The power assignments of the cluster members can be obtained by applying the algorithm3 presented further.

The power assignments calculated in this phase will be distributed to the cluster members. But, the cluster members will not yet begin transmitting at these powers. Rather, it may be that these powers will be found to be inadequate as a result of Phase 3 (the intercluster topology control phase). Hence, the final power assignments for all nodes will be computed after Phase 3 is completed. Thus, during Phase 3, all nodes will still utilize their full transmission power. Only after the completion of Phase 3 will nodes start using their assigned transmission power.

We use the Relative Neighborhood Graph to obtain power assignments of various nodes. RNG can effectively sparse a topology. In the Relative neighborhood graph T of a graph G, there is an edge between nodes u and v if and only if there is no other node w (a witness) that is closer to either u or v than u and v are apart from each other, thus RNG also guarantees a k-1 connectivity, so we can assume that all the nodes within a cluster will be connected.

3.4 Phase III: Inter Cluster TC

In Phase II, the intra-cluster topology of the network is set, after this phase, all nodes are connected within their clusters whereas nodes belonging to different clusters are not connected.

In this phase, connectivity between adjacent clusters is considered. For all pairs of clusters C_i, C_j, if the maximum transmission range of the boundary nodes of $u_i \in C_i$ can contact any boundary node of $u_j \in C_j$ we form the connection (u_i, u_j).

For all such successful connections, the transmission power of boundary nodes are set to the maximum of its present transmission power and the new value required to

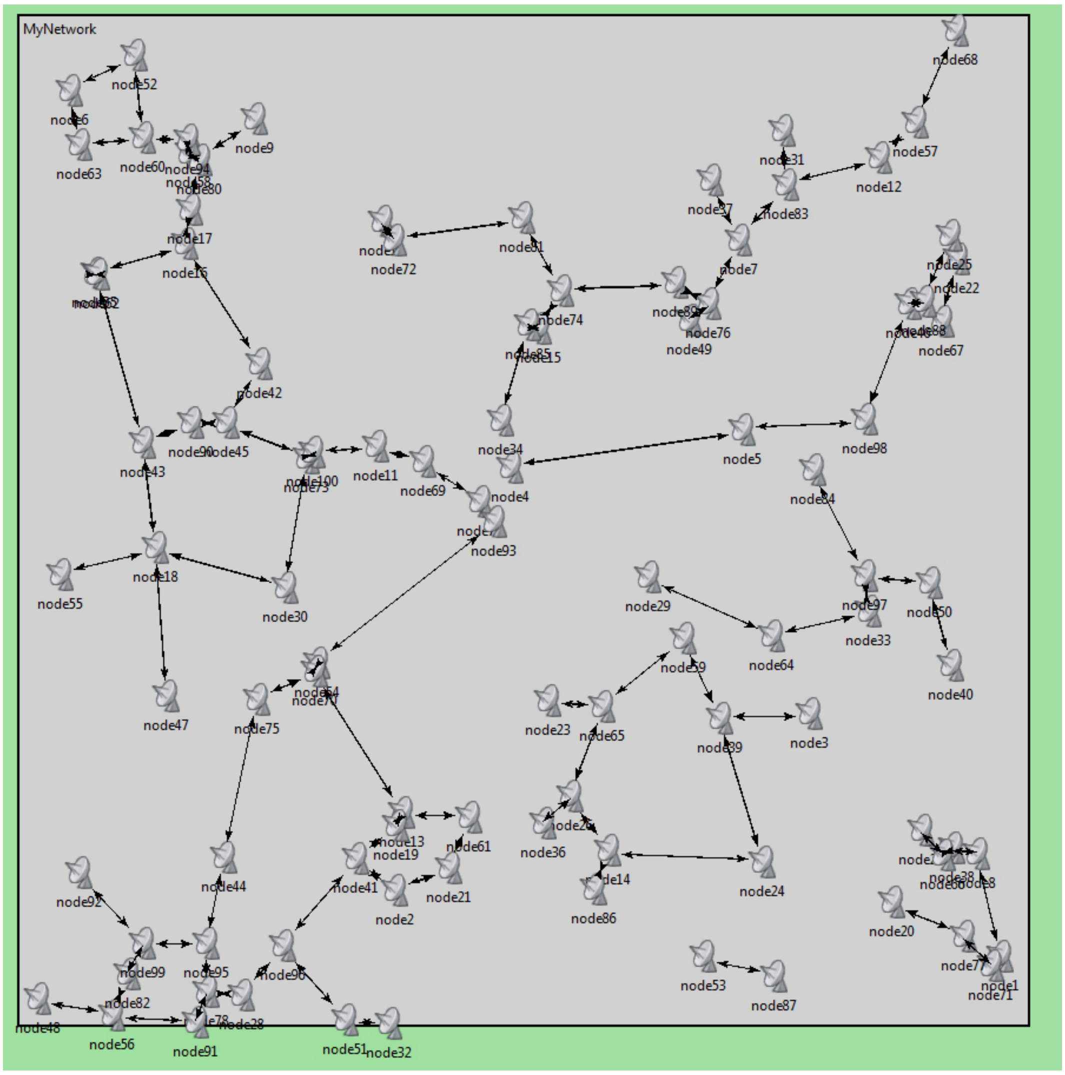

Figure 3.3: Intra Cluster TC of 100 nodes spread in a 1000 x 1000 area

Algorithm 3 Forming Intra Cluster Topology using RNG for Phase II

```
for i = 1 to K do
  for j = 1 to size(clusters[i]) do
    for k = j to size(clusters[i]) do
      formLink = 1
      for l = 1 to size(clusters[i]) do
        if (max(distance(nodes[i],nodes[l]),distance(nodes[j],nodes[l]))¡distance(nodes[i],nodes[j]
        then
          formLink = 0
        end if
      end for
      if formLink == 1 then
        nodes[i].power = max(nodes[i].power, powerAssignment(distance(nodes[i],nodes[j]))
        nodes[j].power = max(nodes[j].power, powerAssignment(distance(nodes[i],nodes[j]))
      end if
    end for
  end for
end for
```

communicate with other clusters.

Now, we present the algorithm for the third phase :

3.5 Conclusion

In this chapter, we present the path loss model communication between nodes. This chapter also shows the implementation of CLTC using k-means in three phases: the cluster formation phase (in which k-means is used), the intra cluster topology control phase (in which relative neighborhood graph is used) and the final inter cluster topology control phase.

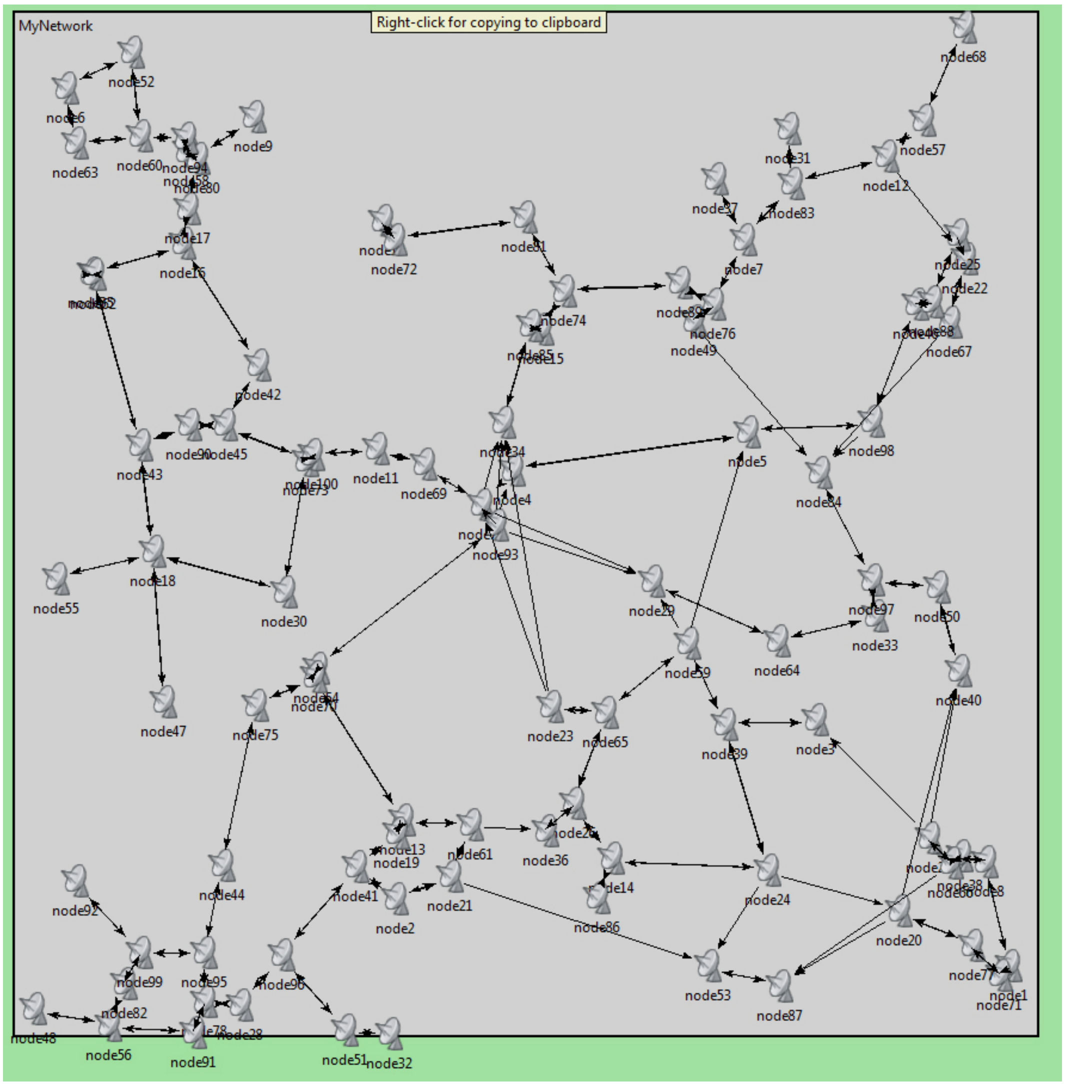

Figure 3.4: Inter Cluster TC of 100 nodes spread in a 1000 x 1000 area

Algorithm 4 inter cluster topology control for phase III

```
for i = 1 to K do
  for j = i to K do
    for k = 1 to clusters[i] do
      for l = 1 to clusters[j] do
        if distance(nodes[k],nodes[l]) ¡ minDist) then
          minDist = distance(nodes[k],nodes[l])
          node1 = k
          node2 = l
        end if
      end for
    end for
    if powerAssignment(minDist) ¿ nodes[node1].power then
      nodes[node1].power = powerAssignment(minDist)
    end if
    if powerAssignment(minDist) ¿ nodes[node2].power then
      nodes[node2].power = powerAssignment(minDist)
    end if
  end for
end for
```

Chapter 4

Simulation and Results

In this chapter we present the Simulation of the network, the output plots and its analysis.

4.1 Simulation

For the Simulation of the Network, Omnet++ was used. OMNeT++ is an extensible, modular, component-based C++ simulation library and framework, primarily for building network simulators. First, we create a simple module called "node". This module contains all functionalities that the WSN nodes can carry out independently:

- **Sensing:** data is generated virtually by each node, this data acts as the sensed data.
- **Computation:**The computation done on data can be specified for each node.
- **Communication:**The data is sent to other nodes by either specifying the output port to be used or the target node id.

Then a network is created. We set the simulation area to 1000x1000 for this network and initialize the network with 100 nodes of the simple module created earlier. The topology of the network can be set in this network by specifying the connections between nodes.
The network can now be simulated by running the project as a Omnet++ simulation. All simulation data and logs are saved to a le which can be used later for analysis.

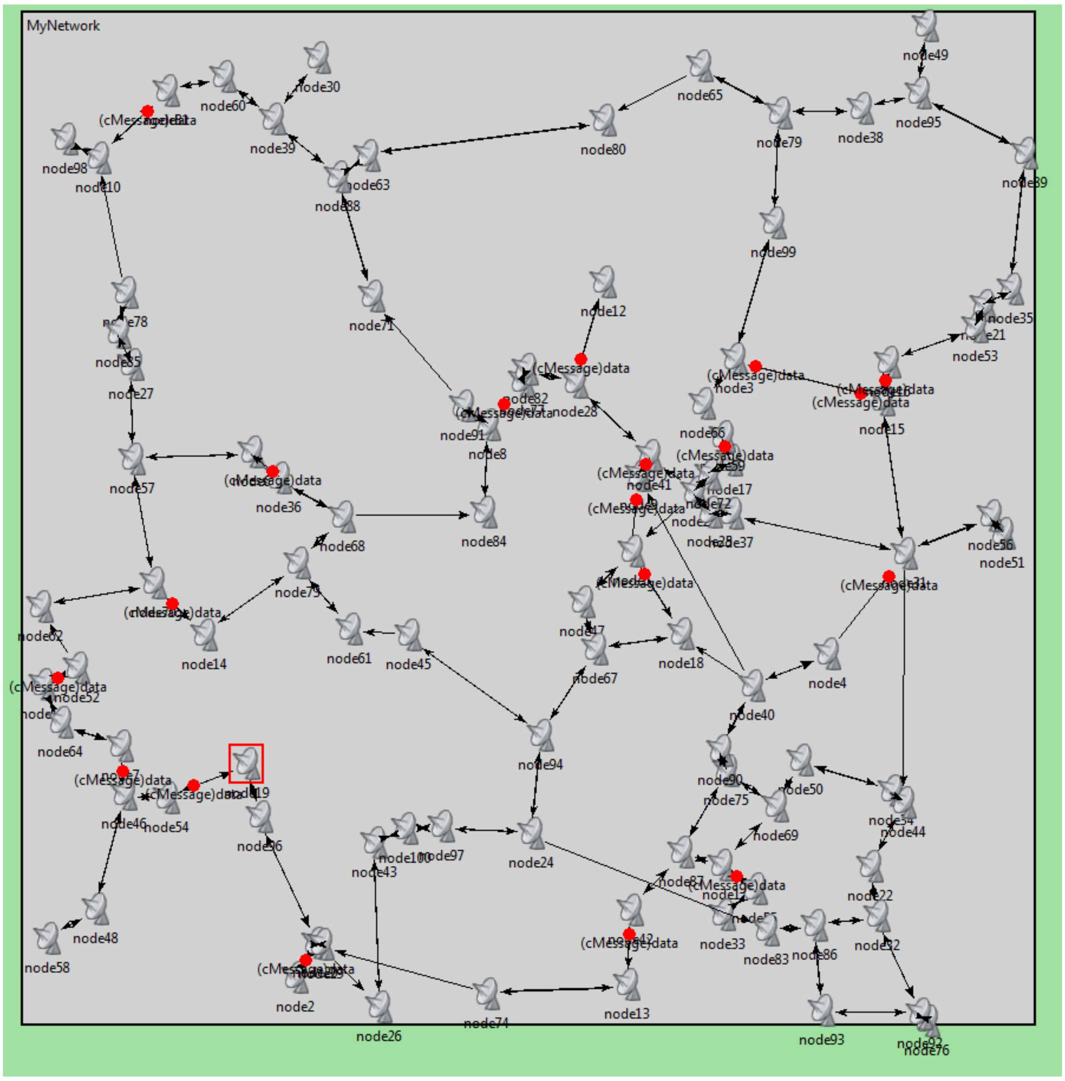

Figure 4.1: Simulating a 100 node WSN ins Omnet++

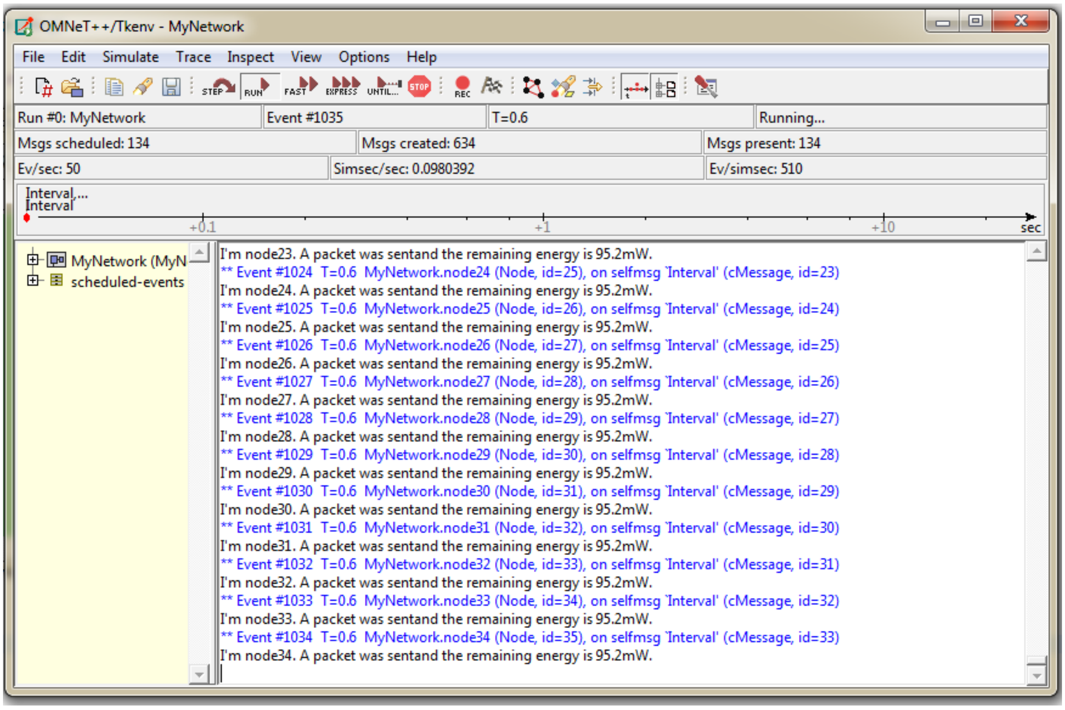

Figure 4.2: Simulation results of 100 node WSN in Omnet++

4.2 Results

The results collected from the simulation were plot to a graph. We study the variation average transmission power of nodes with the number of nodes in the network. We simulate the network in a constant area (of 1000x1000 unit area) with constant maximum transmission power of the nodes.

4.2.1 Average Transmission Power vs. Number of Nodes

The simulation if run 10 times for each value of number of nodes varying from 50 to 500 in intervals of 50 nodes and are averaged. The results obtained for networks with

- No topology control
- K-Means without CLTC
- K-Means with CLTC

are plot vs. the number of nodes.

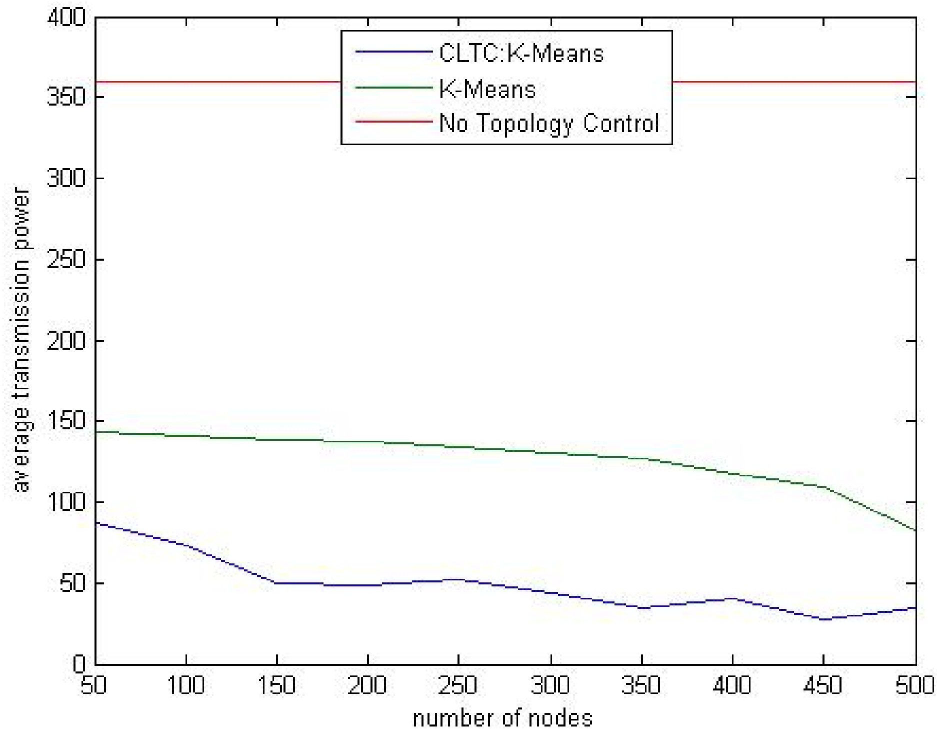

Figure 4.3: plot of average transmission power. vs number of nodes

4.2.2 Node Power Depletion

The simulation is run for 100 nodes and the node power depletion is plot for networks with no topology control, networks with k-means clustering and networks with CLTC implementation of k-means.

4.2.3 Node Lifetime

The simulation is run for 100 nodes and the node lifetime is plot for networks with no topology control, networks with k-means clustering and networks with CLTC implementation of k-means.

4.3 Analysis

From the Simulation and the Results Obtained we conclude that:

- When no topology control is deployed and all nodes transmit at maximum power, the average transmission power of nodes is a constant (with the value =

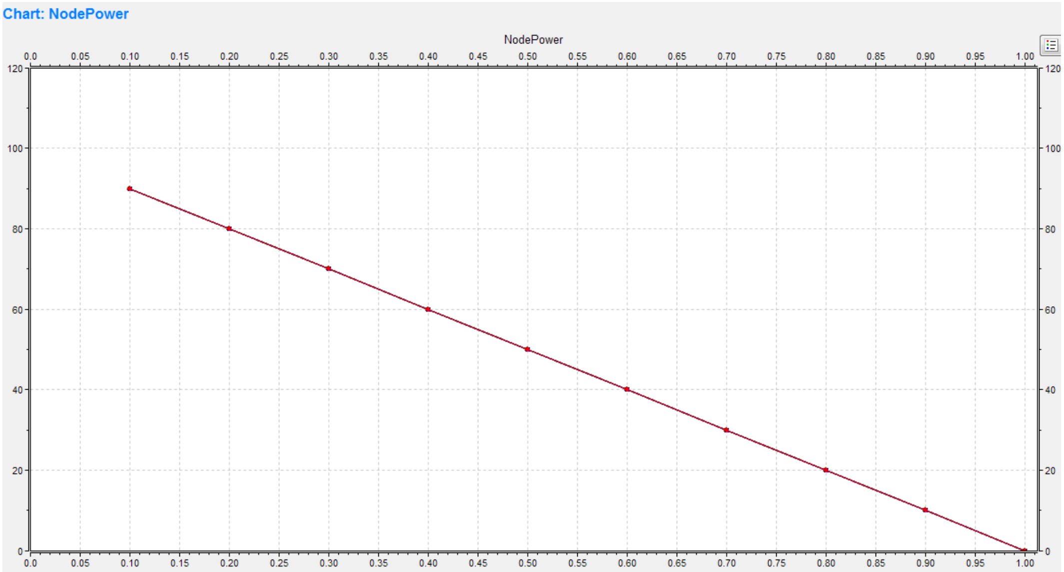

Figure 4.4: node power depletion vs. time for network with no topology control

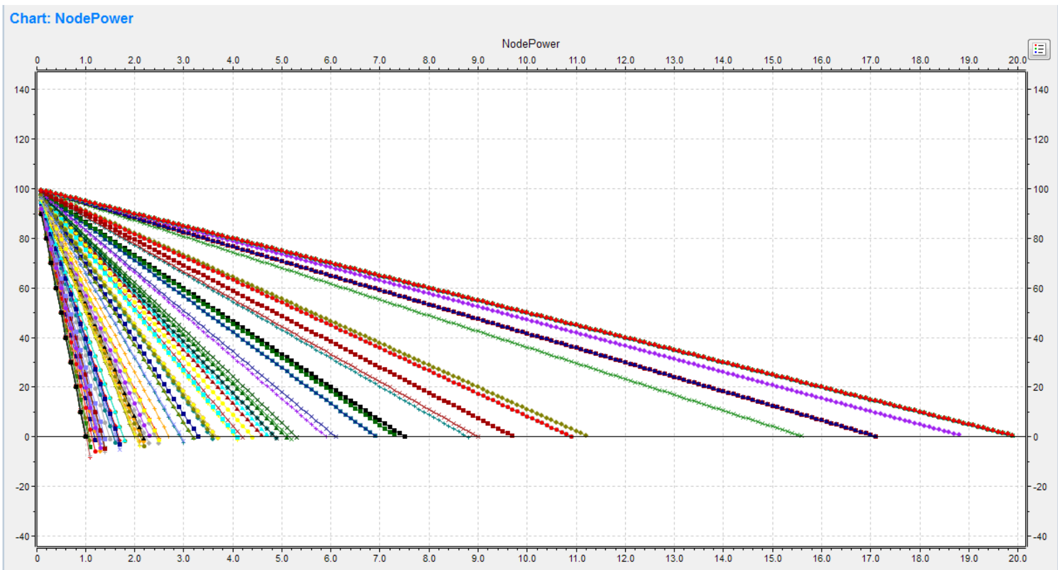

Figure 4.5: node power depletion vs. time for network with no k-means cluster based topology control

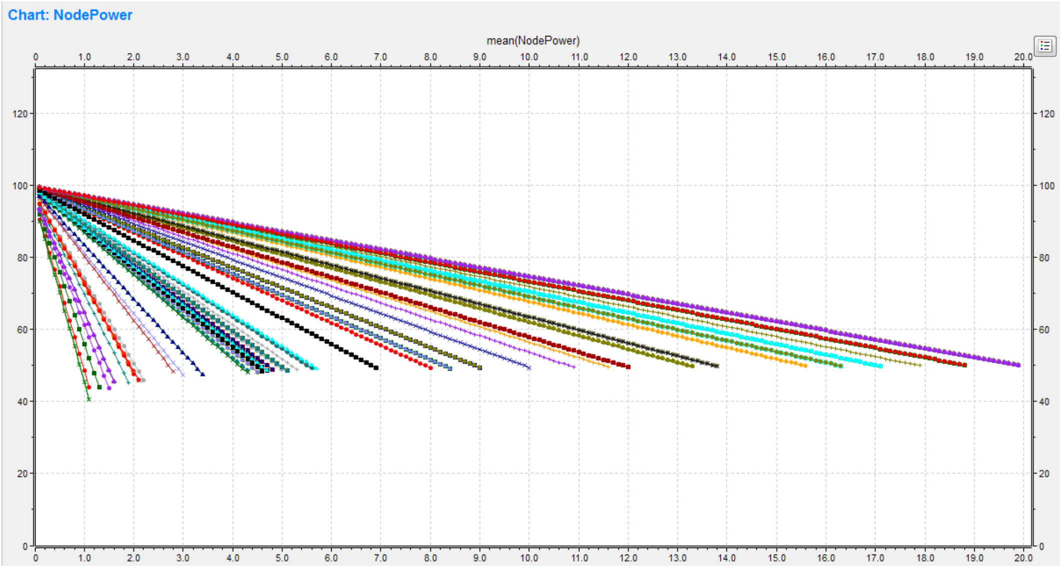

Figure 4.6: node power depletion vs. time for network with CLTC:k-means based topology control

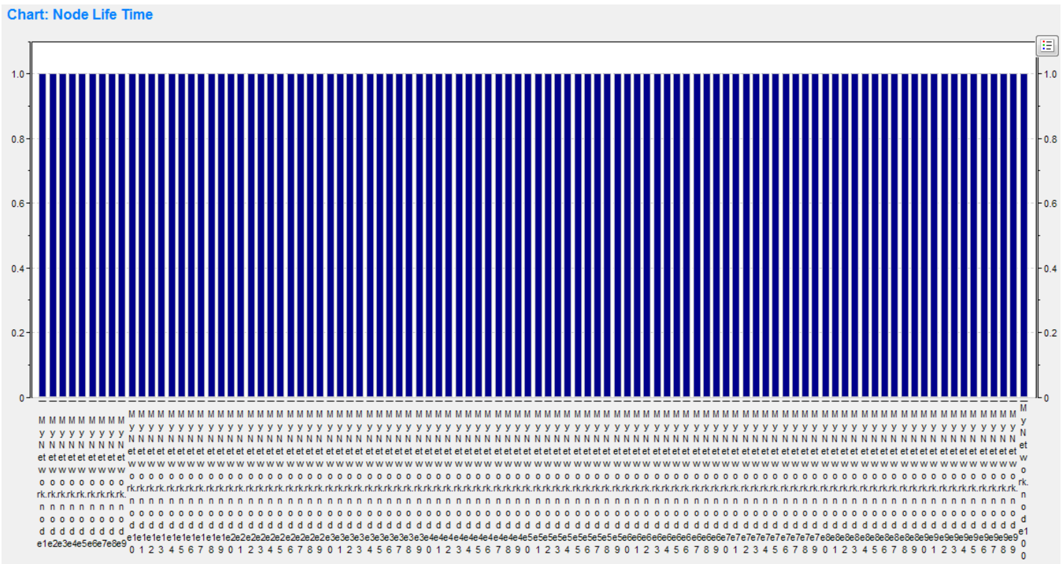

Figure 4.7: node life time of 100 nodes for network with no topology control

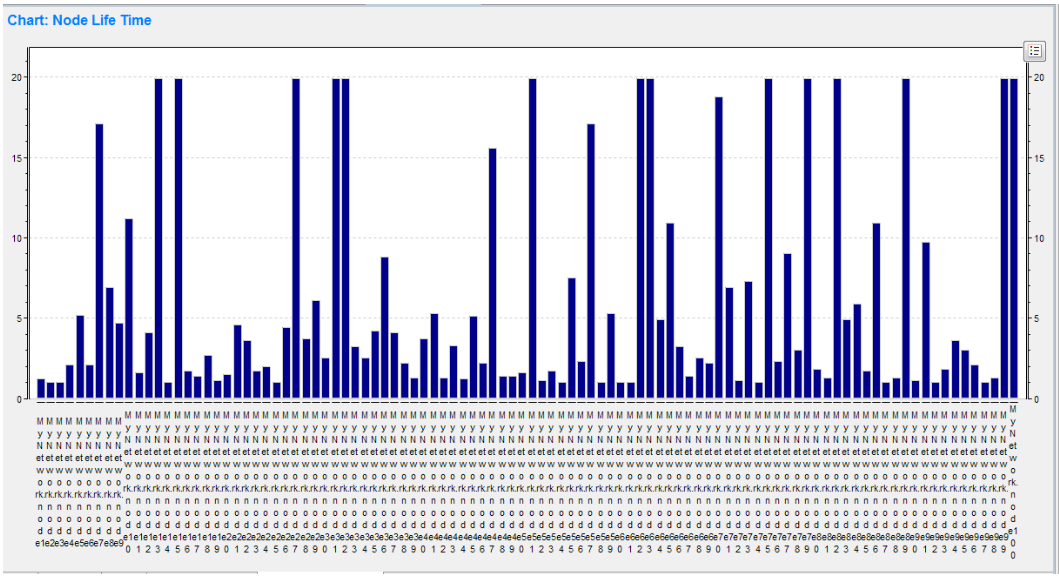

Figure 4.8: node life time of 100 nodes for network with k-means cluster based topology control

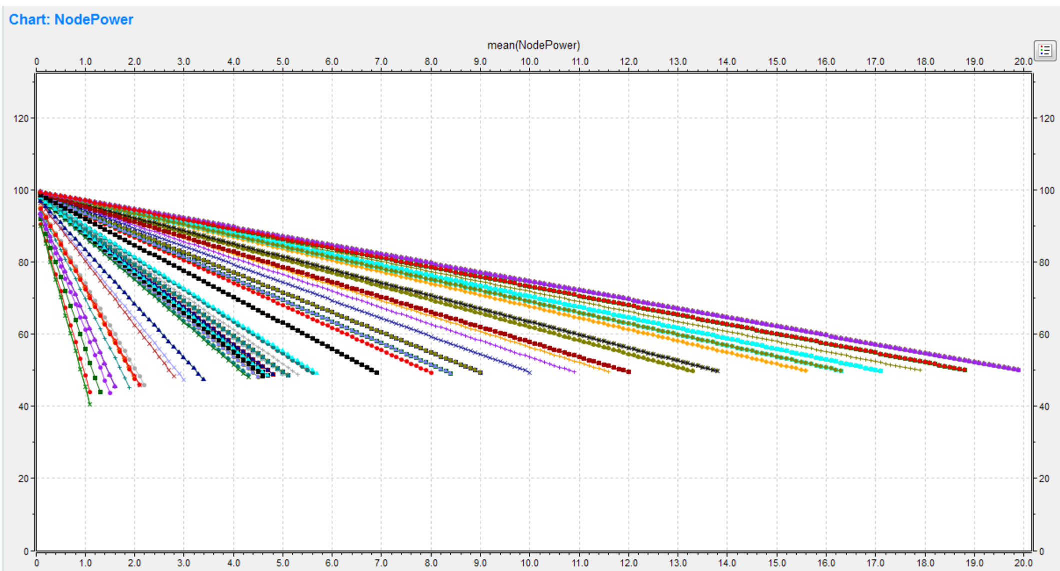

Figure 4.9: node life time of 100 nodes for network with CLTC:k-means based topology control

maximum transmission power of the node)

- Simple K-Means shows a much lower average transmission power as compared to networks with no topology control. Moreover, the average transmission power in case of k-means decreases as the number of nodes in the network increases.

- When CLTC is used, the average transmission power of the nodes is lesser than that of k-means, showing improvement. The transmission powers of nodes decreases with the increasing number on node deployment.

4.4 Conclusion

In this chapter we presented the simulation of the WSN using Omnet++. We compared the average transmission power of nodes vs. the number on nodes in case of networks with no topology control, with k-means clustering based topology control and with CLTC:k-means based topology control. We also analyzed the eect of the proposed work on node power depletion and node lifetime as compared to simple k-means or no topology control.

Chapter 5

Conclusions and Future Work

This thesis proposes modification to the CLTC framework so that it can be applied to Wireless Sensor Networks when the network lifetime has to be optimized. In order to do so, first of all we use a distributed approach in the second phase as compared to the centralized approach initially presented. This assures that the power consumption of cluster heads is minimized.

The second presentation in this thesis is the implementation of the framework to minimize the node power consumption of nodes using k-means clustering, which is a simple clustering method to deploy in WSNs. We also present the effects of this implementation on node lifetime.

The following approaches can be taken up as future work related to this project:

- Study of Network Coverage using CLTC: When the transmission power of nodes are changed, their transmission range changes, hence the network coverage is affected. The study of Network Coverage when implementing CLTC can be done.

- Effects of deploying other algorithms for intra-cluster topology control: We used the Relative Neighborhood graph for intra-cluster topology control; other sparsing algorithms can be implemented.

- Deployment of CLTC to Heterogeneous Networks: Our proposed work assumes a homogeneous network, but CLTC can be deployed to heterogeneous models as well.

Bibliography

[1] Hsiao Hwa Chen Konstantinidis Andreas, Yang Kun and Zhang Qingfu. Energy-aware topology control for wireless sensor networks using manetic algorithms.

[2] Mehdi Kalantari and Mark Shayman. Energy efficient routing in wireless sensor networks. In *Proc. of Conference on Information Sciences and Systems*. Citeseer, 2004.

[3] Holger Karl and Andreas Willig. *Protocols and Architechtures for Wireless Sensor Networks*. John Wiley and Sons Inc., Norwell, MA, USA, 2005.

[4] D. Minoli K. Shoraby and T. Znati. *Wireless Sensor Network technology, protocols and applications*. Wiley-Interscience, Secaucus, NJ, USA, 2007.

[5] M.R.Ebenezor Jebarani and T. Jayanty. An analysis of various parameters in wireless sensor networks using adaptive fec technique. *International Journal of Ad hoc, Sensor Ubiquitous Computing*, 1(3), 2010.

[6] Paolo Santi. Topology control in wireless ad hoc and sensor netowrks. *ACM computing Surveys*, 37(3):164–194, 2005.

[7] Rui Liu Zhuochuan Huang Jaikaeo Chaiporn Chien-Chung Shen, Chavalit Srisathapornphat and Errol L. Lloyd. Cltc: A cluster based topology control framework for ad hoc networks. *IEEE transactions on mobile computing*, 3(1), 2004.

[8] Kheireddine Mekkaoui and Abdellatif Rahmoun. Short-hops vs. long-hops - energy eciency analysis in wireless sensor networks. *CEUR-WS*, 825.