1-1-2008

Impact of variable transmission range in all-wireless networks

Prathima Sajja

University of Nevada, Las Vegas

Follow this and additional works at: https://digitalscholarship.unlv.edu/rtds

Repository Citation


https://digitalscholarship.unlv.edu/rtds/2385
IMPACT OF VARIABLE TRANSMISSION RANGE IN ALL-WIRELESS NETWORKS

by

Prathima Sajja

A thesis submitted in partial fulfillment of the requirements for the

Master of Science in Computer Science
School of Computer Science
Howard R. Hughes College of Engineering

Graduate College
University of Nevada, Las Vegas
August 2008
The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleed-through, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.
The Thesis prepared by

PRATHIMA SAJJA

Entitled

IMPACT OF VARIABLE TRANSMISSION RANGE IN ALL-WIRELESS NETWORKS

is approved in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN COMPUTER SCIENCE

Examination Committee Chair

Dean of the Graduate College

Examination Committee Member

Examination Committee Member

Graduate College Faculty Representative
ABSTRACT

Impact of Variable Transmission Range in All-Wireless Networks

by

Prathima Sajja

Dr. Ajoy K. Datta, Examination Committee Chair
Professor of Computer Science
University of Nevada, Las Vegas

In this thesis, we propose three distributed algorithms for self-adjusting the transmission range of nodes in wireless network. The objective is to vary the transmission radii of selective sensor nodes to lower the energy spent in broadcasting or the diameter. The sensor nodes start arbitrarily with different transmission ranges. The nodes positions are fixed, and can adjust the transmission power. However, increasing the transmission power to reach more nodes may consume more energy. So, the goal is to reduce the transmission power (i.e., save energy) without reducing the reachability (in terms of the number of nodes).

We propose two algorithms that increase the transmission range of nodes. Increasing the transmission range of selective nodes will lower
the diameter but increase the total energy. The proposed algorithm computes the ratio of the increase in transmission range to the increase in number of nodes of every sensor node. The node with the smallest ratio will be selected to increase its transmission range.

The third algorithm decreases the transmission range of the nodes. Decreasing the transmission range will lower the total energy but increase the diameter of the network. Ratio of decrease in the transmission range to the decrease in the number of nodes is calculated for every node, and the node with the highest ratio is selected to decrease its transmission range.

A larger diameter implies a higher chance of interference between the neighboring nodes. When two nodes are in not in the communication range of each other, there is a probability that both the nodes send the packets to each other at the same time using the same channel. The nodes will not be able to decide by themselves, hence a collision will occur. This is known as hidden terminal problem. A lower diameter implies a higher chance of message duplication. Same message will be received twice.

All three algorithms will be simulated and compared based on the experimental results.
# TABLE OF CONTENTS

ABSTRACT..................................................................................................................... iii

LIST OF FIGURES...................................................................................................... VI

ACKNOWLEDGEMENTS .............................................................................................. vii

CHAPTER 1 INTRODUCTION ................................................................................ 1
  1.1. Contributions ........................................................................................ 5
  1.2. Outline of the Thesis........................................................................... 6

CHAPTER 2 WIRELESS SENSOR NETWORKS................................................ 7
  2.1. Wireless Multicast Advantage ............................................................. 9
  2.2. Hidden Terminal ................................................................................... 10
  2.3. Related Work ......................................................................................... 11

CHAPTER 3 DESCRIPTION OF THE ALGORITHMS ................................... 15
  3.1. Computing the Diameter of a Network .............................................. 17
  3.2. Increasing the Transmission Range .................................................. 18
  3.3. Doubling the Transmission Range.................................................... 23
  3.4. Halving the Transmission Range....................................................... 27

CHAPTER 4 SIMULATIONS ................................................................................. 31
  4.1. Simulations for Algorithm 1 ............................................................. 31
  4.2. Simulations for Algorithm 2 ............................................................. 36
  4.3. Simulations for Algorithm 3............................................................... 40

CHAPTER 5 CODE DESCRIPTION .................................................................... 45
  5.1. Code Description Algorithm 1 .................................................................... 45
  5.2. Code Description Algorithm 2 .................................................................... 49
  5.3. Code Description Algorithm 3 .................................................................... 53

CHAPTER 6 CONCLUSION AND FUTURE WORK......................................... 58

BIBLIOGRAPHY ......................................................................................................... 60

VITA ............................................................................................................................... 63
LIST OF FIGURES

Figure 1. Routing in Wireless Sensor Network ................................................2
Figure 2. The Wireless Multicast Advantage .....................................................9
Figure 3. Hidden Terminal Problem .................................................................11
Figure 4. A Wireless Sensor Network ..............................................................21
Figure 5. A Wireless Sensor Network with Orientation ....................................29
Figure 6. Algorithm 1 - Cases for the Diameter Changes ............................32
Figure 7. Algorithm 1 - Changes of R - Average ........................................34
Figure 8. Algorithm 1 - Changes of R - Average/Network Size ..................35
Figure 9. Algorithm 2 - Cases for Diameter Changes ...................................36
Figure 10. Algorithm 2 - Changes of R - Average ........................................38
Figure 11. Algorithm 2 - Changes of R - Average/Network Size .................40
Figure 12. Algorithm 3 - Cases for Diameter Changes .................................41
Figure 13. Algorithm 3 - Changes of Energy Average .................................43
Figure 14. Algorithm 3 - Changes of Energy Average/Network Size ..........44
ACKNOWLEDGEMENTS

I would like to express my thanks and sincere appreciation to my advisor, Dr. Ajoy K. Datta for his guidance, insight, and support for this research. His trust and confidence in my abilities have truly encouraged me throughout my graduate study. I am also grateful to Dr. Doina Bein for helping and supporting me in completion of my thesis. I would also like to thank Dr. John Minor, Dr. Yoohwan Kim, and Dr. Venkatesan Muthukumar, for participation in my committee.

My special gratitude goes to my family. I would like to dedicate this thesis to them for their understanding, motivation, and patience. I am thankful to all faculty members and friends who made my stay at the University of Nevada, Las Vegas a memorable and valuable experience.
INTRODUCTION

A sensor network is a collection of sensor nodes equipped with sensing, communication (short range radio) and processing capabilities. Each node in a sensor network is equipped with a radio transceiver or other wireless communication device, and a small micro controller.

Wireless sensor networks provide target sensing, data collection, information manipulation and dissemination in a single integrated framework. These nodes perform desired measurements, process the measured data and transmit it to a base station. The areas of applications of sensor networks vary from military, civil, healthcare, and environmental to commercial. Increasing computing and wireless communication capabilities will expand the role of sensors from mere information dissemination to more demanding tasks as sensor fusion, classification, and collaborative target tracking. Due to the low-cost of these nodes, the deployment can be in order of magnitude of thousands to millions nodes. Therefore the sensor nodes are densely scattered in a sensor field, and there are one or more nodes called sinks (or also initiators), capable of communicating with higher level networks.
By a dense deployment of sensor nodes we mean that the nearest neighbor is at a distance much smaller than the transmission range of the node. In general, a spatial distribution of sensors is a two-dimensional Poisson point process. The nodes can be deployed either in random fashion or pre-engineered way. The nodes must coordinate also as to exploit the redundancy provided by the high density of nodes to minimize the total energy consumption, thus extend the lifetime of the system overall, and to avoid collisions. Selecting fewer nodes saves energy, but the distance between neighboring active nodes could be too large, thus the packet loss rate could be so large that the energy required for transmission becomes prohibitive. Energy can be wasted by selecting more nodes, and shared channels will be congested with redundant messages, thus collision and subsequently loss of packets can occur.

Figure 1 depicts a wireless sensor network.
Sensors have limited battery power. The energy budget for communication is many times more than computation with the available technology. Therefore, minimizing communication cost incurred in answering a query in a sensor network will result in longer lasting sensor networks. Hence, communication efficient execution of queries in a sensor network is of significant interest.

A sensor will be able to communicate with its neighbors over the shared wireless medium, but does not have global knowledge of the entire network. Each sensor has the ability to communicate with the neighboring sensors that fall within its transmission radius. However the devices are low-powered with finite resources and this imposes restrictions on their data processing operations and communication activities. The energy constraint sensor nodes in sensor networks operate on limited batteries, so it is very important to use energy efficiently and reduce power consumption.

An important goal in the design and efficient implementation of wireless sensor networks is to save energy and keep the network functional as long as possible. The goal is to combine energy efficiency with a balanced spread of energy consumption among the sensors. Here we discuss and analyze energy efficient data propagation in sensor networks. For guaranteeing energy balance most transmissions must be one hop transmissions, thus data is transmitted over small distances and thus the overall energy consumption in the network is kept low.
Due to geographical distribution of sensors in a sensor network, each piece of data generated in a sensor network has a geographic location associated with it in addition to a time stamp. Hence to specify the data of interest over which query should be answered, each query in a sensor network has a time window and a geographical region associated with it. Given a query in a sensor network, we wish to select a small number of sensors that are sufficient to answer the query accurately. We need to select an optimal set of sensors that satisfy the conditions of coverage as well as connectivity. Constructing an optimal connected sensor cover for a query enables execution of the query in a very energy efficient manner as we need to involve only the sensors in the computed connected sensor cover for processing the query without comprising on its accuracy. When data is sent from one node to the next in a multi-hop network there is a chance that a particular packet may be lost and the odds grow worse as the size of the network increases.

Once a large number of sensor devices are randomly deployed over an area of interest, and since existing infrastructure is not present, the nodes are responsible for self-organizing into a logical communication network structure through which data can be routed, hop by hop, from source to destination. This can be viewed as the initialization phase of the network.
1.1. Contributions

In this thesis, the objective is to vary the transmission radii of selective sensor nodes to lower the energy spent in broadcasting or the diameter.

We propose two algorithms that increase the transmission range of the nodes. The first algorithm increases the transmission range to reach all its two-hop neighbors and the second algorithm doubles the transmission range to reduce the diameter. The proposed algorithms compute the ratio of increase in transmission range to increase in number of nodes of every sensor node. The node with the smallest ratio will be selected to increase its transmission range. The total energy and the diameter of the network before increasing the transmission range and after increasing the transmission range is computed. The total energy of the broadcast tree is the sum of the energy expended at each of the transmitting nodes in the tree except for the leaf nodes. Therefore the total transmission energy is proportional to the total power needed to maintain the tree.

The third algorithm decreases the transmission range of the nodes. Decreasing the transmission range may lower the total energy but increase the diameter of the network. Ratio of decrease in the transmission range to the decrease in the number of nodes is calculated for every node, and the node with the highest ratio is selected to decrease its transmission range.
These algorithms have been evaluated through simulations. Some heuristics may perform quite well or even optimally in some situations, but may perform very poorly in some other situations. Greedy heuristics may only have a slight difference, but the small variation could have a great impact on the heuristics’ analytic performances. These protocols have been discussed in chapter 3.

1.2. Outline of the Thesis

In chapter 2 we present basic notions related to wireless sensor networks. Our three algorithms are presented in detail in Chapter 3, with suggestive examples. The comparative studies are presented in Chapter 4. A brief description of the code is presented in Chapter 5. We finish with concluding remarks in Chapter 6.
CHAPTER 2

WIRELESS SENSOR NETWORKS

A sensor network is a collection of sensor nodes equipped with sensing, communication (short range radio), and processing capabilities. A sensor will be able to communicate with its neighbors over the shared wireless medium, but does not have global knowledge of the entire network. The communication is wireless: e.g., radio, infrared, or optical media. Due to the large numbers of nodes and thus the communication overhead, the sensors may not have any global identification (ID). In some cases, they may carry a global positioning system (GPS). In order to distinguish between neighbors, nodes may have local unique IDs. Examples of such identifiers are 802.11 MAC addresses and Bluetooth cluster addresses. The neighbors of a sensor are defined as all the sensors within its transmission range. The whole network can be viewed as a dynamic graph with time varying topology and connectivity.

Since sensor nodes carry limited, generally irreplaceable power sources, one of the most important constraints on sensor nodes is the lower power consumption requirement. The power restrictions of sensor nodes are raised due to their small physical size and lack of wires. The
power is used for various operations in each node, such as running the sensors, processing the information gathered and data communications. Communication between the sensor nodes consumes most of the available power, much more than sensing and computation. Power limitations greatly affect security, since encryption algorithms introduce a communication overhead between the nodes.

The steps toward a large network consisting of sensor nodes with such limited resources are not easy and present many challenges that are still to be solved. The development of an appropriate algorithm in case of directed networks with asymmetric power requirements remains an open problem. The vision of wireless sensor network is to deploy a large number of smart but inexpensive sensors close to the objects and environment for in-situ sensing and actuation.

Therefore, while traditional networks aim to achieve high quality of service provisions, sensor network protocols must focus primarily on power consumption. They must have inbuilt tradeoff mechanisms that give the end user the option for prolonging network lifetime at the cost of lower throughput or higher transmission delay. The key objective is to maximize network lifetime by managing the power consumption of each node so that global network connectivity can be maintained.
2.1. Wireless Multicast Advantage

A single transmission suffices for reaching all these receivers. All nodes within the communication range of a transmitting node can receive its transmission.

![Diagram of wireless multicast advantage](image)

Figure 2. "The wireless multicast advantage" $P_{i, (j, k)} = \max \{P_{ij}, P_{ik}\}$

Consider Figure 2, in which a subset of multicast tree involves node $i$, which is transmitting to its neighbors, node $j$ and node $k$. The power required to reach node $j$ is $P_{ij}$ and the power required to reach node $k$ is $P_{ik}$. A single transmission at power $P_{i, (j, k)} = \max \{P_{ij}, P_{ik}\}$ is sufficient to reach both node $j$ and node $k$. The ability to exploit this property of wireless communication is referred to as wireless multicast advantage.

As a result of wireless multicast advantage the correct view of the omnidirectional wireless communication medium is a node based environment that is characterized by the following properties:

- A node's transmission is capable of reaching another node if the latter is within communication range.
• The total power required to reach a set of other nodes is the maximum required to reach any of them individually.

When a node sends a packet to a neighboring node and the neighbor has to forward it that uses energy. The bigger the network the more nodes that must forward data and the more energy that is consumed. The end result is as the network grows performance degrades. While energy efficient approaches try to limit the redundancy such that minimum amount of energy is required for fulfilling a certain task, redundancy is needed for providing fault tolerance since sensors might be faulty, malfunctioning or even malicious.

We focus on developing a communication system optimized for sensor networks that require low power consumption and cost. While the sensor itself requires power, we can design the communication system to use as little power as possible, so that the system power will be limited by sensors and not by communication.

2.2. Hidden Terminal Problem

A larger diameter implies a higher chance of interference between the neighboring nodes. When two nodes are in not in the communication range of each other, there is a probability that both the nodes send the packets to each other at the same time using the same channel. This is known as the hidden terminal problem which can be formulated as follows:
Figure 3. Hidden terminal problem

Given four nodes A, B, C and D shown in figure 3 such that the nodes A and C are not in the communication range of each other, node A sends a packet to node B on the same channel and at the same time when node C sends a packet to node D. Neither node A nor node C will be able to determine, by itself, that a collision has occurred.

2.3. Related Work

One major approach for energy conservation is to route a communication session along the route which requires the lowest total energy consumption. The optimization problem is referred to as Minimum-Energy Routing. Among the proposed greedy heuristics three are very popular:

- MST (minimum spanning tree)
- SPT (shortest path tree)
• BIP (broadcast incremental power)

They have been evaluated through simulations. Some heuristics may perform quite well or even optimally in some situations, but may perform very poorly in some other situations. Greedy heuristics may only have a slight difference, but the small variation could have great impact on the heuristics' analytic performances.

Sankarasubramanian et al. [Y. Sankarasubramaniam, 2003] describes wireless sensor networks as event based systems that rely on the collective effort of several micro sensor nodes. Reliable event detection at the sink is based on collective information provided by source nodes and not by any individual report. Conventional end-to-end reliability definitions and solutions are inapplicable in wireless sensor networks. Event-to-sink reliable transport (ESRT) is a novel transport solution developed to achieve reliable event detection in wireless sensor networks with minimum energy expenditure. It includes a congestion control component that serves the dual purpose of achieving reliability and conserving energy. The self-configuring nature of ESRT makes it robust to random, dynamic topology in wireless sensor networks. It can also accommodate multiple concurrent event occurrences in a wireless sensor field.

Wan et al. [C. Wan, 2003] discuss event-driven sensor networks that operate under an idle or light load and then suddenly become active in response to a detected or monitored event. The transport of event pulses
is likely to lead to varying degrees of congestion in the network depending on the sensing application. To address this challenge they proposed energy efficient congestion control scheme for sensor networks called CODA (COngestion Detection and Avoidance). The term of bursty convergecast is proposed by Zhang et al. [H. Zhang, 2005] for multi-hop wireless networks where a large burst of packets from different locations needs to be transported reliably and in real-time to a base station.

Since transmission bandwidth is a scarce commodity in wireless networks, efficient and near minimum cost casting algorithms, namely broadcast, multicast, convergecast, are very useful.

Makki et al. [K. Makki, 1996] address the multicasting problem in order to reach efficient and near-minimum cost algorithms for wireless algorithms. Multicasting reduces the transmission overhead and the time it takes for all the nodes in the subset to receive information.

The node-based nature of wireless communication and the notion of wireless multicast advantage has been emphasized in the seminal paper of Wieselthier et al. [JE Wieselthier, 2000]. The author proposed and evaluated several algorithms for broadcasting tree construction in infrastructureless, all-wireless applications. Energy efficiency is the main performance metric used to evaluate broadcast and multicast trees.

Kirousis et al. [LM Kirousis, 2000] study the problem of assigning transmission ranges to the nodes of a multi-hop packet radio network so as to minimize the total power consumed under the constraint that
adequate power is provided to the nodes to ensure that the network is strongly connected (i.e., each node can communicate along some path in the network to every other node). Such assignment of transmission ranges is called complete.

Wieselthier et al. [JE Wieselthier, Resource management in energy-limited, bandwidth-limited, transceiver-limited wireless networks for session-based multicasting, 2002] consider source initiated multicast session traffic in an ad hoc wireless network, operating under hard constraints on the available transmission energy as well as on bandwidth and transceiver resources. In energy limited applications, fundamental objectives include the maximization of a network's useful lifetime and the maximization of the traffic that is delivered during this lifetime.

Li [Li, 2003] discusses about the progress of applying computational geometry techniques solve topology construction and broadcasting issues in wireless ad hoc networks. The author models the wireless networks by unit disk graphs in which two nodes are connected if their Euclidean distance is no more than one.
CHAPTER 3

DESCRIPTION OF THE ALGORITHMS

In this chapter we present three algorithms. In the first algorithm we virtually increase the transmission range of the selected node to reach its two-hop neighbors. Then we compute the ratio of increase in transmission range to increase in the number of nodes. The node with the least ratio is selected to increase its transmission range. In the second algorithm we virtually double the transmission range of the selected node in order to reach more nodes. Then we compute the ratio of increase in transmission range to increase in number of nodes. The node with the least ratio is selected to double its transmission range. In the third algorithm we virtually decrease the transmission range of the selected node to reduce the energy. Then we compute the ratio of decrease in transmission range to decrease in the number of nodes. The node with the highest ratio is selected to halve its transmission range. The nodes positions are fixed, and can adjust the transmission range. A larger diameter implies a higher chance of interference between neighboring nodes. A lower diameter implies a higher chance of message duplication.
Sensors are miniscule computing devices with a limited battery power. The energy budget for communication is many times more than computation with the available technology. Therefore, minimizing communication cost incurred in answering a query in a sensor network will result in longer lasting sensor networks. Hence, communication efficient execution of queries in a sensor network is of significant interest. Given a query in a sensor network, we wish to select a small number of sensors that are sufficient to answer the query accurately. We need to select an optimal set of sensors that satisfy the conditions of coverage as well as connectivity. Constructing an optimal connected sensor cover for a query enables execution of the query in a very energy efficient manner as we need to involve only the sensors in the computed connected sensor cover for processing the query without comprising on its accuracy.

We consider a network of static sensors that are deployed, with each node knowing its own location and the location of its neighbors. All nodes in the network are assigned with a unique ID. Every node is randomly assigned transmission range. The communication between the nodes can be unidirectional or bidirectional. A node computes all the other nodes that are within its transmission range; these nodes are called one-hop neighbors. The two-hop neighbors will be the union of one-hop neighbors and one-hop neighbors of the one-hop neighbors. We calculate the set of one-hop and two-hop neighbors for each node.
3.1. Computing the diameter of a network

The \textit{diameter} is defined as the longest of the shortest distance between two pair of nodes. To compute the diameter of the network the shortest path between each pair of nodes is computed and the longest of the shortest paths is determined to be the diameter of the network.

To calculate the shortest path between two nodes, the following procedure is followed:

A \( n \times n \) matrix is initialized.

\[ A_{ij} = 1 \text{ if } j \text{ is the one-hop neighbor of } i \]
\[ = \infty \text{ if } j \text{ is not the one-hop neighbor of } j \]

\[ B_{ij} = 1 \text{ if } j \text{ is the one-hop neighbor of } i \]
\[ = \infty \text{ if } j \text{ is not the one-hop neighbor of } j \]

\[ A^n \rightarrow \text{ all-pairs shortest path} \]

The matrix \( A \) is multiplied by itself for \( n \) number of times where \( n \) is the number of nodes.

\[ C = A \times B \]

where \( C[i,j] = \min_{k=1,...,n} \{ A[i,k] + B[k,j] \} \)

The final matrix \( C[i,j] \) will have the shortest path between any pair of nodes.

The longest of the shortest paths will be chosen as the diameter of the network.

The diameter will be \( \infty \) if the network is disconnected and a finite number if the network is connected.
3.2. Increasing the transmission range to reach two-hop neighbors

**Objective 1:** Reaching more nodes with less increase in power.

For the first algorithm, we virtually increase the transmission range of every node so that it will be able to reach all its two-hop neighbors. The final one-hop neighbors set of each node is computed after increasing the transmission range. The ratio of increase in energy to the increase in the one-hop neighbors is computed. This ratio gives a tradeoff between energy and reachability. The node with minimum ratio is selected to increase its transmission range. The goal of the algorithm is to try and make the maximum number of nodes as one-hop neighbors with a little increase in energy. This will help reduce the diameter of the network.

The diameter is the longest minimum path between two nodes. Reducing the diameter will reduce the time in delivering the messages. This algorithm tries to make sure that with a small increase in energy more nodes are reached and diameter of the network is reduced.

**Description of Algorithm 1:**

The wireless sensor network starts in an arbitrary configuration: The sensor nodes start arbitrarily with different transmission ranges, and can adjust the transmission power.

Let $r_i$ be the transmission range of node $i$ and $N_i^1$ be the one-hop neighborhood of node $i$. This variable is maintained by an underlying local topology maintenance protocol that adjusts its value in case of topological changes in the network due to failure of nodes, links or both.
If node i decides to extend its transmission range to reach its two-hop neighbors, node i will be able to acquire more nodes in its one-hop neighborhood. The cost of this increase is measured in terms of how many new nodes can be reached in one-hop by this increase in the transmission range.

Let \( N_i^2 \) be the set of nodes situated at no more than two hops (one-hop and two-hop neighborhood) before the increase. Let \( N_i^1, \delta \) be the one-hop neighborhood of the node i obtained by increasing its transmission range from \( r_i \) to \( r_i + \delta \). Assume that every node performs this \( \delta \) increase. The number of new nodes is \( | N_i^1, \delta - N_i^1 | \). If this number is 0 (no new nodes are acquired) then for calculation purpose it is assumed to be 0.1 (or other number between 0 and 1, and smaller than 1).

In this algorithm, within each neighborhood (a node and its one-hop neighbors), the node which achieves the highest number of new reachable nodes by increasing its transmission range to include all the nodes that were in its two-hop neighborhood will be the one to be selected to permanently increase its transmission range.
Algorithm 1 follows the following steps:

---

**Algorithm 1**

For each node i:

**Step 1** Calculate \( N_i^1 \).

**Step 2** Calculate \( N_i^2 \).

**Step 3** Calculate the transmission range \( r_i \) necessary such node i will reach its two-hop neighbors. Calculate the increase in transmission range \( \Delta r_i = r'_i - r_i \).

**Step 4** Calculate the new set of one-hop neighbors \( N_{N_i} \) that are obtained by i increasing its transmission range as specified above.

**Step 5** Calculate the ratio \( N_{R_i} = \frac{\text{increase in transmission range}}{\text{increase in the number of nodes}} = \frac{\Delta r_i}{|N_{N_i}^2 - N_i^2|} \)

**Step 6** Calculate the total energy and the diameter of the network before and after increasing the transmission of the selected node.

---

Consider the network in figure 4 where the numbers are the distances between the nodes. The transmission range of the nodes is as follows:

\( r_a = 5, \ r_b = 3, \ r_c = 2, \ r_d = 2, \ r_e = 5, \ r_f = 5, \ r_g = 4, \ r_h = 3, \ r_i = 2, \ r_j = 5, \ r_k = 3, \ r_l = 4 \)
The one-hop neighbors are: \( N_a^1 = \{b, i, j, l\} \), \( N_b^1 = \{a, c\} \), \( N_c^1 = \{b, d\} \), \( N_d^1 = \{c, e\} \), \( N_e^1 = \{d, f\} \), \( N_f^1 = \{e, g\} \), \( N_g^1 = \{f, h\} \), \( N_h^1 = \{g, i\} \), \( N_i^1 = \{a, h\} \), \( N_j^1 = \{a, k\} \), \( N_k^1 = \{j\} \), \( N_l^1 = \{a\} \).

The two-hop neighbors are (the nodes situated at two-hops are marked as a separate set): \( N_a^2 = \{b, i, j, l\} \cup \{c, h, k\} \), \( N_b^2 = \{a, c\} \cup \{d, i, j, l\} \), \( N_c^2 = \{b, d\} \cup \{a\} \), \( N_d^2 = \{c, e\} \cup \{b, f\} \), \( N_e^2 = \{d, f\} \cup \{c, g\} \), \( N_f^2 = \{e, g\} \cup \{h\} \), \( N_g^2 = \{f, h\} \cup \{e, i\} \), \( N_h^2 = \{g, i\} \cup \{a, f\} \), \( N_i^2 = \{a, h\} \cup \{b, g, j, l\} \), \( N_j^2 = \{a, k\} \cup \{b, i, l\} \), \( N_k^2 = \{j\} \cup \{a\} \), \( N_l^2 = \{a\} \cup \{b, i, j\} \).

Figure 4. A wireless sensor network
If each node wants to reach all its two-hop neighbors, it has to have the transmission range presented in Table 1. The increase in the transmission range and the ratio of increase are also presented.

<table>
<thead>
<tr>
<th></th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
<th>g</th>
<th>h</th>
<th>i</th>
<th>j</th>
<th>k</th>
<th>l</th>
</tr>
</thead>
<tbody>
<tr>
<td>r'</td>
<td>8</td>
<td>8</td>
<td>5</td>
<td>8</td>
<td>9</td>
<td>8</td>
<td>9</td>
<td>7</td>
<td>7</td>
<td>9</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Δr</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>6</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>N</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>6</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>R</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>6</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**Table 1. Adjusting transmission range**

If each node virtually increases its transmission range to reach all its two-hop neighbors, one can easily observe from this example that some other nodes which were at three or more hop distance will be reachable when the node increases its power. For example, when node a increases its transmission range to reach in one hop its two-hop neighbors, the nodes {d, g} will be in one hop range to node a.

The new one-hop neighborhood are presented below. The other nodes are marked as a separate set: \( NN_a^1 = \{b, c, h, i, j, k, l\} \cup \{d, g\} \), \( NN_b^1 = \{a, c, d, i, j, l\} \cup \{e, h\} \), \( NN_c^1 = \{a, b, d\} \), \( NN_d^1 = \{b, c, e, f\} \cup \{a\} \), \( NN_e^1 = \{c, d, f, g\} \cup \{b\} \), \( NN_f^1 = \{e, g, h\} \), \( NN_g^1 = \{e, f, h, i\} \cup \{a\} \), \( NN_h^1 = \{a, f, g, l\} \cup \{b\} \), \( NN_i^1 = \)}
Following Algorithm 1, the node with smallest ratio will be selected to increase its transmission range, in this case it is node a.

The total energy of the network before increasing the transmission range of the selected node is 43.

The total energy of the network after increasing the transmission range of the selected node is 46.

The diameter of the network before increasing the transmission range is 6.

The diameter of the network after increasing the transmission range is 3.

3.3. Doubling the transmission range

*Description of Algorithm 2:*

In our second algorithm, within each neighborhood (a node and its one-hop neighbors), the node which achieves the highest number of new reachable nodes by simply doubling its transmission range will be the one to be selected to permanently increase its transmission range. We consider a network of static energy constrained sensors that are deployed with each node knowing its own location and the location of its neighbors. All nodes in the network are assigned with a unique ID. Every node is randomly assigned transmission range. Additionally, these sensor nodes have limited processing power, storage and energy. The
communication between the nodes can be bidirectional. The nodes check to see if the distances between the sensor nodes is within the transmission range, if so those nodes become the immediate neighbors and are called one-hop neighbors.

We compute the set of one-hop for each node. Then we virtually double the transmission range of every node. The final one-hop neighbors set of each node is computed after virtually doubling the transmission range. The ratio of increase in energy to the increase in the one-hop neighbors is computed. This ratio gives a tradeoff between energy and reachability. The node with minimum ratio is selected to finally double its transmission range. The goal of the algorithm is to try and make the maximum number of nodes as one-hop neighbors with a little increase in energy. This will help reduce the diameter of the network.

The diameter is the longest minimum path between two nodes. Reducing the diameter will reduce the time in delivering the messages. This algorithm tries to make sure that by doubling energy of a selected node more nodes are reached and diameter of the network is reduced.

If a node would double its transmission range, the ratios of increase are presented in Table 3.3.
Table 2. Doubling transmission range

<table>
<thead>
<tr>
<th></th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
<th>g</th>
<th>h</th>
<th>i</th>
<th>j</th>
<th>k</th>
<th>l</th>
</tr>
</thead>
<tbody>
<tr>
<td>r'</td>
<td>10</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>10</td>
<td>10</td>
<td>8</td>
<td>6</td>
<td>4</td>
<td>10</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>D</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>R</td>
<td>6</td>
<td>1</td>
<td>0.1</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>0.1</td>
<td>5</td>
<td>0.1</td>
<td>3</td>
</tr>
</tbody>
</table>

The new one-hop neighborhood are: $\text{DN}_a^1 = \{b, c, d, e, g, h, i, j, k, l\}$, $\text{DN}_b^1 = \{a, c, i\}$, $\text{DN}_c^1 = \{b, d\}$, $\text{DN}_d^1 = \{b, c, e\}$, $\text{DN}_e^1 = \{a, b, c, d, f, g\}$, $\text{DN}_f^1 = \{c, d, e, g, h, i\}$, $\text{DN}_g^1 = \{a, f, h, i\}$, $\text{DN}_h^1 = \{a, g, i\}$, $\text{DN}_i^1 = \{a, h\}$, $\text{DN}_j^1 = \{a, b, c, h, i, k, l\}$, $\text{DN}_k^1 = \{j\}$, $\text{DN}_l^1 = \{a, b, i, h\}$

Node a has the smallest ratio and will be selected to increase its transmission range.

The total energy of the network before increasing the transmission range is 43.

The total energy of the network after increasing the transmission range is 48.

The diameter of the network before increasing the transmission range is 6.

The diameter of the network after increasing the transmission range is 3.
The algorithm follows the following steps:

**Algorithm 2**

For each node i:

Step 1   Calculate $N_i^1$.

Step 2   Double the transmission range $r_i$ and calculate the set of one-hop neighbors $DN_i^1$ that are obtained by doubling its transmission range.

Step 3   Calculate the ratio $D R_i = \frac{\text{increase in transmission range}}{\text{increase in the number of nodes}} = \frac{d r_i}{|DN_i^1 - N_i^1|}$.

Step 4   Calculate the total energy and the diameter of the network before and after increasing the transmission of the selected node.

There will also be a case where every node is connected to each other node in the network i.e there will be no two-hop neighbors. When we try to increase the energy it may happen that the new transmission range is less than or equal to the old transmission range. In that case we do not want to change the old transmission range to the new transmission range, so old transmission range is retained.
3.4. Halving the transmission range

Objective 2: Reduce the transmission power without losing connectivity, in order to save energy.

Description of algorithm 3:

A node reduces its transmission range by half and tries not to lose many nodes. The node which loses the least number of nodes with the highest power decrease will be allowed to decrease its transmission range.

We consider a network of static energy constrained sensors that are deployed with each node knowing its own location and the location of its neighbors. All nodes in the network are assigned with a unique ID. Every node is randomly assigned transmission range. Additionally, these sensor nodes have limited processing power, storage and energy. The communication between the nodes can be bidirectional. The nodes check to see if the distances between the sensor nodes is within the transmission range, if so those nodes become the immediate neighbors and are called one-hop neighbors.

We compute the set of one-hop for each node. Then we virtually reduce the transmission range of every node by half of the original transmission range. The final one-hop neighbors set of each node is computed after halving the transmission range. The ratio of decrease in energy to the decrease in the one-hop neighbors is calculated. This ratio gives a tradeoff between energy and reachability. The node with
maximum ratio is selected to decrease its transmission range. The goal of the algorithm is to lose minimum number of nodes as one-hop neighbors halving the energy spent.

The algorithm follows the following steps:

Algorithm 3

For each node i::

Step 1 Calculate $N_i^l$.

Step 2 Virtually halve the transmission range and calculate the new set of one-hop neighbors $HN_i^l$ that are obtained by $i$ halving its transmission range.

Step 3 Calculate the ratio $HR_i = \frac{\text{decrease in transmission range}}{\text{decrease in the number of nodes}} = \frac{\Delta r_i}{|N_i^l - HN_i^l|}$

Step 4 Calculate the total energy and the diameter of the network before and after halving the transmission of the selected node.

Consider the network in Figure 5. A node is represented as $i(x, y, r)$ where $i$ is the node-id, $x, y$ are the coordinate positions and $r$ is the transmission range. The transmission ranges of the nodes are: $r_a = 68$, $r_b = 24$, $r_c = 25$, $r_d = 66$, $r_e = 23$.

The one-hop neighbors are: $N_a^l = \{b, c, d, e\}$, $N_b^l = \{a, c, d, e\}$, $N_c^l = \{b\}$, $N_d^l = \{a, b, c, e\}$, $N_e^l = \{b\}$. 

28
The two-hop neighbors are: $N_a^2 = \{b, c, d, e\}$, $N_b^2 = \{a, c, d, e\}$, $N_c^2 = \{a, b, d, e\}$, $N_d^2 = \{a, b, c, e\}$, $N_e^2 = \{a, b, c, d\}$.

The new one-hop neighbors after halving the transmission range are:

$HN_a^1 = \{b, c, d, e\}$, $HN_b^1 = \{a, e\}$, $HN_c^1 = \{\}$, $HN_d^1 = \{a, b, c\}$, $HN_e^1 = \{b\}$.

The new two-hop neighbors after halving the transmission range are:

$HN_a^2 = \{b, c, d, e\}$, $HN_b^2 = \{a, c, d, e\}$, $HN_c^2 = \{\}$, $HN_d^2 = \{a, b, c, e\}$, $HN_e^2 = \{a, b\}$.

Figure 5. Wireless sensor network with orientation

If a node would halve its transmission range, the decrease ratios are given in Table 3.4.
Table 3. Halving transmission range

<table>
<thead>
<tr>
<th>r'</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
</tr>
</thead>
<tbody>
<tr>
<td>H R</td>
<td>34</td>
<td>12</td>
<td>12.5</td>
<td>33</td>
<td>11.5</td>
</tr>
<tr>
<td></td>
<td>0.1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Nodes a, and e have the smallest ratio and will be selected to increase its transmission range.

The total energy before halving the transmission range is 206. The total energy after halving the transmission range is 172. The diameter of the network before halving the transmission range is 2. The diameter of the network after halving the transmission range is 2.
SIMULATIONS

Extensive experiments have been conducted to compare the efficiency of each algorithm. We have considered 60 networks in Euclidean space of size 5, 10, 20... 100 nodes with arbitrary coordinates and arbitrary transmission ranges being generated, and we have applied the three proposed algorithms to them. In case a generated network is disconnected, the diameter is $\infty$.

Given such a network, for each of the three algorithms, we compute the total energy and the diameter of the network before and after adjusting the transmission range.

For each algorithm we consider the case of only one node changing its transmission radius.

4.1. Simulations for algorithm 1

For Algorithm 1, with respect to the change in diameter of the network, we distinguish four cases:

- Case A: the diameter of the network changes from $\infty$ to finite
  (from disconnected to connected)
• Case B: the diameter of the network remains $\infty$
• Case C: the diameter of the network decreases
• Case D: the diameter of the network remains constant

After running 60 experiments for networks of sizes 5, 10, 20... 100 nodes, the results obtained are presented in Figure 6.

Figure 6. Algorithm 1 – Cases for the diameter changes

Considering only the cases where the diameter before increasing the transmission range is finite, we measure the efficiency of Algorithm 1 by
calculating the increase of total energy versus the decrease in diameter. Namely let,

\[ \Delta \text{Energy} = \text{Total\_energy\_after} - \text{Total\_energy\_before} \]

and

\[ \Delta \text{Diameter} = \text{Diameter\_before} - \text{Diameter\_after} \]

where:

- Total\_energy\_before represents the sum of the energy of all the nodes in the network before Algorithm 1 is applied,
- Total\_energy\_after represents the sum of the energy of all the nodes in the network after Algorithm 1 is applied.
- Diameter\_before represents the diameter of the network before Algorithm 1 is applied.
- Diameter\_after represents the diameter of the network after Algorithm 1 is applied.

To compare the total increase in energy when applying Algorithm 1, we normalize the increase of the total energy, namely we compute

\[ \Delta \text{energy} = \frac{\Delta \text{Energy}}{\text{Total\_energy\_before}} \]

The normalized energy associated with a specific network to which Algorithm 1 is applied is independent on the size of the distance scaling factor among the nodes.

Algorithm 1 is more efficient if for a given amount of increase in total energy, the diameter of the network decreases by a large amount. For each network, we compute the ratio between the normalized energy and
the decrease in diameter \( R = \frac{\text{energy}}{\text{Diameter}} \) and we average this ratio among all networks of the same size.

The results obtained are presented in Figure 7. We observe that, as the network size increases, the trend of \( R \) is to decrease. This means that for a decrease of one unit of the diameter, larger networks spend overall less energy than smaller networks.

![Algorithm 1](image)

Figure 7. Algorithm 1 – changes of R-average
For the purpose of comparing the efficiency of Algorithm 1 for networks of various sizes, we divide the increase in the total power evenly among the number of nodes, namely we compute $\Delta$energy$_n = \frac{\Delta\text{energy}}{\text{network size}}$

We use the energy$_n$ value of instead of energy to compute the ratio between the normalized energy and the decrease in diameter $R_n = \frac{\text{energy}_n}{\text{Diameter}}$ and we average this ratio among all networks of the same size.

The results obtained are presented in Figure 8. Since the values of $R_n$ are small, we multiply the results by 10. We observe that, as the network size increases, the value of $R_n$ continually decreases. This means that for a decrease of one unit of the diameter, larger networks spend per node less energy than smaller networks.

![Figure 8. Algorithm 1 – changes of R-average / network size](image)
4.2. Simulations for Algorithm 2

For Algorithm 2, with respect to the change in diameter of the network, we distinguish four cases:

- Case A: the diameter of the network changes from $\infty$ to finite (from disconnected to connected)
- Case B: the diameter of the network remains $\infty$
- Case C: the diameter of the network decreases
- Case D: the diameter of the network remains constant

After running 60 experiments for networks of sizes 5, 10, 20... 100 nodes, the results obtained are presented in Figure 9.
Considering only the cases where the diameter before doubling the transmission range is finite, we measure the efficiency of Algorithm 2 by calculating the increase of total energy versus the decrease in diameter. Namely let,

\[ \Delta \text{Energy} = \text{Total-energy}_{\text{after}} - \text{Total-energy}_{\text{before}} \]

and

\[ \Delta \text{Diameter} = \text{Diameter}_{\text{before}} - \text{Diameter}_{\text{after}} \]

where:

- \( \text{Total-energy}_{\text{before}} \) represents the sum of the energy of all the nodes in the network before Algorithm 2 is applied,
- \( \text{Total-energy}_{\text{after}} \) represents the sum of the energy of all the nodes in the network after Algorithm 2 is applied.
- \( \text{Diameter}_{\text{before}} \) represents the diameter of the network before Algorithm 2 is applied.
- \( \text{Diameter}_{\text{after}} \) represents the diameter of the network after Algorithm 2 is applied.

To compare the total increase in energy when applying Algorithm 2, we normalize the increase of the total energy, namely we compute

\[ \Delta \text{energy} = \frac{\Delta \text{Energy}}{\text{Total-energy}_{\text{before}}} \]

The normalized energy associated with a specific network to which Algorithm 2 is applied is independent on the size of the distance scaling factor among the nodes.
Algorithm 2 is more efficient if for a given amount of increase in total energy, the diameter of the network decreases by a large amount. For each network, we compute the ratio between the normalized energy and the decrease in diameter \( R = \frac{\text{energy}}{\text{Diameter}} \) and we average this ratio among all networks of the same size.

The results obtained are presented in Figure 10. We observe that, as the network size increases, the trend of \( R \) is to decrease. This means that for a decrease of one unit of the diameter, larger networks spend overall less energy than smaller networks.

---

Figure 10. Algorithm 2 – changes of R-average
For the purpose of comparing the efficiency of Algorithm 2 for networks of various sizes, we divide the increase in the total power evenly among the number of nodes, namely we compute

\[ \Delta \text{energy}_n = \frac{\Delta \text{energy}}{\text{network size}} \]

We use the \text{energy}_n value of instead of energy to compute the ratio between the normalized energy and the decrease in diameter \( R_n = \frac{\text{energy}_n}{\text{Diameter}} \)

and we average this ratio among all networks of the same size.

The results obtained are presented in Figure 11. Since the values of \( R_n \) are small, we multiply the results by 10. We observe that, as the network size increases, the value of \( R_n \) continually decreases. This means that for a decrease of one unit of the diameter, larger networks spend per node less energy than smaller networks.
Figure 11. Algorithm 2 – changes of R-average / network size

4.3. Simulations for Algorithm 3

For Algorithm 3, with respect to the change in diameter of the network, we distinguish four cases:

- Case A: the diameter of the network changes from finite to $\infty$ (from connected to disconnected)
- Case B: the diameter of the network remains $\infty$
- Case C: the diameter of the network is finite and increases
- Case D: the diameter of the network is finite and remains constant
After running 60 experiments for networks of sizes 5, 10, 20... 100 nodes, the results obtained are presented in Figure 12.

![Algorithm 3 - Diameter](image)

**Figure 12. Algorithm 3 - Cases for diameter changes**

Considering only the cases where the diameter before reducing the transmission range remains finite and constant, we measure the efficiency of Algorithm 3 by calculating the decrease of total energy when the diameter remains constant. Namely let,

\[ \Delta \text{Energy} = \text{Total_energy}_{\text{before}} - \text{Total_energy}_{\text{after}} \]

where:
• Total_energy_before represents the sum of the energy of all the nodes in the network before Algorithm 3 is applied,

• Total_energy_after represents the sum of the energy of all the nodes in the network after Algorithm 3 is applied.

To compare the total decrease in energy when applying Algorithm 3, we normalize the decrease of the total energy, namely we compute

\[ \Delta \text{energy} = \frac{\Delta \text{Energy}}{\text{Total\_energy\_before}} \]

The normalized energy associated with a specific network to which Algorithm 3 is applied is independent on the size of the distance scaling factor among the nodes.

Algorithm 3 is more efficient if for a given amount of decrease in total energy, the diameter of the network does not change (remains constant). We average the value of energy among all networks of the same size. The results obtained are presented in Figure 13. We observe that, as the network size increases, the value of energy average decreases. This means that larger networks save overall less energy than smaller networks.
Figure 13. Algorithm 3 – changes of energy average

For the purpose of comparing the efficiency of Algorithm 2 for networks of various sizes, we divide the decrease in the total power evenly among the number of nodes, namely we compute

\[ \Delta \text{energy}_n = \frac{\Delta \text{energy}}{\text{network size}} \]

The results obtained are presented in Figure 14. Since the values of \( \text{energy}_n \) are small, we multiply the results by 10. We observe that, as the network size increases, the value of \( \text{energy}_n \) continually decreases. This means that larger networks spend per node less energy than smaller networks.
Figure 14. Algorithm 3 – changes of energy average / network size
CHAPTER 5

CODE DESCRIPTION

5.1 Code description of Algorithm 1

Input to the main program: the number of nodes \( n \) and the maximum transmission range. Output of the main program: The total energy of the network before increasing the transmission range, the total energy of the network after increasing the transmission range, the diameter of the network before increasing the transmission range and the diameter of the network after increasing the transmission range.

Input for the main program is a set of variables whose values are read interactively.

The variables are the numNodes which is the number of nodes and the maxRange which is the maximum transmission range read from the user. The number of nodes and the maximum transmission range is accepted from the user and the node positions and the transmission range is generated randomly using the rand() function. The output of the rand() function is \((x, y, \text{range})\) where \(x\) and \(y\) are the coordinate positions and range is the transmission range of the nodes. The arrays \(x\) and \(y\)
store the x and y coordinates of the node and the array range stores the transmission range of all the nodes. The function \textit{distance} computes the distance between every pair of nodes. The input to this function is the set of coordinates and the output is the distance between any two pair of nodes.

The function \textit{one-hop neighbor} computes the one-hop neighbors of all the nodes. The input is the distance between the nodes and the transmission range of the nodes. The output is the one-hop neighbors of all the nodes and is stored in the array \textit{onehop}. The module checks to see if the distance between the nodes is less than or equal to the transmission range and if so, the node becomes the one-hop neighbor.

The function \textit{two-hop neighbor} computes the two-hop neighbors of all the nodes. The input is the one-hop neighbors of the nodes and the output is the two-hop neighbors of all the nodes. This function performs the union of one-hop neighbors and the one-hop neighbors of the one-hop neighbors. Two hop neighbors of all the nodes are stored in the array \textit{twohop}. The isNodeexists function is used to avoid any redundancy of nodes in computing the two-hop neighbors.

The module "max distance of two-hop neighbors" is used to find out the two-hop neighbor that is at the farthest distance and the transmission range of the node is increased by this distance so that all the two-hop neighbors can be reached. The new transmission range of all the nodes is stored in the array \textit{newtransrange}. 

46
The module "final neighbors" is used to compute the final neighbors of all the nodes after increasing the transmission range.

The "ratio" module is used to compute the ratio of all the nodes. Ratio of a node is the increase in energy to the increase in the number of nodes. It is observed that two special cases arise in computing the denominator. In the following cases the denominator becomes zero. To avoid such situations following measures are taken:

Case1: Where there are no one-hop neighbors. For a node that does not have one-hop neighbors we want to make sure that that particular node is not selected to increase its transmission range. So we divide the numerator by $1/\text{maxRange}$.

Case2: The number of one-hop neighbors before increasing the transmission range is same as the number of one-hop neighbors after increasing the transmission range. To avoid choosing such nodes we divide the numerator by 0.1.

The ratio of all the nodes is stored in the array ratio.

The module "minratio" gets the node with the least ratio. The input is the ratio of all the nodes and the output is the node with the minimum ratio. The node with the minimum ratio is selected to increase its transmission range.

The module "old diameter" computes the diameter of the network before increasing the transmission range. The input is the onehop array and the output is the diameter of the network which is stored in the
variable diameter. To compute the diameter a matrix is initialized in the following way:

\[ \text{hops}_{ij} = \begin{cases} 1 & \text{if } j \text{ is the one-hop neighbor of } i \\ \infty & \text{if } j \text{ is not the one-hop neighbor of } j \end{cases} \]

\[ \text{C}_{ij} = \begin{cases} 1 & \text{if } j \text{ is the one-hop neighbor of } i \\ \infty & \text{if } j \text{ is not the one-hop neighbor of } j \end{cases} \]

diam = \text{hops} \times \text{C}

\[ \text{diam}[i,j] = \min_{k=1,\ldots,n} \{ \text{hops}[i,k] + \text{C}[k,j] \} \]

The final matrix \( \text{diam}[i,j] \) will have the shortest path between any pair of nodes.

The longest of the shortest paths will be chosen as the diameter of the network and is stored in the variable \text{diameter}.

The total energy which is the sum of transmission ranges of all the nodes is computed and is stored in the variable \text{totalenergybefore}.

The total energy after increasing the transmission range is also computed and stored in the variable \text{totalenergyafter}.

The diameter of the network after increasing the transmission range is calculated in a similar way and the output is stored in the variable \text{newdiameter}.

For example:

Enter the number of nodes (max: 10000)

Note that nodes have maximum coordinates \((10,10)\)

60
Enter transmission range: (1-100)

15

The total energy before increasing the transmission range is 490

The total energy after increasing transmission range is 492

The diameter of the network before increasing the transmission range is 8

The new diameter of the network after increasing the transmission range of the selected node is 6

For the above example the number of nodes 60 and the transmission range 15 is the input to the main program. The output of the program is the total energy before increasing the transmission range which is 490, total energy of the network after increasing the transmission range which is 492, diameter of the network before increasing the transmission range which is 8 and the diameter of the network after increasing the transmission range which is 6.

5.2. Code description of Algorithm 2

The input to the main program is the number of nodes n and the maximum transmission range. Output of the main program: the total energy of the network before doubling the transmission range, the total energy of the network after doubling the transmission range, the diameter of the network before doubling the transmission range and the diameter of the network after doubling the transmission range.
Input for the main program is a set of variables whose values are read interactively. The variables are the numNodes which is the number of nodes and the maxRange which is the maximum transmission range read from the user. The number of nodes and the maximum transmission range is accepted from the user and the node positions and the transmission range is generated randomly using the rand() function. The arrays x and y store the x and y coordinates of the node and the array range stores the transmission range of all the nodes.

The function distance computes the distance between every pair of nodes. The input to this function is the set of coordinates and the output is the distance between any two pair of nodes.

The function one-hop neighbor computes the one-hop neighbors of all the nodes. The input is the distance between the nodes and the transmission range of the nodes. The output is the one-hop neighbors of all the nodes and is stored in the array onehop. The module checks to see if the distance between the nodes is less than or equal to the transmission range and if so, the node becomes the one-hop neighbor. The new transmission range is the computed by doubling the old transmission range.

The “ratio” module is used to compute the ratio of all the nodes. Ratio of a node is the increase in energy to the increase in the number of nodes. It is observed that two special cases arise in computing the
denominator. In the following cases the denominator becomes zero. To avoid such situations following measures are taken:

Case 1: Where there are no one-hop neighbors. For a node that does not have one-hop neighbors we want to make sure that that particular node is not selected to increase its transmission range. So we divide the numerator by 1/maxRange.

Case 2: The number of one-hop neighbors before increasing the transmission range is same as the number of one-hop neighbors after increasing the transmission range. To avoid choosing such nodes we divide the numerator by 0.1.

The ratio of all the nodes is stored in the array ratio.

The module "minratio" gets the node with the least ratio. The input is the ratio of all the nodes and the output is the node with the minimum ratio. The node with the minimum ratio is selected to increase its transmission range.

The module "old diameter" computes the diameter of the network before increasing the transmission range. The input is the one-hop array and the output is the diameter of the network which is stored in the variable diameter. To compute the diameter a matrix is initialized in the following way:

$$\text{hops}_{ij} = 1 \text{ if } j \text{ is the one-hop neighbor of } i$$

$$= \infty \text{ if } j \text{ is not the one-hop neighbor of } j$$

$$C_{ij} = 1 \text{ if } j \text{ is the one-hop neighbor of } i$$
= ∞ if j is not the one-hop neighbor of j

diam = hops × c

diam[i, j] = \min_{k=1,...,n} \{ hops[i, k] + c[k, j]\}

The final matrix diam[i, j] will have the shortest path between any pair of nodes. The longest of the shortest paths will be chosen as the diameter of the network and is stored in the variable diameter. The total energy which is the sum of transmission ranges of all the nodes is computed and is stored in the variable totalenergybefore. The total energy after increasing the transmission range is also computed and stored in the variable totalenergyafter. The diameter of the network after increasing the transmission range is calculated in a similar way and the output is stored in the variable newdiameter.

For example:

Enter the number of nodes (max: 10000)

Note that nodes have maximum coordinates (10,10)

80

Enter transmission range: (1-100)

7

The total energy before doubling transmission range is 333

The total energy after doubling transmission range is 334

The diameter of the network before doubling transmission range is 15

The new diameter of the network after doubling transmission range of the selected node is 9
The new diameter of the network after doubling transmission range of the selected node is 6.

For the above example the number of nodes 80 and the transmission range 7 is the input to the main program. The output of the program is the total energy before doubling the transmission range which is 333, total energy of the network after doubling the transmission range which is 334, diameter of the network before doubling the transmission range which is 15 and the diameter of the network after doubling the transmission range which is 9.

5.3. Code description of Algorithm 3

Input to the main program: the number of nodes n and the maximum transmission range. Output of the main program: the total energy of the network before decreasing the transmission range, the total energy of the network after decreasing the transmission range, the diameter of the network before decreasing the transmission range and the diameter of the network after decreasing the transmission range.

Input for the main program is a set of variables whose values are read interactively. The variables are the numNodes which is the number of nodes and the maxRange which is the maximum transmission range read from the user. The number of nodes and the maximum transmission range is accepted from the user and the node positions and the transmission range is generated randomly using the rand() function.
The arrays x and y store the x and y coordinates of the node and the array range stores the transmission range of all the nodes.

The function distance computes the distance between every pair of nodes. The input to this function is the set of coordinates and the output is the distance between any two pair of nodes.

The function one-hop neighbor computes the one-hop neighbors of all the nodes. The input is the distance between the nodes and the transmission range of the nodes. The output is the one-hop neighbors of all the nodes and is stored in the array onehop. The module checks to see if the distance between the nodes is less than or equal to the transmission range and if so, the node becomes the one-hop neighbor. The new transmission range is the computed by halving the old transmission range.

The “ratio” module is used to compute the ratio of all the nodes. Ratio of a node is the decrease in energy to the decrease in the number of nodes. It is observed that two special cases arise in computing the denominator. In the following cases the denominator becomes zero. To avoid such situations following measures are taken:

Case1: Where there are no one-hop neighbors. For a node that does not have one-hop neighbors we want to make sure that that particular node is not selected to decrease its transmission range. So we divide the numerator by maxRange.
Case 2: The number of one-hop neighbors before decreasing the transmission range is same as the number of one-hop neighbors after decreasing the transmission range. To avoid choosing such nodes we divide the numerator by 0.1.

The ratio of all the nodes is stored in the array ratio.

The module “maxratio” finds the node with the maximum ratio. The input is the ratio of all the nodes and the output is the node with the maximum ratio. The node with the maximum ratio is selected to decrease its transmission range.

The module “old diameter” computes the diameter of the network before decreasing the transmission range. The input is the onehop array and the output is the diameter of the network which is stored in the variable diameter. To compute the diameter a matrix is initialized in the following way:

\[
\text{hops}_{ij} = \begin{cases} 
1 & \text{if } j \text{ is the one-hop neighbor of } i \\
\infty & \text{if } j \text{ is not the one-hop neighbor of } j 
\end{cases}
\]

\[
\text{C}_{ij} = \begin{cases} 
1 & \text{if } j \text{ is the one-hop neighbor of } i \\
\infty & \text{if } j \text{ is not the one-hop neighbor of } j 
\end{cases}
\]

\[
\text{diam} = \text{hops} \times \text{C}
\]

\[
\text{diam}[i,j] = \min_{k=1,...,n} \{ \text{hops}[i,k] + \text{C}[k,j] \}
\]

The final matrix diam[i,j] will have the shortest path between any pair of nodes. The longest of the shortest paths will be chosen as the diameter of the network and is stored in the variable diameter. The total energy
which is the sum of transmission ranges of all the nodes is computed and is stored in the variable totalenergybefore. The total energy after decreasing the transmission range is also computed and stored in the variable totalenergyafter. The diameter of the network after decreasing the transmission range is calculated in a similar way and the output is stored in the variable newdiameter.

For example:

Enter the number of nodes (max: 10000)

Note that nodes have maximum coordinates (10,10)

5

Enter transmission range: (1-100)

88

The total energy before decreasing the transmission range is 266

The total energy after decreasing transmission range by half is 237

The diameter of the network before reducing the transmission range by half is 2

The new diameter of the network after decreasing transmission range of the selected node by half is 2

For the above example the number of nodes 5 and the transmission range 88 is the input to the main program. The output of the program is the total energy before decreasing the transmission range which is 266, total energy of the network after decreasing the transmission range which is 237, diameter of the network before decreasing the transmission range

56
range which is 2 and the diameter of the network after decreasing the transmission range which is 2.
CHAPTER 6

CONCLUSION AND FUTURE WORK

In this paper we propose three distributed algorithms for self-adjusting the transmission range of nodes in wireless network. The objective is to vary the transmission radii of selective sensor nodes to lower the energy spent in broadcasting or the diameter. The sensor nodes start arbitrarily with different transmission ranges. The nodes positions are fixed, and can adjust the transmission power. However, increasing the transmission power to reach more nodes may consume more energy. So, the goal is to reduce the transmission power (i.e., save energy) without reducing the reachability (in terms of the number of nodes).

We propose two algorithms that increase the transmission range of nodes. Increasing the transmission range of selective nodes will lower the diameter but increase the total energy. The proposed algorithm computes the ratio of the increase in transmission range to the increase in number of nodes of every sensor node. The node with the smallest ratio will be selected to increase its transmission range. It is observed that, as the network size increases, the value of energy average decreases. This
increase the diameter of the network. Ratio of the decrease in the transmission range to the decrease in the number of nodes is calculated for every node, and the node with the highest ratio is selected to decrease its transmission range. It is observed for algorithm 3 that as the network size increases, the value of energy average decreases. This means that larger networks save overall less energy than smaller networks.

Though in our experiments we have modified the transmission range of a single node in the network, we have described our algorithms in terms of selecting nodes from individual neighborhoods. A neighborhood is a node together with its neighbors. Also, our experiments were conducted in 2-dimensional Euclidean space. The three algorithms can be applied to graphs using 3-dimensional Euclidean metrics. In fact, our algorithms can be applied to general graphs in which the distance between two nodes is an arbitrary positive value. The impact of variable transmission range can be studied for static nodes. The three algorithms can be combined with other clustering algorithms.
BIBLIOGRAPHY


VITA

Graduate College
University of Nevada, Las Vegas

Prathima Sajja

Local Address:
1555 E Rochelle Ave, Apt#247
Las Vegas, NV 89119, USA.

Degree:
Bachelor of Technology in Computer Science and Information Technology Jawaharlal Nehru Technological University, India
June 2005

Thesis Title:
Impact of Variable Transmission Range in All-Wireless Networks

Thesis Examination Committee:
Chairperson, Dr. Ajoy Datta, Ph. D.
Committee Member, Dr. John T Minor, Ph. D.
Committee Member, Dr. Yoohwan Kim, Ph. D.
Graduate College Representative, Dr. Venkatesan Muthukumar, Ph. D.