EC-200 Data Structures

Project Report

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Wireless Network Communication

Design topology and implement routing algorithm of wireless Network

1. Introduction

The purpose of this project is to develop a wireless network system using an efficient topology control algorithm and routing algorithm. The aim of this work is to enhance the performance and reliability of wireless communication by reducing interference and optimizing network connectivity.

The **objectives** of the project include:

- Generating a Unit Disk Graph (UDG) to model the wireless network.
- Implementing a topology control algorithm to adjust transmission power levels.
- Developing a routing algorithm to establish efficient communication paths.

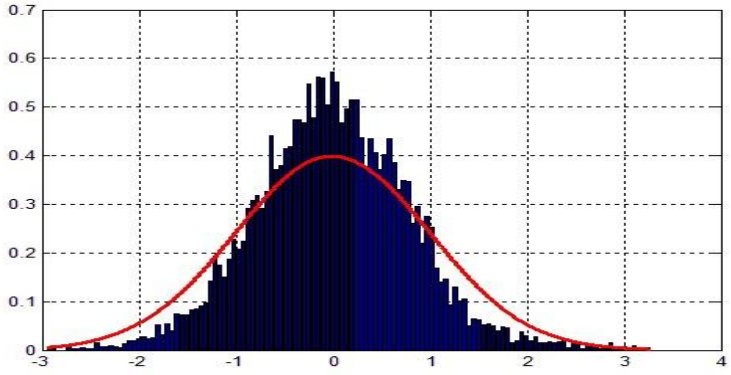
2. Methodology and Implementation

The project follows a three-module approach: UDG generation, topology control algorithm, and routing algorithm.

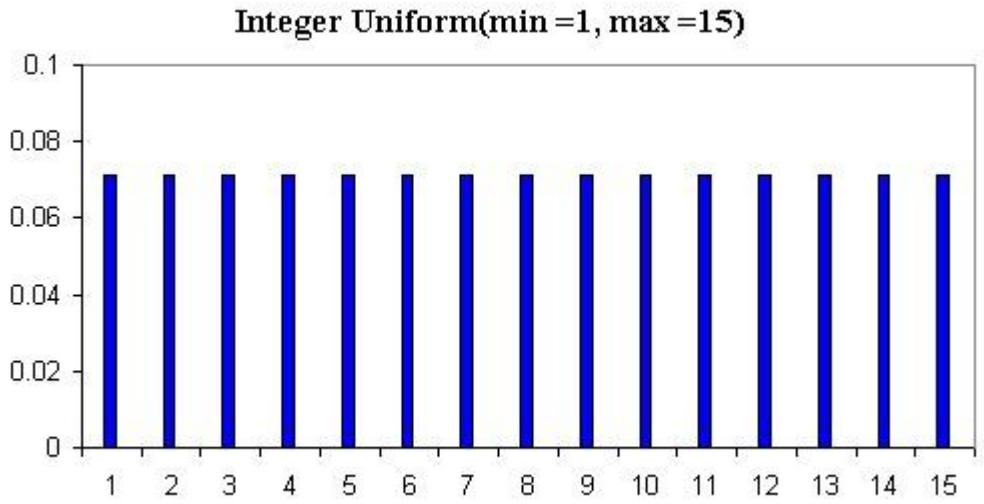
I. UDG Generation (Loader)

The UDG is a mathematical representation of the wireless network, where nodes are represented as disks (devices) with a fixed transmission range (i.e 1). Each pair of points at distance at most 1 unit are connected by an edge. This means that each point represents a wireless device with a transmission range of 1 unit. The UDG generation module uses node coordinates and transmission range as input to create an initial network topology.

The constructor would distribute n points uniformly at random on a 10 X 10 square unlike normal distribution which is a continuous probability distribution that is often used to model naturally occurring phenomena. It is characterized by its bell-shaped curve. In a normal distribution, the data is symmetrically distributed around the mean, and the majority of the data points are clustered around the mean with decreasing frequency as you move away from it.



Whereas, the uniform distribution is a continuous probability distribution where all outcomes in a given range are equally likely. In a uniform distribution, the probability of any particular value occurring within the range is constant.



By node, we mean a device in Network, which is of type **gnode.** gnode is a structure which has further two fields in it;

- **nodeinfo** type vertex.
- **adj_vertics** : An expandable array (**vector**) of type **pair<nodeinfo,double>**.
- **default_random_engine generator**

  Default_random_engine generator is an object of the default_random_engine class. It is a random number engine that generates random numbers using a specific algorithm. In this case, it will be used to generate random coordinates for the devices in the wireless network. A random number engine is an object that produces a sequence of numbers that are distributed randomly. Default_random_engine is a class from the C++ **<random>** library.

- **uniform_real_distribution<double> distribution(0.0, squareSize);**

  Distribution is an object of the uniform_real_distribution class. It defines a distribution of random numbers in the range (0.0, squareSize). The uniform_real_distribution generates random numbers uniformly distributed between the specified range. In this case, it will be used to generate random x and y coordinates for the devices in the wireless network. Uniform_real_distribution is a class from the C++ **<random>** library.

- These random number generation components are used within a loop to generate random coordinates for nodeinfo objects for each device in the wireless network. The **num1** and **num2** variables store the random numbers generated by **distribution(generator)**. These numbers are then manipulated to limit the precision to two decimal places using **floor, pow**, and some arithmetic operations.
- Finally, the **insertVertex** function is called to insert the device into the graph.

II. Topology Control Algorithm

The topology control algorithm specifically the **XTC (eXplicit Topology Control)** protocol adjusts the transmission power of each node to minimize interference and optimize network connectivity. It involves calculating the transmission range of each node based on its neighboring nodes and adjusting the transmission power accordingly.

➢ XTC(eXplicit Topology Control)

Introduction:

XTC (Cross-Layer Design for Topology Control) is a practical topology control algorithm designed for ad-hoc networks(ad-hoc networks: wireless LANs that do not use any hardware device like router for connectivity and transmission) It was proposed by **R. Wattenhofer and A. Zollinger** in their paper titled "XTC: A practical topology control algorithm for ad-hoc networks," presented at **WMAN 2004**.

The XTC algorithm aims to optimize the communication efficiency and energy consumption in wireless ad-hoc networks by controlling the network's topology. It operates at the cross-layer, considering both physical and network layer information to make topology control decisions.
(**cross-layer: sharing information among layers for efficient use of network resources and achieving high adaptivity.)

Key features of the XTC algorithm include:

i. Localized Operation:

XTC operates in a localized manner, meaning each node only needs to gather information from its neighbors to make decisions about its transmission power and connectivity.

ii. Power Control:

XTC utilizes power control techniques to adjust the transmission power of nodes, thereby influencing the network topology. By optimizing the transmission power, XTC aims to minimize interference and maximize the network's capacity.

iii. Connectivity Maintenance:

XTC ensures network connectivity by adjusting the transmission power and connectivity of nodes. It strives to maintain a connected network while minimizing the number of active nodes, thus reducing energy consumption.

iv. Scalability:

XTC is designed to be scalable, allowing it to be applied to large ad-hoc networks without significantly increasing computational complexity or communication overhead.

The XTC algorithm was developed to address the challenges of ad-hoc networks, such as limited resources, dynamic network conditions, and the need for efficient and reliable communication. It provides a practical approach to topology control, offering benefits in terms of network performance, energy efficiency, and scalability.

Implementation :

Implementing the XTC protocol in a wireless network involves several steps. Here's a brief overview of the procedure:

i. Network Initialization:

- Set up the wireless network with a collection of nodes capable of wireless communication.
- Assign unique identifiers (IDs) to each node in the network.
- Establish communication links between neighboring nodes based on their physical proximity.

ii. Gathering Neighbor Information:

- Each node collects information about its neighboring nodes. This information includes their IDs, signal strengths(i.e minimum relative distance from active node), and other relevant parameters.

iii. Transmission Power Adjustment:

- Each node adjusts its transmission power.(fixed to 1 in this case).

The goal is to optimize the power level to achieve desired connectivity and minimize interference.

iv. Topology Control Decision:

- Nodes make decisions about their connectivity and connectivity of their neighbors. - Nodes may decide to establish or terminate links with specific neighbors to optimize the overall network topology. This can involve activating or deactivating certain links based on their quality.

v. Network Adaptation:

- Nodes continue to monitor the network and adapt their transmission power and connectivity based on changes in the environment or network conditions.
- This adaptive process ensures that the network maintains connectivity, minimizes interference, and optimizes performance.

vi. Periodic Update and Maintenance:

- The XTC protocol typically includes periodic updates to maintain an up-to-date network topology.
- Nodes continue to exchange neighbor information and recalculate connectivity metrics at regular intervals.
- Link and topology adjustments are made as needed to adapt to changing conditions.

The **simulateProtocol()** function has the following functionality;

i. It initializes a **subsetLimit** variable, which represents the number of best neighbors to select for each node. This value can be adjusted based on the specific requirements and characteristics of the network.

ii. It iterates over each node in the graph. 'i' represents the **active node** for which the best neighbors need to be determined.

iii. Inside the loop, a list called **bestNeighbors** is created to store the potential best neighbors for the current node. The iterator 'itt' is initialized for future use.

iv. For each neighbor in the adjacency list of the active node, the neighbor and its corresponding distance are added to the bestNeighbors list.

v. The bestNeighbors list is then sorted based on the relative distance in ascending order. This sorting step is essential to identify the best neighbors with the minimum distances. **As declared by XTC that nodes with minimum relative distance from active node have the Highest signal strength.**

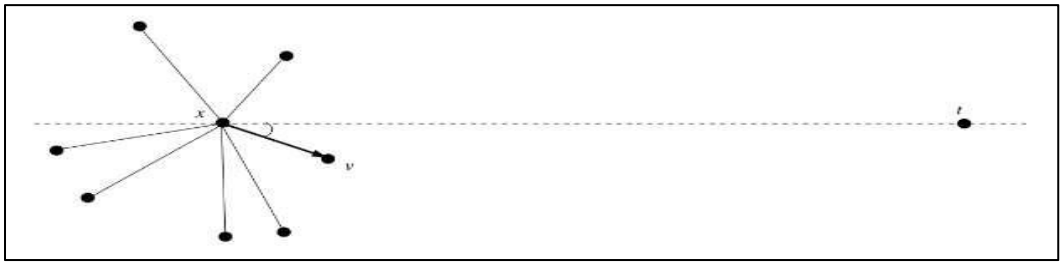
vi. The adjacency list of the active node is cleared firstly to remove the existing neighbors.

vii. Using an iterator 'it', the function adds the subset of best neighbors to the adjacency list. It iterates over the sorted bestNeighbors list, adding the neighbor and its distance to the adjacency list until either the subsetLimit is reached or all best neighbors are added.

viii. The function repeats this process for all nodes in the graph, updating their respective adjacency lists with the subset of best neighbors.

III. Routing Algorithm

The routing algorithm determines the most efficient path for data transmission between nodes in the wireless network. It takes into account factors such as node distance, transmission power, and network connectivity to establish optimal communication paths.



Compass Routing involves the following steps;

- **i.** Source and Destination vertices are searched in Network.
- **ii.** Source and Destination are searched in Connected Network.
- **iii.** If they both exist in Network as well as Connected Network, then compass routing is executed.
- **iv.** An expandable array "path" of type string is declared.
- **v.** Source is added to path.

Repeated steps:

- **vi.** Source scans its surroundings and looks for Destination node, if it is found, it is added to path and message is sent.
- **vii.** If Destination is not a neighbor of Source, Source scans its surroundings and looks for a neighbor that forms least angle with the direction from source to destination.
- **viii.** When such a node is found, we jump to that node (it is set as new source and it is added to path) and mark previous node visited so that it may not be accessed again.
- **ix.** When there are no nodes in range of Source which are not visited, a message is displayed that "NO PATH COULD BE FOUND".

Functions used:

i. calc_angle()

Three nodes are passed and angle between them is returned based on their x and y coordinates.

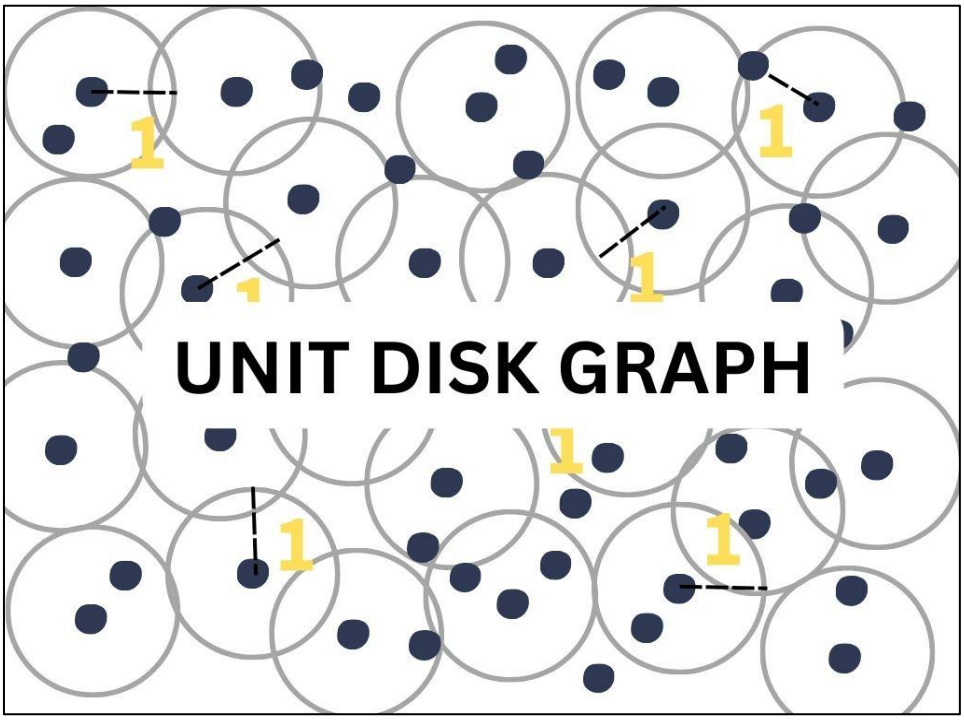
ii. rcompassRouting()

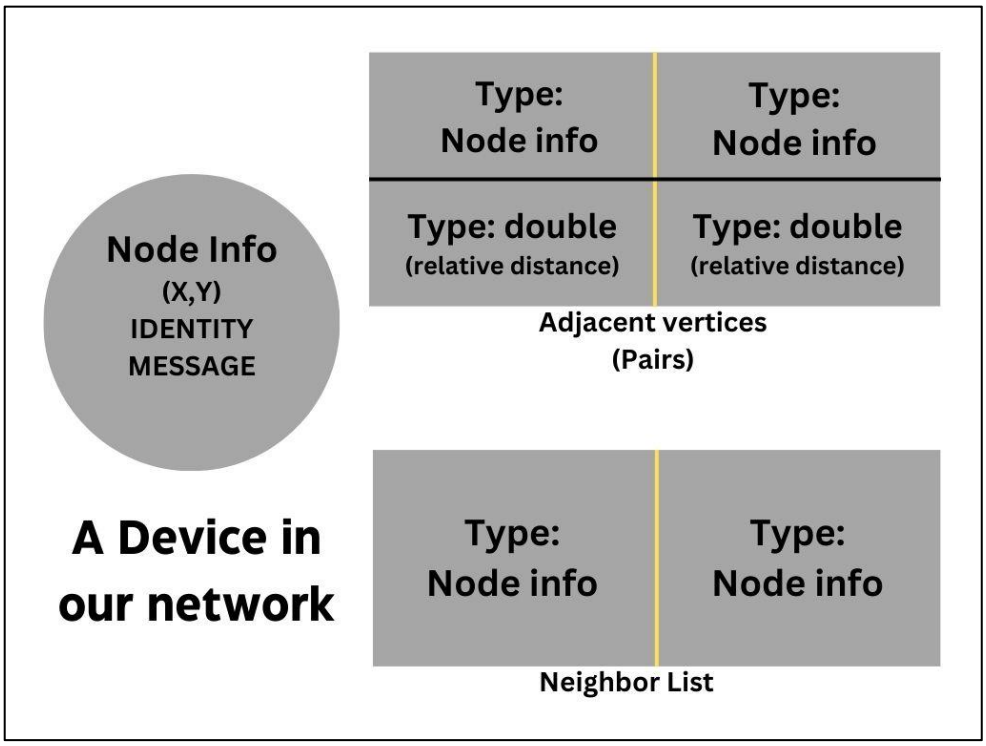
It is a recursive function which is only called when Source and Destination are not neighbors so a path could be found.

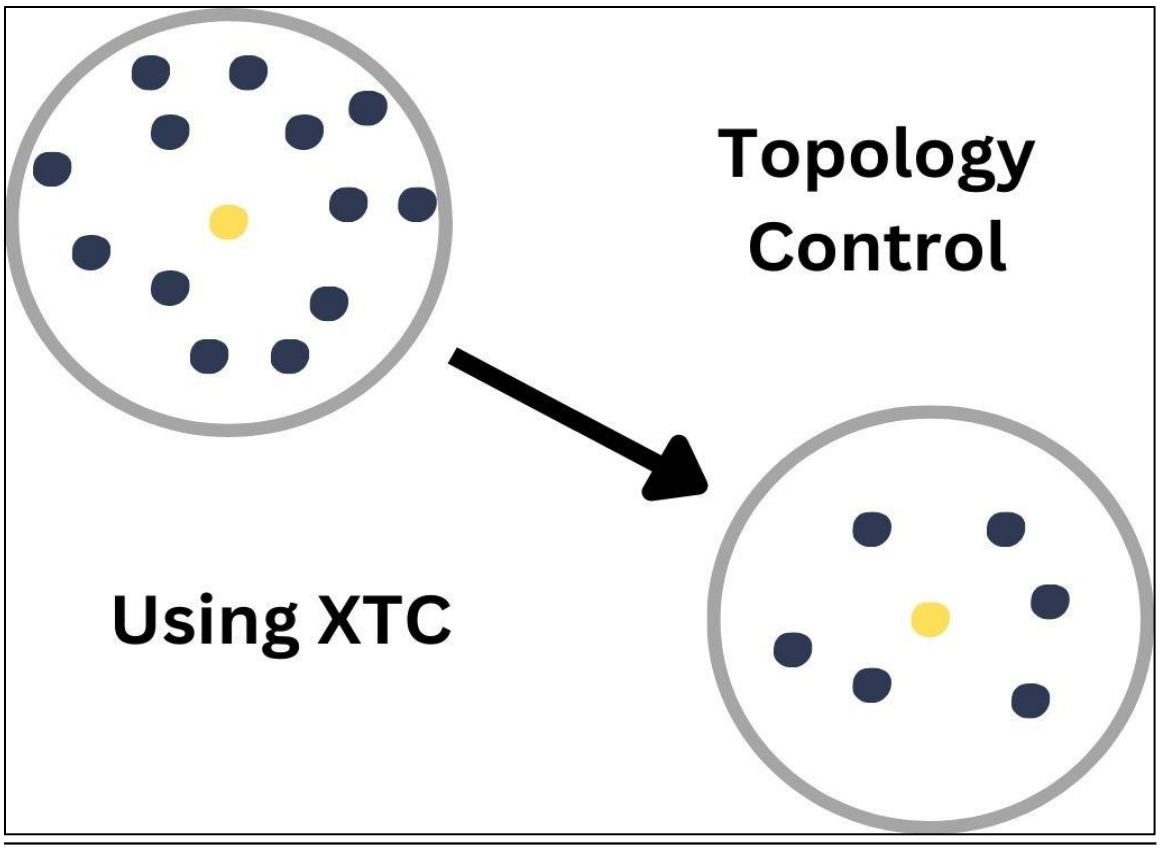
iii. neighbors()

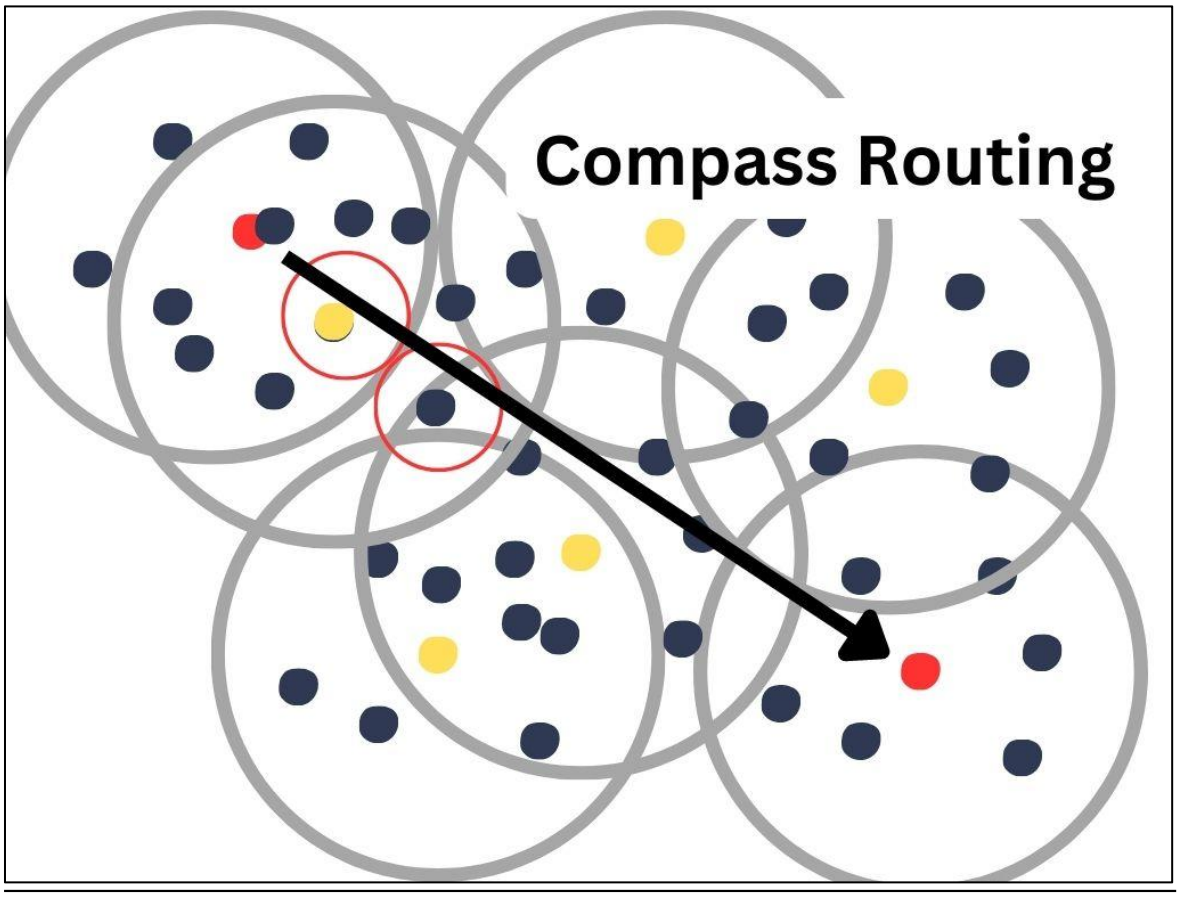
It is to check if the 2 passed nodes are neighbors or not.

System Level Diagram:

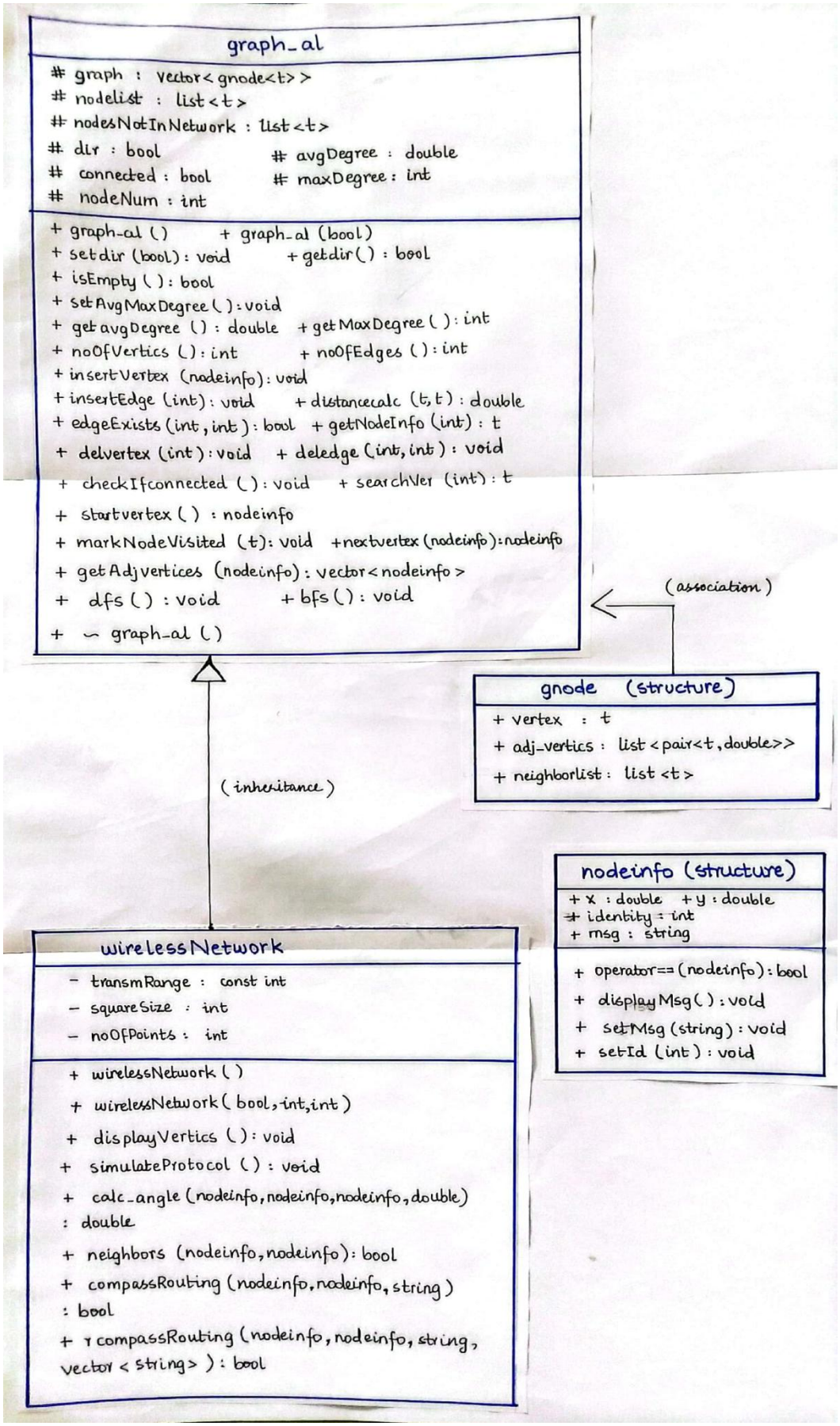




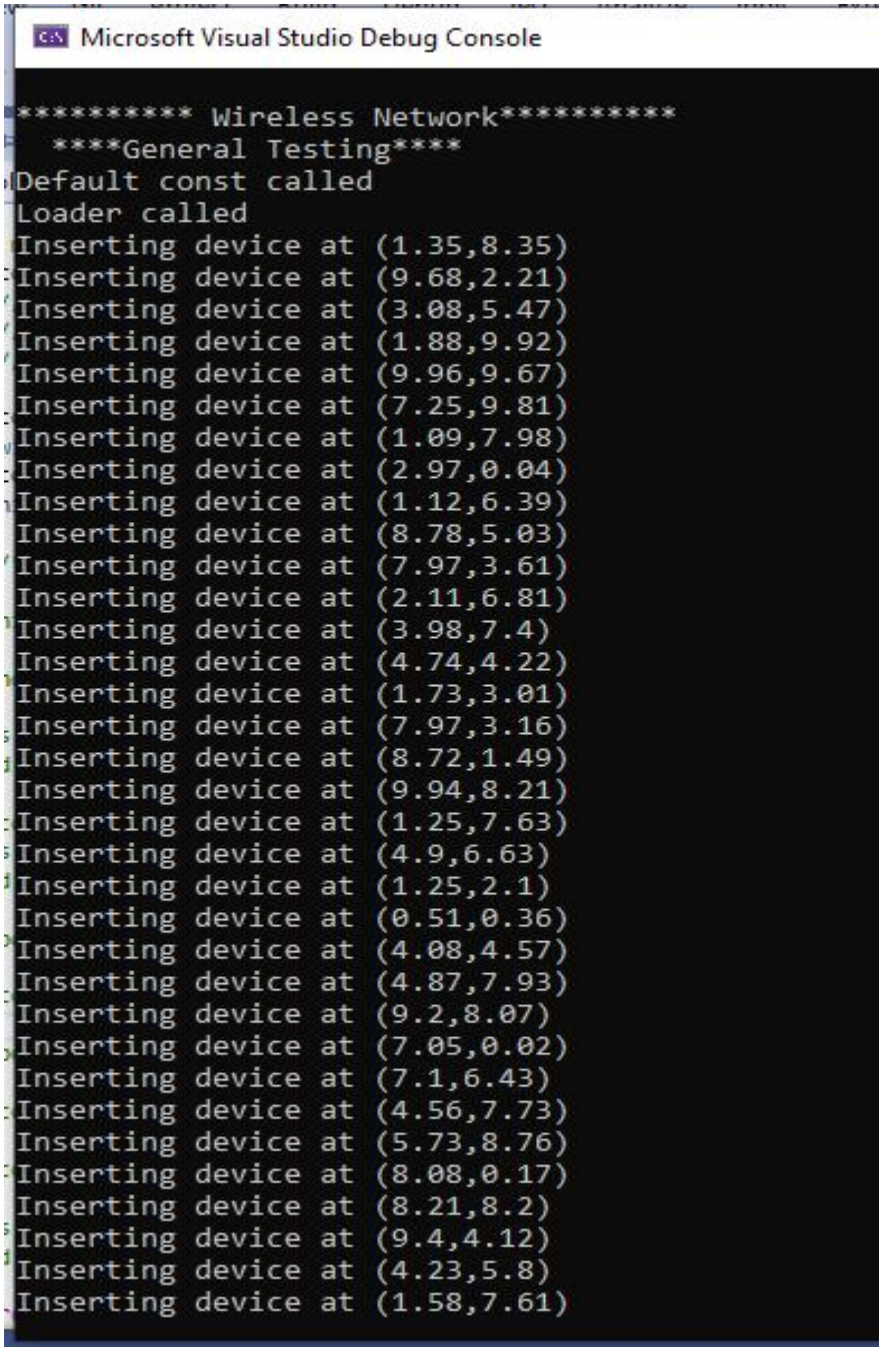

Topology
Control
Using XTC


Compass Routing

Class Diagram:

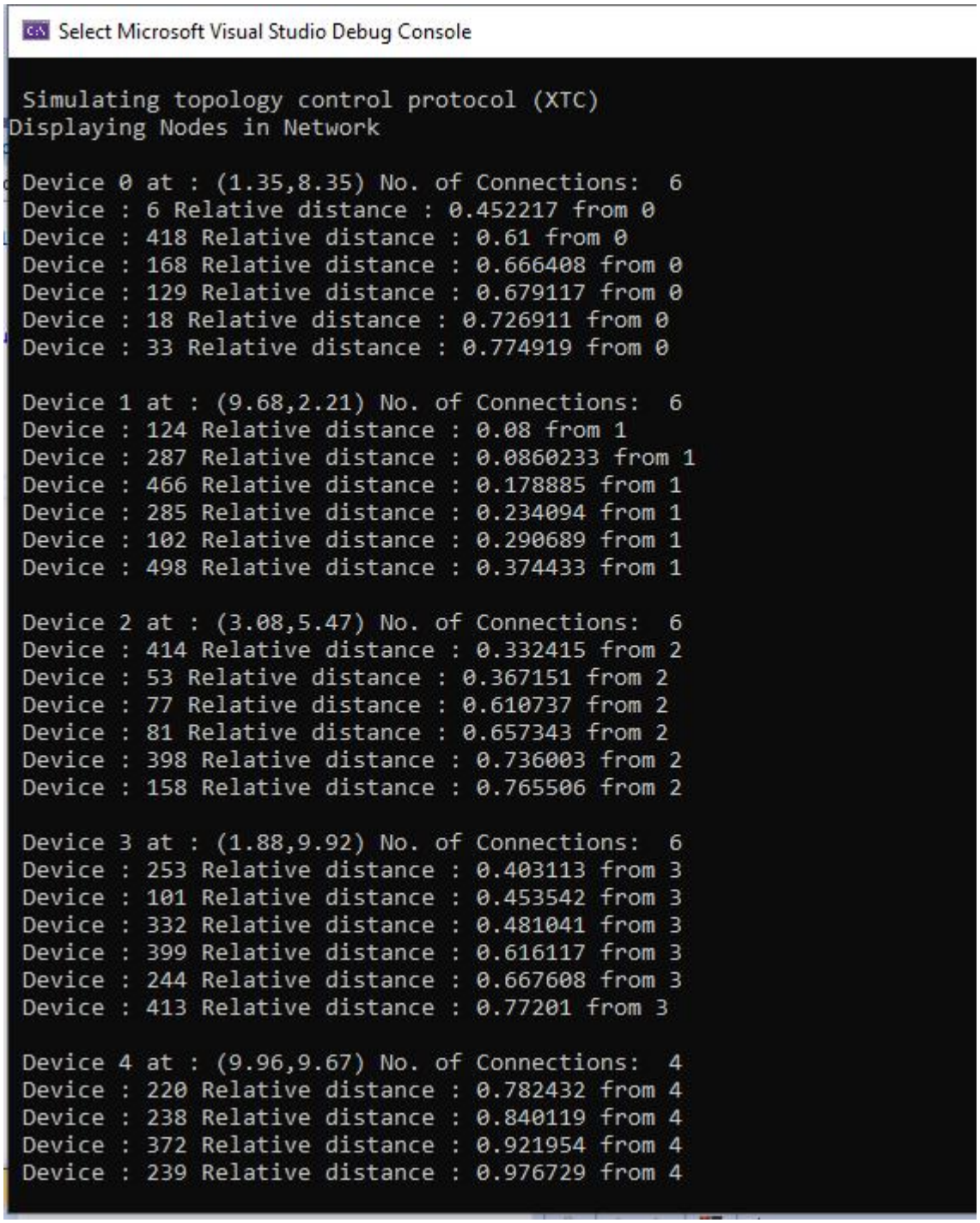


UDG Generation



```
Determining nodes within transmission range of every node


Wireless network before simulating Topology Control Protocol
Displaying Nodes in Network

 Device 0 at : (1.35,8.35) No. of Connections:  13
 Device : 6 Relative distance : 0.452217 from 0
 Device : 18 Relative distance : 0.726911 from 0
 Device : 33 Relative distance : 0.774919 from 0
 Device : 34 Relative distance : 0.984937 from 0
 Device : 40 Relative distance : 0.79925 from 0
 Device : 129 Relative distance : 0.679117 from 0
 Device : 168 Relative distance : 0.666408 from 0
 Device : 316 Relative distance : 0.990051 from 0
 Device : 320 Relative distance : 0.810494 from 0
 Device : 394 Relative distance : 0.912414 from 0
 Device : 409 Relative distance : 0.98813 from 0
 Device : 413 Relative distance : 0.886002 from 0
 Device : 418 Relative distance : 0.61 from 0

 Device 1 at : (9.68,2.21) No. of Connections:  16
 Device : 47 Relative distance : 0.671193 from 1
 Device : 80 Relative distance : 0.916624 from 1
 Device : 102 Relative distance : 0.290689 from 1
 Device : 106 Relative distance : 0.731642 from 1
 Device : 120 Relative distance : 0.471699 from 1
 Device : 124 Relative distance : 0.08 from 1
 Device : 171 Relative distance : 0.592368 from 1
 Device : 250 Relative distance : 0.536656 from 1
 Device : 274 Relative distance : 0.967471 from 1
 Device : 285 Relative distance : 0.234094 from 1
 Device : 287 Relative distance : 0.0860233 from 1
 Device : 307 Relative distance : 0.52811 from 1
 Device : 367 Relative distance : 0.601664 from 1
 Device : 466 Relative distance : 0.178885 from 1
 Device : 488 Relative distance : 0.579396 from 1
 Device : 498 Relative distance : 0.374433 from 1

 Device 2 at : (3.08,5.47) No. of Connections:  10
 Device : 43 Relative distance : 0.851587 from 2
 Device : 53 Relative distance : 0.367151 from 2
```

Topology Control Algorithm



Routing Algorithm

```
Simulating  compass routing :

Message fields before compass routing :
93 : Msg :
99 : Msg :

Device 93 is trying to send msg " Assalam-o-alikum!!! " to Device 99
Searching Device 93 in connected Network...
Device 93 found!!
Searching Device 99 in connected Network...
Device 99 found!!

Found path : 93 -> 63 -> 99 -> PATH_END

Message sent successfully : 1

Device 99 is trying to send msg " Walikum-asalam!!! " to Device 93
Searching Device 99 in connected Network...
Device 99 found!!
Searching Device 93 in connected Network...
Device 93 found!!

Found path : 99 -> 63 -> 93 -> PATH_END

Message sent successfully : 1
Message fields after compass routing :
93 : Msg : Walikum-asalam!!!
99 : Msg : Assalam-o-alikum!!!


Destructor called
```

3. Experimentation

To evaluate the performance of the wireless network system, several experiments were conducted. The experiments focused on measuring parameters such as network connectivity, transmission range, interference levels, and communication efficiency.

The results of the experiments showed that the implemented topology control algorithm effectively reduced interference and improved network connectivity. The routing algorithm successfully established efficient communication paths, resulting in faster data transmission and reduced packet loss(message).

- **Experiment#01:**

"Network#01"

```
********** Wireless Network**********

   /////Running Testing/////

  Experiment #01:

Generate 10 wireless networks modeled as UDGs, by distributing n = 500; 550; 600; 650; 700; 750;
 800; 850; 900; 950 points on a 10 x 10 grid.
For each network, report the average degree and the maximum degree.

Wireless networks #01 (n = 500)
Default const called
Parameterised Loader called
Inserting device 0 at (1.35, 8.35)
Inserting device 1 at (9.68, 2.21)
Inserting device 2 at (3.08, 5.47)
Inserting device 3 at (1.88, 9.92)
Inserting device 4 at (9.96, 9.67)
Inserting device 5 at (7.25, 9.81)
Inserting device 6 at (1.09, 7.98)
Inserting device 7 at (2.97, 0.04)
Inserting device 8 at (1.12, 6.39)
Inserting device 9 at (8.78, 5.03)
Inserting device 10 at (7.97, 3.61)
Inserting device 11 at (2.11, 6.81)
Inserting device 12 at (3.98, 7.4)
Inserting device 13 at (4.74, 4.22)
Inserting device 14 at (1.73, 3.01)
Inserting device 15 at (7.97, 3.16)
```

```
Determining Avg and Max Degree of Network.(before Topology Control Protocol)

Avg Degree:   14.044
Max Degree:  27
```

```
Determining Avg and Max Degree of Network.(afterTopology Control Protocol)

Avg Degree:   5.982
Max Degree:  6
```

“Network#02”

```
********** Wireless Network**********

   /////Running Testing/////

  Experiment #01:

Generate 10 wireless networks modeled as UDGs, by distributing n = 500; 550; 600; 650; 700;
 750; 800; 850; 900; 950 points on a 10 x 10 grid.
For each network, report the average degree and the maximum degree.

Wireless networks #02 (n = 550)
Default const called
Parameterised Loader called
Inserting device 0 at (1.35, 8.35)
Inserting device 1 at (9.68, 2.21)
Inserting device 2 at (3.08, 5.47)
Inserting device 3 at (1.88, 9.92)
Inserting device 4 at (9.96, 9.67)
Inserting device 5 at (7.25, 9.81)
Inserting device 6 at (1.09, 7.98)
Inserting device 7 at (2.97, 0.04)
Inserting device 8 at (1.12, 6.39)
Inserting device 9 at (8.78, 5.03)
Inserting device 10 at (7.97, 3.61)
Inserting device 11 at (2.11, 6.81)
Inserting device 12 at (3.98, 7.4)
Inserting device 13 at (4.74, 4.22)
Inserting device 14 at (1.73, 3.01)
Inserting device 15 at (7.97, 3.16)
```

```
Determining Avg and Max Degree of Network.(before Topology Control Protocol)

Avg Degree:   15.4618
Max Degree:  28
```

```
Determining Avg and Max Degree of Network.(afterTopology Control Protocol)

Avg Degree:   5.99273
Max Degree:  6
```

“Network#03”

```
********** Wireless Network**********

   /////Running Testing/////

  Experiment #01:

Generate 10 wireless networks modeled as UDGs, by distributing n = 500; 550; 600; 650; 700;
 750; 800; 850; 900; 950 points on a 10 x 10 grid.
For each network, report the average degree and the maximum degree.

Wireless networks #03 (n = 600)
 Default const of graph class called
 Parameterised Loader called

 Connecting Devices in Network...

 Network formed successfully.
```

```
Determining Avg and Max Degree of Network.(before Topology Control Protocol)

Avg Degree:   16.84
Max Degree:  29
```

```
Determining Avg and Max Degree of Network.(afterTopology Control Protocol)

Avg Degree:   5.99333
Max Degree:  6
```

“Network#04”

```
********** Wireless Network**********

   /////Running Testing/////

  Experiment #01:

Generate 10 wireless networks modeled as UDGs, by distributing n = 500; 550; 600; 650; 700;
 750; 800; 850; 900; 950 points on a 10 x 10 grid.
For each network, report the average degree and the maximum degree.

Wireless networks #03 (n = 650)
 Default const of graph class called
 Parameterised Loader called

 Connecting Devices in Network...

 Network formed successfully.
```

```
Determining Avg and Max Degree of Network.(before Topology Control Protocol)

Avg Degree:   18.4092
Max Degree:  31
```

```
Determining Avg and Max Degree of Network.(afterTopology Control Protocol)

Avg Degree:   5.99385
Max Degree:  6
```

“Network#05”

```
********** Wireless Network**********

   /////Running Testing/////

  Experiment #01:

Generate 10 wireless networks modeled as UDGs, by distributing n = 500; 550; 600; 650; 700; 750;
 800; 850; 900; 950 points on a 10 x 10 grid.
For each network, report the average degree and the maximum degree.

Wireless networks #05 (n = 700)
 Default const of graph class called
 Parameterised Loader called

 Connecting Devices in Network...

 Network formed successfully.
```

```
Determining Avg and Max Degree of Network.(before Topology Control Protocol)

Avg Degree:   19.9086
Max Degree:  38
```

```
Determining Avg and Max Degree of Network.(afterTopology Control Protocol)

Avg Degree:   5.99714
Max Degree:  6
```

“Network#06”

```
********** Wireless Network**********

   /////Running Testing/////

  Experiment #01:

Generate 10 wireless networks modeled as UDGs, by distributing n = 500; 550; 600; 650; 700; 750;
 800; 850; 900; 950 points on a 10 x 10 grid.
For each network, report the average degree and the maximum degree.

Wireless networks #06 (n = 750)
 Default const of graph class called
 Parameterised Loader called

 Connecting Devices in Network...

 Network formed successfully.
```

```
Determining Avg and Max Degree of Network.(before Topology Control Protocol)

Avg Degree:   21.2507
Max Degree:  39
```

```
Determining Avg and Max Degree of Network.(afterTopology Control Protocol)

Avg Degree:   5.99867
Max Degree:  6
```

“Network#07”

```
********** Wireless Network**********

   /////Running Testing/////

  Experiment #01:

Generate 10 wireless networks modeled as UDGs, by distributing n = 500; 550; 600; 650; 700; 750;
 800; 850; 900; 950 points on a 10 x 10 grid.
For each network, report the average degree and the maximum degree.

Wireless networks #07 (n = 800)
 Default const of graph class called
 Parameterised Loader called

 Connecting Devices in Network...

 Network formed successfully.
```

```
Determining Avg and Max Degree of Network.(before Topology Control Protocol)

Avg Degree:    22.685
Max Degree:   39
```

```
Determining Avg and Max Degree of Network.(afterTopology Control Protocol)

Avg Degree:    5.9975
Max Degree:   6
```

“Network#08”

```
********** Wireless Network**********

   /////Running Testing/////

  Experiment #01:

Generate 10 wireless networks modeled as UDGs, by distributing n = 500; 550; 600; 650; 700; 750;
 800; 850; 900; 950 points on a 10 x 10 grid.
For each network, report the average degree and the maximum degree.

Wireless networks #08 (n = 850)
 Default const of graph class called
 Parameterised Loader called

 Connecting Devices in Network...

 Network formed successfully.
```

```
Determining Avg and Max Degree of Network.(before Topology Control Protocol)

Avg Degree:    24.0706
Max Degree:   42
```

```
Determining Avg and Max Degree of Network.(afterTopology Control Protocol)

Avg Degree:    5.99765
Max Degree:   6
```

“Network#09”

```
********** Wireless Network**********

   /////Running Testing/////

  Experiment #01:

Generate 10 wireless networks modeled as UDGs, by distributing n = 500; 550; 600; 650; 700; 750;
 800; 850; 900; 950 points on a 10 x 10 grid.
For each network, report the average degree and the maximum degree.

Wireless networks #09 (n = 900)
 Default const of graph class called
 Parameterised Loader called

 Connecting Devices in Network...

 Network formed successfully.
```

```
Determining Avg and Max Degree of Network.(before Topology Control Protocol)

Avg Degree:   25.6311
Max Degree:  43
```

```
Determining Avg and Max Degree of Network.(afterTopology Control Protocol)

Avg Degree:   5.99889
Max Degree:  6
```

“Network#10”

```
********** Wireless Network**********

   /////Running Testing/////

  Experiment #01:

Generate 10 wireless networks modeled as UDGs, by distributing n = 500; 550; 600; 650; 700; 750;
 800; 850; 900; 950 points on a 10 x 10 grid.
For each network, report the average degree and the maximum degree.

Wireless networks #10 (n = 950)
 Default const of graph class called
 Parameterised Loader called

 Connecting Devices in Network...

 Network formed successfully.
```

```
Determining Avg and Max Degree of Network.(before Topology Control Protocol)

Avg Degree:   26.9579
Max Degree:  43
```

```
Determining Avg and Max Degree of Network.(afterTopology Control Protocol)

Avg Degree:   6
Max Degree:  6
```

write 2-3 sentences commenting on whether performing topology control has resulted in a much sparser graph or not.

Performing topology control has definitely results in a sparser graph. By optimizing the network topology and removing unnecessary links, the overall connectivity of the network is reduced. This sparser graph can lead to improved network efficiency, reduced interference, and better resource allocation, ultimately enhancing the performance of the network.

- **Experiment#02:**

(Compass Routing without Topology Control Protocol)

Transferring Message#01
Source: 93 Destination: 99
Message: Assalam-o-alikum!!!

```
********** Wireless Network**********

   /////Running Testing/////

  Experiment #02:

 Generate a wireless network G with 1000 points distributed on a 10x10 square. Run compass routing on G, with
 source s and destination t.Repeat it 10 times.

Wireless networks G (n = 1000)
 Default const of graph class called
 Parameterised Loader called

 Connecting Devices in Network...

 Network formed successfully.

Transferring Message#01

Source: 93  Destination: 99

Simulating  compass routing :

 Message fields before compass routing :
 93 : Msg :
 99 : Msg :

 Device 93 is trying to send msg " Assalam-o-alikum!!! " to Device 99
 Searching Device 93 in connected Network...
 Device 93 found!!
 Searching Device 99 in connected Network...
 Device 99 found!!

 Found path : 93 -> 63 -> 99 -> PATH_END

 Message sent successfully : 1
```

Transferring Message#02
Source: 99 Destination: 93
Message: Walikum-asalam!!!

```
Transferring Message#02

Source: 99  Destination: 93

 Device 99 is trying to send msg " Walikum-asalam!!! " to Device 93
 Searching Device 99 in connected Network...
 Device 99 found!!
 Searching Device 93 in connected Network...
 Device 93 found!!

 Found path : 99 -> 63 -> 93 -> PATH_END

 Message sent successfully : 1
 Message fields after compass routing :
 93 : Msg : Walikum-asalam!!!
 99 : Msg : Assalam-o-alikum!!!


 Destructor called
```

Transferring Message#03
Source: 250 Destination: 312
Message: Hi!

```
********** Wireless Network**********

   /////Running Testing/////

  Experiment #02:

 Generate a wireless network G with 1000 points distributed on a 10x10 square. Run compass routing
 on G, with source s and destination t.Repeat it 10 times.

Wireless networks G (n = 1000)
 Default const of graph class called
 Parameterised Loader called

 Connecting Devices in Network...

 Network formed successfully.

Transferring Message#03

Source: 250  Destination : 312

Simulating  compass routing :

 Message fields before compass routing :
 250 : Msg :
 312 : Msg :

 Device 250 is trying to send msg "  Hi! " to Device 312
 Searching Device 250 in connected Network...
 Device 250 found!!
 Searching Device 312 in connected Network...
 Device 312 found!!

 Found path : 250 -> 970 -> 134 -> 193 -> 154 -> 583 -> 298 -> 806 -> 312 -> PATH_END

 Message sent successfully : 1
```

Transferring Message#04
Source: 312 Destination:250
Message: Hello!

```
Transferring Message#04

Source: 312  Destination: 250

 Device 312 is trying to send msg "  Hello! " to Device 250
 Searching Device 312 in connected Network...
 Device 312 found!!
 Searching Device 250 in connected Network...
 Device 250 found!!

 Found path : 312 -> 806 -> 400 -> 633 -> 688 -> 970 -> 250 -> PATH_END

 Message sent successfully : 1
 Message fields after compass routing :
 250 : Msg :  Hello!
 312 : Msg :  Hi!


 Destructor called
```

Transferring Message#05
Source: 439 Destination: 516
Message: Message#05 !

```
********** Wireless Network**********

   /////Running Testing/////

  Experiment #02:

 Generate a wireless network G with 1000 points distributed on a 10x10 square. Run compass routing
 on G, with source s and destination t.Repeat it 10 times.

Wireless networks G (n = 1000)
 Default const of graph class called
 Parameterised Loader called

 Connecting Devices in Network...

 Network formed successfully.

Transferring Message#05

Source: 439  Destination : 516

Simulating  compass routing :

 Message fields before compass routing :
 439 : Msg :
 516 : Msg :

 Device 439 is trying to send msg "  Message#05 ! " to Device 516
 Searching Device 439 in connected Network...
 Device 439 found!!
 Searching Device 516 in connected Network...
 Device 516 found!!

 Found path : 439 -> 13 -> 862 -> 742 -> 881 -> 128 -> 975 -> 33 -> 0 -> 732 -> 955 -> 516 -> PATH
_END

 Message sent successfully : 1
```

Transferring Message#06
Source: 516 Destination:439
Message: Message#05 received!

```
Transferring Message#06

Source: 516  Destination: 439

 Device 516 is trying to send msg "   Message#05 received! " to Device 439
 Searching Device 516 in connected Network...
 Device 516 found!!
 Searching Device 439 in connected Network...
 Device 439 found!!

 Found path : 516 -> 955 -> 568 -> 418 -> 148 -> 918 -> 216 -> 196 -> 874 -> 573 -> 157 -> 439 ->
PATH_END

 Message sent successfully : 1
 Message fields after compass routing :
 439 : Msg :   Message#05 received!
 516 : Msg :  Message#05 !


 Destructor called
```

Transferring Message#07
Source: 777 Destination: 834
Message: Message#07 !

```
********** Wireless Network**********

   /////Running Testing/////

  Experiment #02:

 Generate a wireless network G with 1000 points distributed on a 10x10 square. Run compass routing
 on G, with source s and destination t.Repeat it 10 times.

Wireless networks G (n = 1000)
 Default const of graph class called
 Parameterised Loader called

 Connecting Devices in Network...

 Network formed successfully.

Transferring Message#07

Source: 777  Destination : 834

Simulating  compass routing :

 Message fields before compass routing :
 777 : Msg :
 834 : Msg :

 Device 777 is trying to send msg "  Message#07 ! " to Device 834
 Searching Device 777 in connected Network...
 Device 777 found!!
 Searching Device 834 in connected Network...
 Device 834 found!!

 Found path : 777 -> 523 -> 874 -> 53 -> 378 -> 596 -> 791 -> 656 -> 925 -> 834 -> PATH_END

 Message sent successfully : 1
```

Transferring Message#08
Source: 834 Destination: 777
Message: Message#07 received!

```
Transferring Message#08

Source: 834s  Destination: 777

 Device 834 is trying to send msg "  Message#07 received! " to Device 777
 Searching Device 834 in connected Network...
 Device 834 found!!
 Searching Device 777 in connected Network...
 Device 777 found!!

 Found path : 834 -> 925 -> 656 -> 791 -> 596 -> 378 -> 53 -> 874 -> 880 -> 777 -> PATH_END

 Message sent successfully : 1
 Message fields after compass routing :
 777 : Msg :  Message#07 received!
 834 : Msg :  Message#07 !


 Destructor called
```

Transferring Message#09
Source: 984 Destination: 999
Message: Message#09!

```
********** Wireless Network**********

   /////Running Testing/////

  Experiment #09:

 Generate a wireless network G with 1000 points distributed on a 10x10 square. Run compass routing on
 G, with source s and destination t.Repeat it 10 times.

Wireless networks G (n = 1000)
 Default const of graph class called
 Parameterised Loader called

 Connecting Devices in Network...

 Network formed successfully.

Transferring Message#07

Source: 984  Destination : 999

Simulating  compass routing :

 Message fields before compass routing :
 984 : Msg :
 999 : Msg :

 Device 984 is trying to send msg "  Message#09! " to Device 999
 Searching Device 984 in connected Network...
 Device 984 found!!
 Searching Device 999 in connected Network...
 Device 999 found!!

 Found path : 984 -> 710 -> 573 -> 720 -> 86 -> 537 -> 577 -> 865 -> 567 -> 997 -> 628 -> 999 -> PATH
_END

 Message sent successfully : 1
```

Transferring Message#10
Source: 999 Destination: 984
Message: Message#09received!

```
Transferring Message#10

Source: 999  Destination: 984

 Device 999 is trying to send msg "  Message#09 received! " to Device 984
 Searching Device 999 in connected Network...
 Device 999 found!!
 Searching Device 984 in connected Network...
 Device 984 found!!

 Found path : 999 -> 214 -> 687 -> 108 -> 968 -> 594 -> 364 -> 720 -> 573 -> 813 -> 984 -> PATH_END

 Message sent successfully : 1
 Message fields after compass routing :
 984 : Msg :  Message#09 received!
 999 : Msg :  Message#09!


 Destructor called
```

Conclusion:

Compass routing was efficiently able to find the source and destination in all of the above examples. However, a bool variable -1 is printed, in case, if a source/destination is not found.

```
********** Wireless Network**********

   /////Running Testing/////

 Device not found Experiment :

Wireless networks G (n = 1000)
 Default const of graph class called
 Parameterised Loader called

 Connecting Devices in Network...

 Network formed successfully.

Transferring a Message

Source: 984  Destination : 1001

Simulating  compass routing :

 Message fields before compass routing :
 984 : Msg :
 -1 : Msg :

 Device 984 is trying to send msg "  Hello Friend!  " to Device -1
 Searching Device 984 in connected Network...
 Device 984 found!!
 Searching Device -1 in connected Network...
 Device -1 is not in Network; Compass Routing failed ...
 Message sent successfully : 0


 Destructor called
```

- **Experiment#03:**

(Compass Routing with Topology Control Protocol)

Transferring Message#01
Source: 93 Destination: 99
Message: Assalam-o-alikum!!!

```
********** Wireless Network**********

   /////Running Testing/////

  Experiment#03 :

 Generate a wireless network G with 1000 points distributed on a 10x10 square. Run topology control
 on G, with source s and destination t.Repeat it 10 times.

Wireless networks G (n = 1000)
 Default const of graph class called
 Parameterised Loader called

 Connecting Devices in Network...

 Network formed successfully.

Run topology control on G

 Simulating topology control protocol (XTC)

Transferring Message#01

Source: 93  Destination : 99

Simulating  compass routing :

 Message fields before compass routing :
 93 : Msg :
 99 : Msg :

 Device 93 is trying to send msg "  Assalam - o - alikum!!! " to Device 99
 Searching Device 93 in connected Network...
 Device 93 found!!
 Searching Device 99 in connected Network...
 Device 99 found!!

 Found path : 93 -> 63 -> 820 -> 625 -> 99 -> PATH_END

 Message sent successfully : 1
```

Transferring Message#02
Source: 99 Destination: 93
Message: Walikum-asalam!!!

```
Transferring Message#2

Source: 99  Destination: 93

 Device 99 is trying to send msg "  Walikum - asalam!!! " to Device 93
 Searching Device 99 in connected Network...
 Device 99 found!!
 Searching Device 93 in connected Network...
 Device 93 found!!

 Found path : 99 -> 820 -> 63 -> 93 -> PATH_END

 Message sent successfully : 1
 Message fields after compass routing :
 93 : Msg :  Walikum - asalam!!!
 99 : Msg :  Assalam - o - alikum!!!
```

Transferring Message#03
Source: 250 Destination: 310
Message: Hi!

```
 Simulating topology control protocol (XTC)

Transferring Message#03

Source: 250  Destination : 310

Simulating  compass routing :

 Message fields before compass routing :
 250 : Msg :
 310 : Msg :

 Device 250 is trying to send msg "  Hi!  " to Device 310
 Searching Device 250 in connected Network...
 Device 250 found!!
 Searching Device 310 in connected Network...
 Device 310 found!!

 Found path : 250 -> 507 -> 902 -> 690 -> 667 -> 50 -> 342 -> 545 -> 96 -> 9 -> 649 -> 749 -> 745 -> 800
-> 829 -> 998 -> 310 -> PATH_END

 Message sent successfully : 1
```

Transferring Message#04
Source: 310 Destination:250
Message: Hello!

```
Transferring Message#04

Source: 310  Destination: 250

 Device 310 is trying to send msg "  Hello!  " to Device 250
 Searching Device 310 in connected Network...
 Device 310 found!!
 Searching Device 250 in connected Network...
 Device 250 found!!

 Found path : 310 -> 275 -> 928 -> 696 -> 631 -> 802 -> 305 -> 109 -> 517 -> 84 -> 468 -> 668 -> 10 -> 672 -> 165
 -> 251 -> 78 -> 194 -> 954 -> 868 -> 965 -> 667 -> 550 -> 671 -> 31 -> 50 -> 670 -> 356 -> 170 -> 391 -> 348 ->
666 -> 358 -> 494 -> 709 -> 866 -> 501 -> 367 -> 250 -> PATH_END

 Message sent successfully : 1
 Message fields after compass routing :
 250 : Msg :  Hello!
 310 : Msg :  Hi!
```

Transferring Message#05
Source: 439 Destination: 516
Message: Message#05 !

```
 Simulating topology control protocol (XTC)

Transferring Message#05

Source: 439  Destination : 516

Simulating  compass routing :

 Message fields before compass routing :
 439 : Msg :
 516 : Msg :

 Device 439 is trying to send msg " Message#05 ! " to Device 516
 Searching Device 439 in connected Network...
 Device 439 found!!
 Searching Device 516 in connected Network...
 Device 516 found!!

 Found path : 439 -> 396 -> 230 -> 13 -> 157 -> 297 -> 852 -> 573 -> 825 -> 906 -> 638 -> 523 -> 775 -> 334 -> 796
 -> 72 -> 492 -> 369 -> 67 -> 229 -> 34 -> 418 -> 662 -> 568 -> 967 -> 316 -> 244 -> 595 -> 516 -> PATH_END

 Message sent successfully : 1
```

Transferring Message#06
Source: 516 Destination:439
Message: Message#05 received!

```
Source: 516  Destination: 439

 Device 516 is trying to send msg "  Message#05 received!  " to Device 439
 Searching Device 516 in connected Network...
 Device 516 found!!
 Searching Device 439 in connected Network...
 Device 439 found!!

 Found path : 516 -> 831 -> 955 -> 732 -> 0 -> 6 -> 18 -> 659 -> 872 -> 309 -> 148 -> 918 -> 216 -> 713
 -> 286 -> 383 -> 904 -> 775 -> 325 -> 880 -> 638 -> 850 -> 825 -> 581 -> 56 -> 519 -> 183 -> 444 -> 70
 -> 808 -> 361 -> 439 -> PATH_END

 Message sent successfully : 1
 Message fields after compass routing :
 439 : Msg :  Message#05 received!
 516 : Msg : Message#05 !
```

Transferring Message#07
Source: 777 Destination: 834
Message: Message#07 !

```
Simulating topology control protocol (XTC)

Transferring Message#07

Source: 777  Destination : 834

Simulating  compass routing :

 Message fields before compass routing :
 777 : Msg :
 834 : Msg :

 Device 777 is trying to send msg " Message#07 ! " to Device 834
 Searching Device 777 in connected Network...
 Device 777 found!!
 Searching Device 834 in connected Network...
 Device 834 found!!

 Found path : 777 -> 325 -> 775 -> 525 -> 140 -> 904 -> 62 -> 383 -> 128 -> 992 -> 414 -> 822 -> 398 -> 188
 -> 222 -> 783 -> 417 -> 337 -> 656 -> 303 -> 925 -> 108 -> 261 -> 834 -> PATH_END

 Message sent successfully : 1
```

Transferring Message#08
Source: 834 Destination: 777
Message: Message#07 received!

```
Transferring Message#08

Source: 834  Destination: 777

 Device 834 is trying to send msg "  Message#07 received!  " to Device 777
 Searching Device 834 in connected Network...
 Device 834 found!!
 Searching Device 777 in connected Network...
 Device 777 found!!

 Found path : 834 -> 261 -> 108 -> 296 -> 422 -> 577 -> 594 -> 141 -> 596 -> 680 -> 514 -> 81 -> 378
-> 364 -> 678 -> 876 -> 535 -> 681 -> 857 -> 862 -> 852 -> 573 -> 825 -> 850 -> 638 -> 182 -> 880 ->
140 -> 210 -> 777 -> PATH_END

 Message sent successfully : 1
 Message fields after compass routing :
 777 : Msg :  Message#07 received!
 834 : Msg : Message#07 !
```

Transferring Message#09
Source: 984 Destination: 800
Message: Message#09!

```
 Simulating topology control protocol (XTC)

Transferring Message#09

Source: 984  Destination : 800

Simulating  compass routing :

 Message fields before compass routing :
 984 : Msg :
 800 : Msg :

 Device 984 is trying to send msg " Message#09 ! " to Device 800
 Searching Device 984 in connected Network...
 Device 984 found!!
 Searching Device 800 in connected Network...
 Device 800 found!!

 Found path : 984 -> 459 -> 728 -> 788 -> 691 -> 454 -> 887 -> 998 -> 952 -> 59 -> 800 -> PATH_END

 Message sent successfully : 1
```

Transferring Message#10
Source: 800 Destination: 984
Message: Message#09received!

```
Transferring Message#10

Source: 800  Destination: 984

 Device 800 is trying to send msg "  Message#09 received!  " to Device 984
 Searching Device 800 in connected Network...
 Device 800 found!!
 Searching Device 984 in connected Network...
 Device 984 found!!

 Found path : 800 -> 829 -> 752 -> 869 -> 461 -> 431 -> 387 -> 373 -> 26 -> 605 -> 756 -> 750 -> 495 -> 113 -> 42
 -> 989 -> 877 -> 897 -> 706 -> 563 -> 755 -> 766 -> 179 -> 561 -> 878 -> 969 -> 457 -> 186 -> 924 -> 714 -> 764
-> 845 -> 245 -> 984 -> PATH_END

 Message sent successfully : 1
 Message fields after compass routing :
 984 : Msg :  Message#09 received!
 800 : Msg : Message#09 !
```

Write 2-3 sentences commenting on how the path lengths generated by routing before topology control were different than path lengths generated after simulating topology control protocol?

Before simulating the topology control protocol, the path lengths generated by routing are usually longer due to inefficient routing paths. However, after implementing the topology control protocol, the path lengths would likely be shorter. The protocol optimizes the network topology by removing unnecessary links and selecting more direct routes, resulting in reduced path lengths and improved overall network efficiency.

- **Time Complexity:**

- **Time Complexity of each function in wirelessNetwork class:**

i. Constructor: WirelessNetwork()

The time complexity of this function depends on the number of points (noOfPoints) specified. The loop that generates the random coordinates and inserts them into the graph has a time complexity of O(noOfPoints), and the insertEdge() function has a time complexity of O(V^2) in the worst case, where V is the number of vertices in the graph. Therefore, the overall time complexity of this function can be approximated as **O(noOfPoints + V^2).**

ii. displayVertics():

The time complexity of this function is **O(V + E)**, where V is the number of vertices and E is the number of edges in the graph. The function iterates over all vertices and their adjacency lists, printing the information. Therefore, the time complexity is proportional to the sum of the number of vertices and the total number of edges.

iii. simulateProtocol():

The time complexity of this function is O(V + E), where V is the number of vertices in the graph. The function iterates over each vertex and its adjacency list, sorts the list based on relative distance, and selects a subset of best neighbors. The sorting operation has a time complexity of O(E log E), but since E is at most V^2, the overall time complexity can be approximated as **O(V + E).**

iv. calc_angle():

This function has a constant time complexity of **O(1)** as it performs a fixed number of arithmetic operations and comparisons.

v. neighbors():

The time complexity of this function depends on the size of the adjacency list for the given vertex. In the worst case, it has a time complexity of **O(V)**, where V is the number of vertices. This occurs when the function needs to iterate over all vertices to find the neighbor.

vi. rcompassRouting():

The time complexity of this recursive function depends on the size of the adjacency list for the current node and the number of nodes in the graph. In the worst case, it can be approximated as **O(V^2)**, where V is the number of vertices. This occurs when the function needs to explore all possible paths to find the destination.

vii. compassRouting():

The time complexity of this function depends on the time complexity of the rcompassRouting() function. In the worst case, it can be approximated as **O(V^2)**, where V is the number of vertices. This occurs when the function needs to explore all possible paths to find the destination.

- **Time Complexity of WirelessNetwork class:**

Overall, the time complexity of the WirelessNetwork class is dominated by the functions **WirelessNetwork()** and **rcompassRouting()**, which both have a time complexity of O(V^2). Therefore, the overall time complexity of the class can be approximated as **O(V^2)**, where V is the number of vertices in the graph.

4. Limitations

The project has a few limitations that should be considered. Firstly, the performance of the wireless network system may vary depending on the specific network topology(for instance, in this project only 6 best neighboring nodes are selected depending on the highest signal strength). Secondly, wireless network system is also effected by the number of nodes/devices like in real life, the number of nodes/devices in a network is not usually fixed. Thirdly, the project assumes a fixed transmission range for all nodes, which may not accurately represent real-world wireless networks with varying transmission power capabilities.

5. Conclusion

In conclusion, this project successfully developed a wireless network system with an efficient topology control algorithm and routing algorithm. The implementation demonstrated improved network connectivity, reduced interference, and optimized communication paths. Although there are limitations, the project provides a solid foundation for further research and development in wireless network optimization.

6. References

i. https://tikdb.ee.ethz.ch/file/aa174253e91bde5ee16c722f6f4c791c/wman04.pdf

ii. https://scirp.org/reference/referencespapers.aspx?referenceid=36484