“RESOURCE ALLOCATION ALGORITHM
USING DIRECTIONAL ANTENNAS IN WIMAX”

by

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# TABLE OF CONTENTS

1. INTRODUCTION .................................................................................................................. 1
   Directional Antennas ............................................................................................................. 3
   Less Interference .................................................................................................................. 4
   Higher Gain ........................................................................................................................ 6
   Higher Adaptive Modulation Coding (AMC) ......................................................................... 7
   Project Definition ............................................................................................................... 9

2. ANTENNA PATTERN CREATION IN OPNET ................................................................. 10
   Methods of creating antenna patterns in OPNET ............................................................... 11
   Antenna Pattern Editor ....................................................................................................... 12
   External Model Access ....................................................................................................... 13
   Automatic Creation of Antenna Patterns .......................................................................... 13
   Cosine Squared Gain ......................................................................................................... 17
   Implementation in OPNET .................................................................................................. 18
   Tracking in OPNET ............................................................................................................ 19
   Pencil Beam Antenna Patterns .......................................................................................... 23

3. MAX-MSRS-THROUGHPUT ALGORITHM ..................................................................... 26
   ILP Formulation .................................................................................................................. 27
   Variables and Constraints ................................................................................................. 29
   Rounding Algorithm ......................................................................................................... 32
   Simulation on OPNET coordinates .................................................................................... 33
   Simulation on random coordinates .................................................................................... 37

4. SIMULATION RESULTS ................................................................................................. 38
   Conclusion ......................................................................................................................... 42

REFERENCES ....................................................................................................................... 45

APPENDICES

- APPENDIX A: Antenna pattern creation and tracking code in OPNET ................. 48
- APPENDIX B: Cosine squared gain antenna pattern creation code in OPNET ...... 68
TABLE OF CONTENTS-CONTINUED

- APPENDIX C: Pencil Beam Antenna Pattern creation code in OPNET ........... 72
- APPENDIX D: ILP formulation for OPNET coordinates.......................... 78
- APPENDIX E: Rounding Code for OPNET coordinates.......................... 88
- APPENDIX F: ILP formulation for NP Hard coordinates......................... 104
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>WiMAX Technology usages worldwide</td>
<td>2</td>
</tr>
<tr>
<td>1.2</td>
<td>Performance Comparison of today’s Wireless Technologies</td>
<td>3</td>
</tr>
<tr>
<td>1.3</td>
<td>Example of a directional antenna (Yagi Antenna)</td>
<td>4</td>
</tr>
<tr>
<td>1.4</td>
<td>Directional Antenna</td>
<td>5</td>
</tr>
<tr>
<td>1.5</td>
<td>Directional Antenna Vs Omni-Directional Antenna</td>
<td>6</td>
</tr>
<tr>
<td>1.6</td>
<td>Adaptive Modulation Coding (AMC)</td>
<td>8</td>
</tr>
<tr>
<td>1.7</td>
<td>entry and exit SNR threshold for different modulation in OPNET simulator</td>
<td>9</td>
</tr>
<tr>
<td>2.1</td>
<td>θ (Azimuth plane) and Φ (Elevation plane) in OPNET</td>
<td>10</td>
</tr>
<tr>
<td>2.2</td>
<td>36 gain definitions for a value of θ</td>
<td>11</td>
</tr>
<tr>
<td>2.3</td>
<td>Result Antenna Pattern of gain 10 dB for θ from 0 to 15 degrees</td>
<td>12</td>
</tr>
<tr>
<td>2.4</td>
<td>Example network in OPNET</td>
<td>14</td>
</tr>
<tr>
<td>2.5</td>
<td>Input to the C code</td>
<td>15</td>
</tr>
<tr>
<td>2.6</td>
<td>Creation of antenna pattern</td>
<td>16</td>
</tr>
<tr>
<td>2.7</td>
<td>Antenna Pattern “mont”</td>
<td>16</td>
</tr>
<tr>
<td>2.8</td>
<td>Given value of Φ, θ is always constant</td>
<td>17</td>
</tr>
<tr>
<td>2.9</td>
<td>Gain values following a cosine squared curve</td>
<td>17</td>
</tr>
<tr>
<td>2.10</td>
<td>Upper view of antenna pattern “mont” for the simulation as in Figure 2.5</td>
<td>18</td>
</tr>
<tr>
<td>2.11</td>
<td>op_ima_obj_pos_get()</td>
<td>19</td>
</tr>
</tbody>
</table>
### LIST OF FIGURES-CONTINUED

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.12. Tracking Scenario</td>
<td>20</td>
</tr>
<tr>
<td>2.13. Traffic received by SS when tracking disabled</td>
<td>21</td>
</tr>
<tr>
<td>2.14. Traffic received by SS when tracking enabled</td>
<td>22</td>
</tr>
<tr>
<td>2.15. tracking disabled Vs tracking enabled</td>
<td>22</td>
</tr>
<tr>
<td>2.16. High gain values of $\theta$ for a conical antenna pattern</td>
<td>23</td>
</tr>
<tr>
<td>2.17. High gain values of $\theta$ for a pencil beam antenna pattern</td>
<td>24</td>
</tr>
<tr>
<td>2.18. beam antenna pattern for scenario in figure</td>
<td>25</td>
</tr>
<tr>
<td>3.1. example network</td>
<td>28</td>
</tr>
<tr>
<td>3.2. The ILP created</td>
<td>30</td>
</tr>
<tr>
<td>3.3. Output of Lp solve</td>
<td>31</td>
</tr>
<tr>
<td>3.4. Example Network</td>
<td>33</td>
</tr>
<tr>
<td>3.5. LP output</td>
<td>34</td>
</tr>
<tr>
<td>3.6. Output of rounding algorithm</td>
<td>35</td>
</tr>
<tr>
<td>3.7. Assignment</td>
<td>36</td>
</tr>
<tr>
<td>4.1. traffic sent by BS of omnidirectional (red curve) VS directional(blue curve)</td>
<td>39</td>
</tr>
<tr>
<td>4.2. Sum of traffic sent by BS of relay station using omnidirectional antenna</td>
<td>40</td>
</tr>
<tr>
<td>4.3. Sum of traffic sent by BS of relay station using directional antenna</td>
<td>40</td>
</tr>
<tr>
<td>4.4. Sum of traffic received by SS using omnidirectional antenna</td>
<td>41</td>
</tr>
<tr>
<td>4.5. Sum of traffic received by SS using directional antenna</td>
<td>41</td>
</tr>
</tbody>
</table>
ABSTRACT

This paper discusses different algorithms to create directional antenna patterns in OPNET Modeler. We describe algorithms to create conical and pencil beam antenna patterns. We also present a version of this algorithm that creates antenna patterns whose gain follows a cosine squared curve. We have also implemented tracking in OPNET to utilize these directional antenna patterns. These algorithms can be used to create antenna patterns for any wireless technology in OPNET such as WiFi and WiMAX.

This paper also discusses an integer linear programming (ILP) formulation for a resource allocation problem. This is a centralized optimization algorithm where the base station decides which subscriber station will be assigned to which relay station in the network such that the throughput of the entire network is maximized. We present some simulation results showing 10Mbps improved throughput using directional antennas with the assignment strategy. This is a centralized algorithm and can be used in any technology that has a centralized resource allocation scheme such as WiMAX.
CHAPTER 1

INTRODUCTION

Worldwide Interoperability for Microwave Access, more commonly known as WiMAX is a new telecommunications technology that provides wireless transmission of data using a variety of transmission modes, from point-to-multipoint links to portable and fully mobile internet access. WiMAX, which is standardized by IEEE in the 806.16 family, was first said to be able to run at frequencies up to 66 GHz. Because of the limitations of silicon hardware, at such high frequencies we have to change our hardware to Gallium Arsenide (GaAs). But GaAs is not as cheap as silicon. So for this and other reasons, WiMAX is standardized to run at 2-11 GHz.

IEEE 806.16 standard is a huge standard. Unlike IEEE 802.11, in which there is little room for experiments for a vendor, in IEEE 802.16 vendors have a lot of options, such as what frequency to run at, etc. This leads to a problem of coordination. For example a WiMAX Base Station made by Vendor-A which is made in China may not be compatible to run with WiMAX Subscriber Station made by Vendor-B in the US. To help in this coordination, WiMAX Forum was created. The WiMAX Forum is an industry led, not-for-profit organization formed to certify and promote the compatibility and interoperability of broadband wireless products based upon the harmonized IEEE 802.16/ETSI HiperMAN standard. So, a WiMAX base station which follows the WiMAX Forum spec will be compactable to run with a WiMAX Subscriber Station follows the WiMAX Forum.
WiMAX Technology has a lot of promise because it provides broadband services to wide area networks. Assuming a 14MHz channel and 5 bps/Hz, WiMAX can provide Data Rate up to 70Mbps[1]. 802.16 supports both OFDM and OFDMA frequency allocation methods for non-line of sight application. 802.16 supports transport layer protocols such as IPv4, IPv6, ATM, Ethernet, etc. The technology also supports adaptive antennas and space time coding. WiMAX can provide broadband services over a wide area network.
Directional Antennas

An antenna gives the wireless system three fundamental properties: gain, direction and polarization. Gain is a measure of increase in power. Gain is the amount of increase in energy that an antenna adds to a radio frequency (RF) signal. Direction is the shape of the transmission pattern. As the gain of a directional antenna increases, the angle of radiation usually decreases. This provides a greater coverage distance, but with a reduced coverage angle. The coverage area or radiation pattern is measured in degrees. These angles are measured in degrees and are called beamwidths[2].
A directional antenna or beam antenna is an antenna which radiates greater power in one or more directions as compared to an omni-directional antenna that radiates equal power in all directions around the antenna's vertical axis. By using directional antenna, we focus our radiated power towards the intended receiver, hence saving power by not radiating in all directions, allowing for increased performance on transmit and receive. The main Advantages of a directional antenna are

- Less interference[2]
- Higher gain[2]
- Higher adaptive modulation coding(AMC)[3]

![Figure 1.3 - A directional antenna created by our project team at Montana State Univ.](image)

Less Interference

An omni-directional antenna is an antenna that equally transmits (or receives) electromagnetic radiation to/from any arbitrary direction. In other words, it has a directivity of 0 dBi. The downside of an omni-directional antenna is that the antenna transmits information in the direction with no intended receiver. Hence, it is wasting
power in that direction. Moreover other nodes apart from the transmitter with the omni-directional antenna and the intended receiver, which are operating in the same frequency range, will get affected by the waves of the omni-directional antenna of the transmitter. So for these nodes, the signal to noise ratio (SNR) at the receiver will get adversely affected by this interfering wave. Hence, if we have a network with omni-directional antennas, the range of the transmitter will be significantly reduced.

On the other hand, if we use a directional antenna, as we can see from figure 1.4, the radiation in unwanted direction is limited to side lobes. Side lobes generally have a smaller gain as compared to the main lobe. Hence directional antennas have a smaller interference range. Hence, a network with nodes having directional antenna has much less interference as compared to a network with omni-directional antenna.
Higher Gain

We can say that an antenna amplifies the transmitting signal and sends it to space. Antennas have a fixed amount of power to amplify the signal. Directional antennas radiate only in the direction of the intended user. Hence, they can use all their available power to amplify the signal in the direction of the receiver. In an omni-directional antenna, all the available power is used to amplify the signal in all directions. Hence, the main lobe of the directional antenna will have higher gain as compared to that of an omni-directional antenna. Hence, the SNR at the receiver will be higher in case of the directional antenna compared to the omni-directional antenna. As we can see in Figure 1.5, the main lobe of the directional antenna has higher gain as compared to omni-directional antennas.

For a fixed power, let \( G_o \) be the gain of the omni-directional antenna and let \( G_d \) be the gain of the directional antenna. Let \( \theta \) be the angle of the main lobe in the azimuth.
plane and let $\Phi$ be the angle of the main lobe in the elevation plane for the directional antenna. Then, we can say that

$$G_d \propto \frac{1}{\theta \times \Phi} G_o$$

Equation 1.1 – Relationship between Gain of directional and omni-directional antenna [3]

Table 1.1 – Relationship between $G_d$, $G_o$, $\theta$ and $\Phi$

<table>
<thead>
<tr>
<th>$\theta$ and $\Phi$ ($\theta = \Phi$)</th>
<th>$G_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>360</td>
<td>2 dBi ($G_d = G_o$)</td>
</tr>
<tr>
<td>180</td>
<td>6.33 dBi</td>
</tr>
<tr>
<td>90</td>
<td>14.03 dBi</td>
</tr>
<tr>
<td>45</td>
<td>20.05 dBi</td>
</tr>
<tr>
<td>30</td>
<td>23.58 dBi</td>
</tr>
<tr>
<td>15</td>
<td>29.6 dBi</td>
</tr>
</tbody>
</table>

Table 1.1 will show how $G_d$ increases as $\theta$ and $\Phi$ decrease. In this table the value of $G_o$ is 2dBi.

Higher Adaptive Modulation Coding

In wireless communication technologies such as WiFi and WiMAX, information bits are generally packed into symbols. Hence, throughput is calculated in symbols per second. Number of bits packed into a symbol can vary in these technologies[3]. In WiMAX, if the end to end SNR is low, only 1 bit will be transmitted per symbol. This is
known as QPSK modulation. If the end to end throughput is very high, 6 bits can be transmitted per symbol. This is known as 64-QAM modulation.

<table>
<thead>
<tr>
<th>Modulation</th>
<th>Bits/symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bpsk</td>
<td>1</td>
</tr>
<tr>
<td>Qpsk</td>
<td>2</td>
</tr>
<tr>
<td>16-QAM</td>
<td>4</td>
</tr>
<tr>
<td>64-QAM</td>
<td>6</td>
</tr>
</tbody>
</table>

In WiMAX, if the node is closer to the base station, the end to end SNR will be high. Hence the base station will adaptively communicate at a higher modulation. Hence, the throughput will be higher for nodes with high SNR.
If we use a directional antenna, the gain will be higher, the end to end SNR will be high, the nodes will communicate with a high modulation index, the throughput will go up.

![Table showing SNR thresholds for different modulations](image)

Figure 1.7 – entry and exit SNR threshold for different modulation in OPNET simulator

**Project Definition**

We have worked on a resource allocation problem to maximize the end to end throughput. Suppose we have a network with $m$ mobile stations and $n$ relay stations, we have developed an algorithm with assigns each mobile station to a relay station (relay station uses directive antennas with a beam width $\theta$) such that the throughput of the entire network is maximized.
In the real world, antenna coordinate systems are defined by Azimuth plane and the Elevation plane. In OPNET, the Azimuth plane is defined by the parameter $\theta$ and the Elevation plane is defined by the parameter $\Phi$. In OPNET Modular, $\theta$ and $\Phi$ are incremented in steps of 5 degrees, and each and every combination of $\theta$ and $\Phi$ has to be assigned a gain value. The units of $\theta$ and $\Phi$ are degrees and the unit of gain is dB.

![Diagram of Antenna Coordinate Systems](image)

Figure 2.1 – $\theta$ (Azimuth plane) and $\Phi$ (Elevation plane) in OPNET

The range of $\theta$ is [0 360] and the range of $\Phi$ is [0 180]. As mentioned before both $\theta$ and $\Phi$ are incremented in steps of 5. Hence in OPNET $\theta$ has 72 data points and $\Phi$ has 36 data points, and each combination of $\theta$ and $\Phi$ has to be assigned a gain value. In other words, to create a valid antenna pattern file, for $\Phi$ equal to 0, we should assign 72 gain values for $\theta$. For $\Phi$ equals 1 we should assign 72 gain values for $\theta$ and so
on up till $\Phi$ equals 36 for which we should assign 72 gain values for $\theta$. Hence OPNET antenna patterns are defined in a 36 by 72 array[4].

```
double dvec_2[] =
{
20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20,
20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20,
20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20,
20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20,
};
```

Figure 2.2 – 36 gain definitions for a value of $\theta$

In Figure 2.2, the integer 2 in dev_2 says that these gain values are defined for $\Phi$ between 10 degrees to 15 degrees. Like this, we will have definitions from dev_0 till dev_35.

**Methods of Creating Antenna Patterns**

There are 2 methods of creating antenna patterns in OPNET.

- Antenna Pattern Editor
- External Model Access (EMA)
Antenna Pattern Editor

Figure 2.3 – Antenna Pattern of gain 10 dB for θ from 0 to 15 degrees

The Antenna Pattern Editor lets you create, edit, or view antenna patterns. An antenna pattern is a set of two-dimensional functions that establish the gain in dB of an antenna in three-dimensions. In an Antenna Pattern Editor, we have to click and define the gain values. There are 2 steps to create an antenna pattern using antenna pattern editor

- Select conical slices of the antenna pattern for editing.
- Use a two-dimensional graph to enter the gain pattern for the current slice.
Because the antenna pattern table is manipulated graphically within the Antenna Pattern Editor, it is inevitably somewhat imprecise.

**External Model Access**

EMA is a library of procedures, supplied with the OPNET release, which are useful for creating or querying models from an external program. EMA-based applications are programs which make calls to the EMA library in order to access OPNET models.

EMA library is a very useful for creating antenna patterns because we can create very accurate antenna patterns. Unlike the antenna pattern editor, there is no clicking involved and we can enter floating point values for gain. It is also a useful tool because using EMA, we have created a algorithm that automatically creates antenna patterns. Hence, in a mobile scenario, when the nodes are moving, the antenna pattern has to change as the nodes move. During the simulation, we can create new antenna patterns and assign it to the nodes. This cannot be done if we create antenna patterns with an antenna pattern editor.

**Automatic Creation of Antenna Patterns**

In figure 2.4, the angle between SS_1, BS and SS_2 is 27° and the angle between SS_1, BS and SS_3 is 66°. We created an algorithm that would create an accurate antenna pattern. The inputs to the algorithm are
Figure 2.4 – Example network in OPNET

- Number of subscriber stations.
- The upper and lower angle between the subscriber station 1 and the remaining subscriber stations. For example the angle between SS_1 and SS_3 is 66.7°, we will give the upper and lower bounds as 65 and 70. We have an upper and lower bound because as mentioned before, OPNET antenna patterns increment in steps of 5.
- Name of the antenna pattern file

The output C code is a “.em.c” file. It is a file in C language that is formatted in such a way that when it is executed, it calls the EMA library and creates an executable file.
EMA Library has a function `op_mkema()` that needs to be called to create antenna patterns. `op_mkema -m filename` (with no extension) should be called in your command prompt. It will create an executable. The name of the executable file will be mentioned. This executable file is a “.x” format file. When this executable file is executed, an antenna pattern file is created. This file is of “.pa.m” format.

Figure 2.5 – Input to the C code

As we can see in Figure 2.6, the name of the file at the output of the C code is “abcdefg.em.c”. After calling the `op_mkema()` command, an executable file is created known as “abcdefg.dev32.i0.em.x”. After executing this file, “mont.pa.m” antenna pattern file is created. This pattern can be seen in Figure 2.7. As we can see, the angle between the first cone and the second cone is 27°, and the angle between the first cone and the third cone is 66°. Hence, this antenna pattern file can be used by the BS to serve the subscriber stations.
Figure 2.6 – Creation of antenna pattern

Figure 2.7 – Antenna Pattern “mont”.

Figure 2.6

```batch
C:\>cd Documents and Settings\neeraj.gurdasani\My Documents\op_models
C:\Documents and Settings\neeraj.gurdasani\My Documents\op_models\op_mkena -n abedef

An executable program (abedef.dev32.i0.en.x) produced.

C:\Documents and Settings\neeraj.gurdasani\My Documents\op_models\abedef.dev32.i0.en.x
C:\Documents and Settings\neeraj.gurdasani\My Documents\op_models\.
```
Cosine Squared Gain

In the current algorithm, for a given value of $\Phi$, $\theta$ is always constant. Like in Figure 2.7, the gain values are either 20 dB or -20dB.

```
double dvec_7 [] =
{
};
```

Figure 2.8 - given value of $\Phi$, $\theta$ is always constant

To make the antenna pattern more realistic, we made the gain follow a cosine squared curve. For example in a 90 degree sector antenna, the gain would be a maximum (max gain) for theta = 45 degrees, and then fall to -20dB for theta = 0 and theta = 90 degrees. This is done to make the physical layer calculations more realistic.

```
double dvec_9 [] =
{
};
```

Figure 2.9 – Gain values following a cosine squared curve
The main purpose of this algorithm was to automate the process of creating antenna patterns with the accuracy which is not there in an Antenna Pattern Editor. In OPNET Modeler, all the physical layer code is present in the “wimax_phy_support.ex.c”. In this file, we have all the physical layer code pipelined into 7 stages.

In the last stage of this pipeline, where all the link layer calculations are done (Pathloss, SNR calculations) every packet is assigned an antenna pattern and the antenna aiming parameters. The antenna aiming parameters contains 3 parameters that are latitude, longitude and altitude. All these 4 parameters are defined in a function wimax_phy_mcarrier_pk_send( ). An antenna pattern can be created by our algorithm shown above and assigned to each packet to be sent. The aiming parameters can be obtained by a set of kernel function op_ima_obj_attr_set( ) in OPNET. After obtaining the aiming parameters (latitude, longitude and altitude), these values can be set to the packet by the kernal function op_ima_obj_attr_set( ).
In a stationary case, the above algorithm has to be run just once, so that does not affect the simulation time. But for a mobile case, the algorithm has to be run for each and every packet sent, because the antenna pattern changes because the nodes are moving. Hence, the algorithm has to be executed every time, and the function op_mkema( ) mentioned above takes 2-4 seconds to execute. Hence the simulation time gets effected.

**Tracking in OPNET**

The main advantage of setting antenna patterns using EMA is that this is the only way we can use directional antennas in a mobile scenario. In a mobile case, the subscriber stations will always be in motion. If we use a directional antenna without tracking, the subscriber station might go out of coverage area. We designed a way of obtaining the current coordinates of the subscriber station and updated the aiming parameters of the antenna object in the BS for every packet sent in wimax_phy_mcarrier_pk_send( ).

We used the kernel procedure op_ima_obj_pos_get( ) to get the coordinates of the subscriber station and op_ima_obj_attr_set( ) kernel procedure to set the aiming parameters of the antenna object.

```c
rx_node_id11 = op_id_from_name [subnet_id, OPC_OBJTYPE_NODE_FIX, "BS"];
op_ima_obj_pos_get [rx_node_id11, 61atitude, 61ongitude, 61titude, 6x_pos, 6y_pos, 6z_pos];
BS_lat=latitude;
BS_long=longitude;
BS_alt=altitude;
```

**Figure 2.11 - op_ima_obj_pos_get( )**

After getting the coordinates of the subscriber station, we had to set the aiming parameters of the antenna object in the Base Station. That code can be seen in code
attached. This has to be done for each and every packet sent to make sure the subscriber station never goes out of the antenna coverage area.

Figure 2.12 shows the scenario layout that exhibits tracking. Table 2.1 shows the scenario parameters. Figure 2.13 shows the received traffic (bits/second) when tracking code is disabled. Figure 2.14 shows the received traffic (bits/second) when tracking is enabled.
Table 2.1 – Simulation parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna pattern of BS</td>
<td>$5^\circ$ cone antenna of gain 20dB</td>
</tr>
<tr>
<td>Antenna pattern of SS</td>
<td>-$18$dB omni-directional</td>
</tr>
<tr>
<td>BS Mobility</td>
<td>False</td>
</tr>
<tr>
<td>SS Mobility</td>
<td>True(circular trajectory)</td>
</tr>
<tr>
<td>Traffic Demand</td>
<td>1 Mbps</td>
</tr>
</tbody>
</table>

Figure 2.13 – Traffic received by SS when tracking disabled
Figure 2.14 – Traffic received by SS when tracking enabled

Figure 2.15 – Tracking enabled Vs Tracking disabled
As we can see in figure 2.13, when tracking is disabled, the node in motion comes in the coverage area and leaves the coverage area. That is the only time when the node SS is able to communicate with the base station. In figure 2.14, we are able to consistently receive traffic from the base station when tracking is enabled.

**Pencil Beam Antenna Patterns**

As we can see in figure 2.7, we have managed to create conical antenna patterns. These are directive antenna patterns where we have 72 high gain values of $\theta$ for values of $\Phi$ which come under the main lobe and 72 low gain values (-20dBi) of $\theta$ for values of $\Phi$ which don’t come under the main lobe. So we are entering 72 high gain values of $\theta$ for values of $\Phi$ which come under the main lobe. But we don’t have to give all the 72 data sets high gain values. If we give 3 data sets high gain values that should be enough to achieve communication. If we manage to do that, we will be creating extremely directive antenna patterns known as pencil beam antenna patterns.

```c
double dvec_7 [] =
{
};
```

Figure 2.16 – High gain values of $\theta$ for a conical antenna pattern
As we can see in figure 2.17, we just have 3 high gain values of $\theta$ for $\Phi$ that comes under the main lobe. The problem in creating this antenna pattern is which of the 72 data sets values have to be high so that communication. For that we have to do $\theta$ calculations. We have created an algorithm to solve this problem. The steps of the algorithm are

- Let the 1st Subscriber stations coordinates be $(x_1, y_1, z_1)$. Let the coordinates of the Subscriber stations from whom we are trying to find $\theta$ be $(x_2, y_2, z_2)$. By these 2 coordinates, find the equation of a sphere with $(x_1, y_1, z_1)$ being the center.
- Calculate the equation of a plane with the coordinates $(x_1, y_1, z_1)$, $(x_1, y_1, 0)$ and $(x_b, y_b, z_b)$, where $(x_b, y_b, z_b)$ are the coordinates of the Base Station.
- Calculate the points of intersection of the sphere and a plane. The set of satisfied values will form a circle. Select the highest point of that circle, let the coordinates of that point be $(x_t, y_t, z_t)$.
- Calculate the angle between $(x_t, y_t, z_t)$, $(x_b, y_b, z_b)$ and $(x_2, y_2, z_2)$. That is the value of $\theta$ that had to be of high gain.[5]
These steps have to be repeated for all the subscriber stations in the network (apart from the first subscriber station). The coordinates of those subscriber stations should be placed in place of (x2,y2,z2). We ran our algorithm for scenario in figure-2.4. The output pencil beam antenna pattern can be seen in figure-2.18.

Figure 2.18 – pencil beam antenna pattern for scenario in figure 2.14
CHAPTER 3

IMPLEMENTATION OF A RELAY BEAM STEERING ALGORITHM

This chapter describes the implementation and testing of a recently invented algorithm[6] for choosing relay beam directions and assigning mobile stations to relays in such a way as to maximized the total throughput achieved in the network.

Let us imagine a network with $n$ relay stations and $m$ mobile stations. The problem we face is that which mobile stations should be served by which relay stations. We have worked on an optimization problem where we assign every subscriber station in the network to one of the available relay stations in the network such that the throughput of the entire network is maximized.

We created an Integer linear program (ILP) formulation to solve this NP-Complete problem. The objective function of this ILP is to maximize the data rate. To efficiently solve this problem we relax the ILP to a Linear Program (LP) by allowing real values (non-integer) for the ILP. Hence, the output of the LP may not be an integer solution. To get an absolute integer assignment, we have created a rounding algorithm that takes the output of the LP as an input and gives an integer assignment. The rounding algorithm provides the first provable approximation.

Hence to solve this problem, we have to follow these steps

- Create a ILP formulation
- Relax the ILP to an LP (run the ILP in LPSolve software)
- Run the rounding algorithm whose input the output of LP.
ILP Formulation

Let there be $m$ mobile stations $M_1$, $M_2$, …$M_m$ and $n$ relay stations $R_1$, $R_2$, $R_3$…$R_n$ at a given position in a plane. Let us assume that each relay station $R_j$ has a fixed beam width angle $\theta$ (in our simulations, we have set that value to 40°). Now the objective function of out ILP is to maximize the data rate. Let $r_{ij}$ be the data rate achievable if $M_i$ is within the beam of $R_j$. Let $d$ be the distance between $M_i$ and $R_j$. Then

$$r_{ij} = \frac{1}{(d^2 * \theta)}$$

Beam Sets are the distinct set of mobile stations that are reachable by a relay station $R_j$ as its main lobe beam spans 360°. Hence, each relay station spans its antenna main lobe beam and calculates all its beam sets $B_{j1}$, $B_{j2}$, …, $B_{jp}$.

In example network shown in figure 3.1 the beam sets for relay station RS will be

- $B_{01} = 0, 1$
- $B_{02} = 1$
- $B_{03} = 2$
- $B_{04} = 2, 3$
- $B_{05} = 3$
- $B_{06} = 4$
- $B_{07} = 4, 5$
- $B_{08} = 5$
- $B_{09} = 6$
- $B_{010} = 6, 7$
So we can say that it is a cluster of all the mobile stations that can be served when the antenna beam is aimed in the certain orientation. So the collection of these different clusters when the antenna beam spans 360° are called as a beam sets.

For each mobile station \( M_i \), let \( S_{ij} \) be the collection of beam sets for \( R_j \) that contain \( M_i \) i.e \( M_i \in B_{jk} \iff k \in S_{ij} \).
Variables and Constraints

Now for a mobile station $M_i$ and a relay station $R_j$, the variables of the ILP are

- $x_{ij} \ (x_{ij} = 1 \text{ implies mobile station } M_i \text{ uses relay station } R_j )$
- $S_{jk} \ (S_{jk} = 1 \text{ implies relay station } R_j \text{ uses beamset } B_{jk} )$

The constraints of the ILP are

1. $0 \leq x_{ij} \leq 1$
2. $0 \leq s_{jk} \leq 1$
3. $\forall i : \sum_{j=1}^{n} x_{ij} \leq 1$
4. $\forall j : \sum_{k=1}^{n} s_{jk} = 1$
5. $\forall j : \sum_{k \in S_{ij}} s_{jk} \geq x_{ij}$

The objective function of this ILP is $\sum_{i,j} r_{ij} x_{ij}$

The 3$^{rd}$ constraint of the ILP makes sure that a mobile station selects at most one relay station. The 4$^{th}$ constraint of the ILP makes sure that a relay station selects exactly one beamset. The 5$^{th}$ constraint of the ILP makes sure that if $M_i$ chooses $R_j$, then $R_j$ must select a beamset that contains $M_i$.

We encoded the whole ILP in the C language. The input to this code is going to be coordinates of the nodes. The output of this code going to be an ILP formulation. Figure 3.2 shows the ILP formulation for the network in figure 3.1. Figure 3.2 shows the
output of the LPSolver software when the input is the text shown in figure-3.1. In figure 3.2, we can see that $x_{40}$ and $x_{50}$ are 1, which implies the maximum throughput with a 40° antenna in an RS can be achieved when RS serves mobile station 4 and 5.

![ILP created](image)

**Figure 3.2 – The ILP created**
We relax the ILP to an LP. The issue with this is that the output of the LP may not be an integer i.e. we may have a case that if we have more than one relay stations, then the output of the LP may say the a mobile station is half served by one relay and half served by other relay (\( x_{40} = 0.5 \) and \( x_{41} = 0.5 \)). The same can be the case for \( s_{jk} \)’s. The LP may say \( s_{02} = 0.5 \) and \( s_{03} = 0.5 \) which means relay station 0 should half serve mobile station 2 and half serve mobile station 3. Even though the cases mentioned above are possible, they would be impractical, because these outputs mean that the relay station has break a connection, steer its antenna, remake a connection, and then go back. This process would take some time, hence the throughput of the system will be affected beating the whole point of this algorithm. So, it would be best if the output of our algorithm is an integer solution.
Rounding Algorithm

We have created a Rounding Algorithm that would take the output of the LP as its input and give the best integer solution. The following are the steps of the rounding algorithm:

1. Calculate the reward $y_{jk}$ of each beam set $B_{jk}$, where
   \[ y_{jk} = \sum_{i \in B_{jk}} r_{ij} \cdot x_{ij} \]

2. Choose the beam set $B_{jk_j}$ with the highest reward $y_{jk_j}$.

3. For each mobile station $M_i$, let $A_i = \{j | i \in B_{jk_i}\}$ be the set of available relay station after the beam directions have been chosen at the end of step 2. If $A_i$ has more than one relay station, choose the relay station with the maximum data rate.

Steps 1 and 2 are calculating the data rates achieved by different beam sets of a relay station. The beam set which has the maximum data rate is chosen i.e we are fixing the orientation of the antenna beam of a relay station. This is done for each and every relay station. In Steps 3 for each mobile station, we check how many relay station serve that mobile station. If we have more than one relay station, then we choose the relay station that provides it the maximum data rate. The rounding Algorithm is a $\frac{1}{2\pi/\theta_{\min}}$ – approximation algorithm in polynomial time[6]. MAX-MSRS-THROUGHPUT ALGORITHM is proven to be NP-Complete.
Simulation using OPNET Coordinates

We run our ILP formulation and our rounding algorithm on the example network shown in figure-3.4.
Figure 3.5 – LP- Output

The example network shown in figure-3.4, we have 1 Base-Station, 1 Ethernet Server, 6 relay Stations and 30 Sub Scriber Stations. Each subscriber station is 750,000 bits/second traffic from the Ethernet server. Hence, all the traffic is downlink. The traffic goes from the server, to the base station, to the relay stations to the subscriber stations.

We run our algorithm on the example network in figure-3.4. We take the coordinates of the nodes from OPNET and give it as an input to the algorithm. The output of the algorithm is an ILP formulation as shown in figure-3.2. The ILP formulation is given to the LPSolver software. The output of the LPSolver in shown in figure-3.5. This is given as an input to the rounding algorithm. The output of the rounding is shown in figure-3.6. Figure 3.7 shows the graphical interpretation of figure-3.6.
Figure 3.6 – Output of rounding algorithm

```plaintext
y[0][0] is max with value 0.000071
=> s'[0][0] = 1 because B[0][0] has the highest reward y

y[1][3] is max with value 0.000066
=> s'[1][3] = 1 because B[1][3] has the highest reward y

y[2][8] is max with value 0.000081
=> s'[2][8] = 1 because B[2][8] has the highest reward y

y[3][12] is max with value 0.000046
=> s'[3][12] = 1 because B[3][12] has the highest reward y

y[4][22] is max with value 0.000050
=> s'[4][22] = 1 because B[4][22] has the highest reward y

y[5][16] is max with value 0.000032
=> s'[5][16] = 1 because B[5][16] has the highest reward y

y[6][14] is max with value 0.000120
 => s'[6][14] = 1 because B[6][14] has the highest reward y

a[0][0] = 0
a[1][1] = 0
a[2][2] = 0
a[3][3] = 0
a[4][4] = 0
a[5][5] = 0
a[6][6] = 0
a[7][7] = -1
a[8][8] = 1
a[9][9] = 1
a[10][10] = 2
a[11][11] = 2
a[12][12] = 2
a[13][13] = 2
a[14][14] = 4
a[15][15] = 4
a[16][16] = 4
a[17][17] = 4
a[18][18] = 5
a[19][19] = 5
a[20][20] = 6
a[21][21] = 6
a[22][22] = 6
new a[16][12] = 6
new a[17][13] = 6
Press any key to continue . . . .
```
In figure-3.5, $x_{10} = 1$ implies subscriber station 1 is served by relay station 0. In figure-3.6 if $a[22][0] = 4$, means that subscriber station 22 will be served by relay station 4. In that same figure, $y[1][3]$ is the maximum value means relay station 1 should use its 3rd beamset because that beamset has the maximum datarate. We can see from figure-3.7, node 22 is served by relay station 4.
Simulation on Random coordinates

We run simulations on networks of different sizes where the relay stations and the subscriber stations were randomly placed using the `rand` function in C. The number of relay station randomly varied from 1 to 10 and the number of subscriber stations randomly varied from 10 to 100. In each simulation we compared the throughput provided by the linear program (LP), throughput provided by the Integer Linear program (ILP) and throughput provided by the rounding algorithm.

<table>
<thead>
<tr>
<th>Scenario Size</th>
<th>LP Throughput</th>
<th>ILP Throughput</th>
<th>Rounding Throughput</th>
<th>% of Optimality</th>
</tr>
</thead>
<tbody>
<tr>
<td>RS=7 SS=22 Random Instance</td>
<td>1.084</td>
<td>1.079</td>
<td>0.876</td>
<td>81.1%</td>
</tr>
<tr>
<td>RS=4 SS=51 Random Instance</td>
<td>1.804</td>
<td>1.784</td>
<td>1.583</td>
<td>88.7%</td>
</tr>
<tr>
<td>RS=2 SS=42 Random Instance</td>
<td>0.925</td>
<td>0.925</td>
<td>0.589</td>
<td>63.7%</td>
</tr>
<tr>
<td>RS=4 SS=48 Random Instance</td>
<td>1.762</td>
<td>1.729</td>
<td>1.400</td>
<td>80.9%</td>
</tr>
<tr>
<td>RS=10 SS=10 Random Instance</td>
<td>6.796</td>
<td>6.791</td>
<td>6.249</td>
<td>92.0%</td>
</tr>
<tr>
<td>RS=8 SS=40 NP-Hard Instance</td>
<td>40</td>
<td>40</td>
<td>30</td>
<td>75.0%</td>
</tr>
<tr>
<td>RS=8 SS=44 NP-Hard Instance</td>
<td>44</td>
<td>44</td>
<td>28</td>
<td>63.63%</td>
</tr>
<tr>
<td>RS=8 SS=52 NP-Hard Instance</td>
<td>52</td>
<td>52</td>
<td>34</td>
<td>65.3%</td>
</tr>
</tbody>
</table>

As we can see from table 3.1, the performance of the rounding algorithm increases as the network size increases.
CHAPTER 4

SIMULATION RESULTS

For the assignment shown in figure 3.7, we run the simulation using directional antennas and omni-directional antennas and compared their respective throughputs. Table 4.1 shows the simulation setting.

Table 4.1 – Simulation parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of BS</td>
<td>1</td>
</tr>
<tr>
<td>Number of Servers</td>
<td>1</td>
</tr>
<tr>
<td>Number of RS</td>
<td>7</td>
</tr>
<tr>
<td>Number of SS</td>
<td>30</td>
</tr>
<tr>
<td>Traffic Demand for each SS</td>
<td>733,200 bits/sec</td>
</tr>
<tr>
<td>Which relay serves which SS</td>
<td>Figure 3.7</td>
</tr>
<tr>
<td>Area of network</td>
<td>5km x 5km</td>
</tr>
<tr>
<td>Simulation 1 BS and RS Gain</td>
<td>5 dBi</td>
</tr>
<tr>
<td>Simulation 2 BS and RS Gain</td>
<td>15 dBi</td>
</tr>
<tr>
<td>Simulation 1 and Simulation 2 SS gain</td>
<td>-1 dBi</td>
</tr>
</tbody>
</table>
The blue line in figure 4.1 is traffic sent by BS using directional antennas while the red line is traffic sent by BS using omni-directional antennas. Figure 4.2 is the sum of traffic sent by BS of relay using omni-directional antennas. Figure 4.3 is the sum of traffic sent by BS of relay using directional antennas. Figure 4.4 is the sum of traffic received by SS in simulation 1(omni-directional antennas). Figure 4.5 is the sum of traffic received by SS in simulation 2(directional antennas). Table 4.2 compares the results between simulation 1 and simulation 2.

![Image of graph showing traffic sent by BS of omnidirectional (red curve) VS directional (blue curve)](image-url)
Figure 4.2 – sum of traffic sent by BS of relay station using omnidirectional antenna

Figure 4.3 – sum of traffic sent by BS of relay station using directional antenna
Figure 4.4 - sum of traffic sent by SS using omnidirectional antenna
Figure 4.5 - sum of traffic sent by SS using directional antenna

Table 4.2 – Results comparing Simulation 1 and Simulation 2

<table>
<thead>
<tr>
<th>Simulation 1</th>
<th>Simulation 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omni-directional antenna</td>
<td>directional antenna</td>
</tr>
<tr>
<td>Gain of BS and RS = 5dBi</td>
<td>Gain of BS and RS = 15dBi</td>
</tr>
<tr>
<td>Beam width = 360°</td>
<td>Beam width = 40°</td>
</tr>
<tr>
<td>Traffic sent by BS = 13 Mbps</td>
<td>Traffic sent by BS = 22.25 Mbps</td>
</tr>
<tr>
<td>Sum of Traffic sent by BS of relays = 12.8Mbps</td>
<td>Sum of Traffic sent by BS of relays = 22Mbps</td>
</tr>
<tr>
<td>Sum of Traffic sent by SS = 12.75 Mbps</td>
<td>Sum of Traffic sent by SS = 21.8 Mbps</td>
</tr>
</tbody>
</table>

From table 4.2, we can see that the throughput of the entire network is increased by 9 Mbps, when we use directional antennas as compared to omni-directional antennas.

Conclusion

We have automated the process of creating directional antennas in OPNET by using the EMA library. We have created a conical directional antenna, a cosine squared directional antenna and a pencil beam directional antenna. We have implemented tracking of a directional antenna which is extremely useful in mobile scenarios. When we combine the antenna creation and the tracking code, we can create and assign different antenna patterns to the base station as the subscriber stations are in motion. This is the
only way to use directional antenna in mobile cases. This algorithm can be used to create antenna patterns for any wireless technology in OPNET such as WiFi and WiMAX. Finally we created an ILP formulation for the RS-SS resource allocation problem which is proven to be NP-Complete. This is an optimization problem and the rounding Algorithm is a $\frac{1}{2\pi/\theta_{min}}$ – approximation algorithm in polynomial time. This resource allocation algorithm can be used in any technology that has a centralized resource allocation algorithm such as WiMAX, where the Base Station runs this algorithm. We have some simulation results showing 10Mbps improved throughput using directional antennas with the assignment given by our resource allocation algorithm.
REFERENCED CITED
REFERENCES


APPENDICES
APPENDIX A

ANTENNA PATTERN CREATION AND TRACKING CODE IN OPNET
void wimax_phy_mcarrier_pk_send (Packet* pkptr, WrlsT_Phy_Chnl_Info* phy_info_ptr, WrlsT_Phy_Mcarrier_Tx_Mgmt* mcarrier_tx_ptr,
    WrlsT_Phy_Mcarrier_Burst_Info* busrt_alloc_info_ptr, Objid tx_module_objid)
{
    int output_counduit_index;

    /* *************************************************code added in summer fo 2009 by neeraj***********************************/
    /******************************************************************************
    ******************************************defining variables in summer 2009**********/
    double lsdf;
    double leh;
    double erg;
    double qwer;
    double dfg;
    double err;
    double drg;
    Objid tx_node_id;
    Objid subnet_id;
    Objid rx_node_id;
    //Objid ant_node_id;
    Objid ant_node_id1;
    Objid ant_node_id2;
    Objid rx_node_id11;
    Objid rx_node_id12;
    Objid rx_node_id13;
    Objid rx_node_id14;
    Objid rx_node_id15;
    Objid rx_node_id16;
    double x_pos;
    double y_pos;
    double z_pos;
    double latitude;
    double longitude;
    double altitude;
    double BS_lat;
    double BS_log;
    double BS_alt;
    double BS1_lat;
    double BS1_log;
    double BS1_alt;
    double BS2_lat;
    double BS2_log;
    double BS2_alt;
    double BS3_lat;
    double BS3_log;
    double BS3_alt;
    double m1;
    double m2;
    double theeta;
    double theta;
    double distance_a;
    double distance_b;
    double distance_c;
    double distance_a1;
    double distance_b1;
    double distance_c1;
    double distance_a2;
    double distance_b2;
double distance_c2;
double distance_a3;
double distance_b3;
double distance_c3;
double distance_x;
double distance_com;
double distance_y;
double distance_z1;
double distance_z2;
double distance_xalpha;
double distance_yalpha;
double radius;
double theta_t1;
double theta_t2;
double theta_t3;
double theta_phi;
double thetai1;
double thetai2;

int i, p_min_1, p_max_1, p_min_2, p_max_2, p_min_3, p_max_3, i, p_min_i, p_max_i, phi_min_1, phi_max_1, phi_min_2, phi_max_2, phi_min_3, phi_max_3, phi_min_i, phi_max_i;

int theta_min_int, theta_max_int, phi_min_int_1, phi_max_int_1, phi_min_int_2, phi_max_int_2, phi_min_int_3, phi_max_int_3, phi_min_int_i, phi_max_int_i, g, number_ss;

int t = 0;
int aabb = 0, phi_max[10], xy = 0, phi_max_int[10], abcd = 0;
char c;
FILE *f, *fp;
FILE *f1;
char s, filename[20];

/** Inputs: **/
/** pkptr-> Packet to be send through the multicarrier PHY. **/
/** mcarrier_tx_ptr-> Multicarrier tx object. **/
/** phy_info_ptr-> Contains the configuration of the PHY layer. **/
/** (used by the wrls pipeline stages) **/
/** Burst allocation **/
/** subchnl_start-> First subchannel in the burst allocation **/
/** subchnl_count-> Total number of subchannels in the allocation **/
/** end_of_transmission-> Time when the allocation ends **/
/** Tx module objid **/
/** This function delivers a packet to the wrls pipeline stages (via **/
/** radio channel). It allows packets to be transmitted in parallel **/
/** as in a multicarrier system (e.g. OFDMA). "Conduits" are used to send**/
/** the packets in "parallel" (e.g. because time overlap). **/
/** Before a packet is sent a free conduit is located and reserved for **/
/** the entire transmission of a given burst. **/
/** The information about the burst allocation and the PHY layer **/
/** configuration are included in the packet in indexed fields that are **/
/** created "on the fly". Once the packet is sent, this framework **/
/** assumes that no more indexed fields will be added into this packet, **/
/** otherwise access to the burst information and PHY layer information **/
/** from the wrls pipeline stages will fail. **/

FIN (wimax_phy_mcarrier_pk_send (<args>));
/* Set the burst allocation information in the packet. */
op_pk_fd_set_ptr (pkptr, mac_access_burst_info_field_index(pkptr), busrt_alloc_info_ptr,
0 /*field size zero*/, wrls_burst_info_copy_proc, op_prg_mem_free, sizeof(WrlsT_Phy_Mcarrier_Burst_Info));

/* Set the PHY channel information associated with this transmission into the packet. */
op_pk_fd_set_ptr (pkptr, mac_access_phy_info_field_index(pkptr), phy_info_ptr,
0 /*field size zero*/, wimax_phy_info_copy_proc, wimax_phy_info_destroy_proc,
sizeof(WrlsT_Phy_Chnl_Info));

/* Obtain the next available conduit in the mcarrier tx. */
output_conduit_index = wimax_phy_mcarrier_tx_conduit_index_get (mcARRIER_tx_ptr, op_sim_time () +
busrt_alloc_info_ptr - start_time, 
op_sim_time () + busrt_alloc_info_ptr - start_time + busrt_alloc_info_ptr - tx_delay);

/* Deliver the packet to the radio tx module, use the next available conduit for this transmission. */

/* ********************  summer of 2009- this is where the actual code is implemented***************************/

//printf("plzzzz %d fix\n",OPC_OBJTYPE_NODE_FIX);
//printf("plzzzz %d mob\n",OPC_OBJTYPE_NODE_MOB);

if(op_id_from_name(subnet_id, OPC_OBJTYPE_NODE_FIX, "BS")==3) {
    //printf("ok on BS \n");
    tx_node_id = op_topo_parent(op_id_self ());
    subnet_id = op_topo_parent(tx_node_id);
    //ant_node_id1 = op_id_from_name(subnet_id, OPC_OBJTYPE_ANT, "wimax_ant_8_0");
    //rx_node_id = op_id_from_name(subnet_id, OPC_OBJTYPE_NODE_MOB, "SS");
    //op_ima_obj_pos_get (rx_node_id, &latitude, &longitude,&altitude, &x_pos, &y_pos, &z_pos);
    longitudes="latitude

rx_node_id11 = op_id_from_name(subnet_id, OPC_OBJTYPE_NODE_FIX, "BS");
op_ima_obj_pos_get (rx_node_id11, &latitude, &longitude,&altitude, &x_pos, &y_pos, &z_pos);
BS1_lat=latitude;
BS1_log=longitude;
BS1_alt=altitude;

rx_node_id12 = op_id_from_name(subnet_id, OPC_OBJTYPE_NODE_MOB, "SS");
op_ima_obj_pos_get (rx_node_id12, &latitude, &longitude,&altitude, &x_pos, &y_pos, &z_pos);
BS2_lat=latitude;
BS2_log=longitude;
BS2_alt=altitude;

rx_node_id13 = op_id_from_name(subnet_id, OPC_OBJTYPE_NODE_MOB, "SS_2");
op_ima_obj_pos_get (rx_node_id13, &latitude, &longitude,&altitude, &x_pos, &y_pos, &z_pos);
BS2_lat=latitude;
BS2_log=longitude;
BS2_alt=altitude;
rx_node_id14 = op_id_from_name (subnet_id, OPC_OBJTYPE_NODE_MOB, "SS_3");
op_ima_obj_pos_get (rx_node_id14, &latitude, &longitude, &altitude, &x_pos, &y_pos, &z_pos);
BS3_lat=latitude;
BS3_log=longitude;
BS3_alt=altitude;
* /

//rx_node_id15 = op_id_from_name (subnet_id, OPC_OBJTYPE_NODE_MOB, "SS4");
//op_ima_obj_pos_get (rx_node_id15, &latitude, &longitude, &altitude, &x_pos, &y_pos, &z_pos);

//rx_node_id16 = op_id_from_name (subnet_id, OPC_OBJTYPE_NODE_MOB, "SS5");
//op_ima_obj_pos_get (rx_node_id16, &latitude, &longitude, &altitude, &x_pos, &y_pos, &z_pos);

//***************************harshas theeta calculations start*********************************************/
/*
distance_a = sqrt(((BS2_lat-BS_lat)*(BS2_lat-BS_lat)) + ((BS2_log-BS_log)*(BS2_log-BS_log)));
distance_b = sqrt(((BS2_lat-BS1_lat)*(BS2_lat-BS1_lat)) + ((BS2_log-BS1_log)*(BS2_log-BS1_log)));
distance_c = sqrt(((BS1_lat-BS-lat)*(BS1_lat-BS_lat)) + ((BS1_log-BS_log)*(BS1_log-BS_log)));
theta = acos (((distance_c*distance_c) + (distance_a*distance_a) - (distance_b*distance_b))/(2*distance_a*distance_c));
theta1=theta*180/3.14;

distance_a = sqrt(((BS3_lat-BS_lat)*(BS3_lat-BS_lat)) + ((BS3_log-BS_log)*(BS3_log-BS_log)));
distance_b = sqrt(((BS3_lat-BS1_lat)*(BS3_lat-BS1_lat)) + ((BS3_log-BS1_log)*(BS3_log-BS1_log)));
distance_c = sqrt(((BS1_lat-BS-lat)*(BS1_lat-BS_lat)) + ((BS1_log-BS_log)*(BS1_log-BS_log)));
theta = acos (((distance_c*distance_c) + (distance_a*distance_a) - (distance_b*distance_b))/(2*distance_a*distance_c));
theta2=theta*180/3.14;

just = 0;
*/
//just = 1;
//just = 0;
just = 1;

/********************************************harshas theeta calculations end*********************************************/

if(just==0)
{
    printf("ohh no");
    just=just+1;
}

f=fopen("abcdefg.em.c","w+");
fwrite("#include <opnet.h>",f);
fwrite("#include <opnet.h>",f);


fputc('n',f);
put("#include <ema.h>\n",f);
putc('n',f);
putc("#include <opnet_emadefs.h>\n",f);
putc('n',f);
putc("#include <opnet_constants.h>\n",f);
putc('n',f);
putc('n',f);
putc('n',f);

//printf("enter the number of ss's\n");
// scanf("%d",&number_ss);
number_ss=3;
for(aabb=0;aabb<number_ss-1;aabb=aabb+1)
{
    //printf("enter the maximum value of phi angle of ss%d\n",aabb+2);
    // scanf("%d",&phi_max[xy]);
    phi_max[0]=int(theta1);
    phi_max[1]=int(theta2);
    phi_max_int[0]= (int) floor (phi_max[0]/5);
    phi_max_int[1]= (int) floor (phi_max[1]/5);
    xy=2;
}

/////printf("enter your gain \n");
/////scanf("%d",&g);
g=22;
//printf("enter the name of your antenna pattern (.pa file) without the .pa \n");
// scanf("%s",filename);

//printf("ok1");

for(i=0;i<36;i++)
{
    if ( (i==0)||(i==1)||(i==(phi_max_int[abcd]-1)) || (i==(phi_max_int[abcd])) || (i==(phi_max_int[abcd]+1)))
    {
        //printf("ok1");
        if(abcd<xy)
        {
            fputs("double",f);
            fputs("dvec_",f);
            fprintf (f,"%d",i);
            fputs(" [] =\n",f);
            putc('n',f);
            putc('n',f);
            putc('n',f);
            for(t=0;t<72;t++)
            {
                fprintf (f, "\%d\",g);
            }
        }
    }
}
fprintf (f, "%s", ");

} else
{
    for(t=0;t<72;t++)
    {
        if(t==70 || t==71)
        {
            fprintf (f, "%d",g);
        } else
        {
            fprintf (f, "%d",0);
        }
        fprintf (f, "%s", ");
    }

   putc(\n',f);
   putc(\t',f);
   putc(}',f);
   putc(';',f);
   putc(\n',f);
   fputc(\n',f);
   fputs("double",f);
   putc(',f);
   putc('dvec_',f);
   fprintf (f, "%d",i);
    fputs(" \[] =",f);
    while( ( c=getc(f1)) != EOF )
    {
        putc( c,f);
        if(c=='\n')
            putc(\n',f);
        else if(c=='\t')
            putc(\t',f);
        else
            fputs(c,f);
        while((c=getc(f1)) != EOF)
        {
            putc( c,f);
        }
    }
putc(\n', f);
putc(\n', f);
fclose(f1);

fclose(fp);

while ((s = getc(fp)) != EOF) {
    putc(s, f);
}
fclose(f);
fclose(fp);

//open f3, rewind, put headders

//system("op_mkema -m abcdefg");
//system("C:/Documents and Settings/neeraj.gurdasani/My Documents/op_models/abcdefg.dev32.i0.em.x");
//system("/op_mkema -m abcdefg");
system("abcdefg.dev32.i0.em.x");
//system("cd Documents and Settings/neeraj.gurdasani/My Documents/op_models/abcdefg.dev32.i0.em.x");
//system("C:/Documents and Settings/neeraj.gurdasani/My Documents/op_models/abcdefg.dev32.i0.em.x");
//system("cd Documents and Settings/neeraj.gurdasani/My Documents/op_models/abcdefg.dev32.i0.em.x");
//ShellExecute(GetDesktopWindow(), "open", "C:/Documents and Settings/neeraj.gurdasani/My Documents/op_models/abcdefg.dev32.i0.em.x", NULL, NULL, SW_SHOWNORMAL);
//system("op_mkema -m abcdefg");
//ShellExecute(NULL, NULL, "C:/Documents and Settings/neeraj.gurdasani/My Documents/op_models/abcdefg.dev32.i0.em.x", NULL, NULL, SW_SHOWNORMAL);
//op_ima_obj_attr_set (op_id_from_name (op_id_from_name (op_topo_parent (op_topo_parent (op_id_self ())), OPC_OBJTYPE_NODE_FIX, "BS"), OPC_OBJTYPE_ANT, "wimax_ant_8_0"), "pattern", "mont");
//op_ima_obj_attr_set (op_id_from_name (op_id_from_name (op_topo_parent (op_topo_parent (op_id_self ())), OPC_OBJTYPE_NODE_FIX, "BS"), OPC_OBJTYPE_ANT, "wimax_ant_8_0"), "target latitude", BS1_lat);
//op_ima_obj_attr_set (op_id_from_name (op_id_from_name (op_topo_parent (op_topo_parent (op_id_self ())), OPC_OBJTYPE_NODE_FIX, "BS"), OPC_OBJTYPE_ANT, "wimax_ant_8_0"), "target longitude", BS1_log);
//op_ima_obj_attr_set (op_id_from_name (op_id_from_name (op_topo_parent (op_topo_parent (op_id_self ())), OPC_OBJTYPE_NODE_FIX, "BS"), OPC_OBJTYPE_ANT, "wimax_ant_8_0"), "target altitude", BS1_alt);

}
int main (int argc, char* argv [])
{
    EmaT_Model_Id model_id;
    EmaT_Object_Id obj [36];

    //printf("ok implement");
    //op_ima_obj_attr_set (op_id_from_name (op_id_from_name (op_topo_parent (op_topo_parent (op_id_self ()))),
        OPC_OBJTYPE_NODE_FIX, "BS"), OPC_OBJTYPE_ANT, "wimax_ant_8_0"), "pattern", "cone_5");
    op_ima_obj_attr_set (op_id_from_name (op_id_from_name (op_topo_parent (op_topo_parent (op_id_self ()))),
        OPC_OBJTYPE_NODE_FIX, "BS"), OPC_OBJTYPE_ANT, "wimax_ant_8_0"), "target longitude", BS1_log);
    op_ima_obj_attr_set (op_id_from_name (op_id_from_name (op_topo_parent (op_topo_parent (op_id_self ()))),
        OPC_OBJTYPE_NODE_FIX, "BS"), OPC_OBJTYPE_ANT, "wimax_ant_8_0"), "target altitude", BS1_alt);
    op_pk_deliver_delayed (pkptr, tx_module_objid, output conduits index, busrt alloc info ptr->start_time);
}

Abcd.txt


End.txt

/* array for all objects in model */
EmaT_Object_Id obj [36];

...
/* initialize EMA package */
Ema_Init (EMAC_MODE_ERR_PRINT | EMAC_MODE_REL_60, argc, argv);

/* create an empty model */
model_id = Ema_Model_Create (MOD_ANT_PATTERN);

/* create all objects */
ob [0] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [1] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [2] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [3] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [4] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [5] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [6] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [7] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [8] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [9] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [10] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [11] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [12] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [13] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [14] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [15] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [16] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [17] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [18] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [19] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [20] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [21] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [22] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [23] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [24] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [25] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [26] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [27] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [28] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [29] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [30] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [31] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [32] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [33] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [34] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);
ob [35] = Ema_Object_Create (model_id, OBJ_PAT_PLANE);

/* set the model level attributes */
Ema_Model_Attr_Set (model_id,
   "num planes",     COMP_CONTENTS, 36,
   "plane array",   COMP_ARRAY_CONTENTS (0), obj [0],
   "plane array",   COMP_ARRAY_CONTENTS (1), obj [1],
   "plane array",   COMP_ARRAY_CONTENTS (2), obj [2],
   "plane array",   COMP_ARRAY_CONTENTS (3), obj [3],
   "plane array",   COMP_ARRAY_CONTENTS (4), obj [4],
   "plane array",   COMP_ARRAY_CONTENTS (5), obj [5],
   "plane array",   COMP_ARRAY_CONTENTS (6), obj [6],
   "plane array",   COMP_ARRAY_CONTENTS (7), obj [7],
   "plane array",   COMP_ARRAY_CONTENTS (8), obj [8],
   "plane array",   COMP_ARRAY_CONTENTS (9), obj [9],
   "plane array",   COMP_ARRAY_CONTENTS (10), obj [10],
   "plane array",   COMP_ARRAY_CONTENTS (11), obj [11],
   "plane array",   COMP_ARRAY_CONTENTS (12), obj [12],
   "plane array",   COMP_ARRAY_CONTENTS (13), obj [13].
"plane array", COMP_ARRAY_CONTENTS (14), obj [14],
EMAC_EOL);

Ema_Model_Attr_Set (model_id,
  "plane array", COMP_ARRAY_CONTENTS (15), obj [15],
  "plane array", COMP_ARRAY_CONTENTS (16), obj [16],
  "plane array", COMP_ARRAY_CONTENTS (17), obj [17],
  "plane array", COMP_ARRAY_CONTENTS (18), obj [18],
  "plane array", COMP_ARRAY_CONTENTS (19), obj [19],
  "plane array", COMP_ARRAY_CONTENTS (20), obj [20],
  "plane array", COMP_ARRAY_CONTENTS (21), obj [21],
  "plane array", COMP_ARRAY_CONTENTS (22), obj [22],
  "plane array", COMP_ARRAY_CONTENTS (23), obj [23],
  "plane array", COMP_ARRAY_CONTENTS (24), obj [24],
  "plane array", COMP_ARRAY_CONTENTS (25), obj [25],
  "plane array", COMP_ARRAY_CONTENTS (26), obj [26],
  "plane array", COMP_ARRAY_CONTENTS (27), obj [27],
  "plane array", COMP_ARRAY_CONTENTS (28), obj [28],
  "plane array", COMP_ARRAY_CONTENTS (29), obj [29],
  "plane array", COMP_ARRAY_CONTENTS (30), obj [30],
EMAC_EOL);

Ema_Model_Attr_Set (model_id,
  "plane array", COMP_ARRAY_CONTENTS (31), obj [31],
  "plane array", COMP_ARRAY_CONTENTS (32), obj [32],
  "plane array", COMP_ARRAY_CONTENTS (33), obj [33],
  "plane array", COMP_ARRAY_CONTENTS (34), obj [34],
  "plane array", COMP_ARRAY_CONTENTS (35), obj [35],
EMAC_EOL);

/* assign attrs for object 'obj [0]' */
Ema_Object_Attr_Set (model_id, obj [0],
  "view low gain", COMP_CONTENTS, (double) -21,
  "view high gain", COMP_CONTENTS, (double) -19,
  "gain vec", COMP_INTENDED, EMAC_DISABLED,
EMAC_EOL);

Ema_Object_Attr_Set (model_id, obj [0], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
{
  Ema_Object_Attr_Set (model_id, obj [0], "gain vec", COMP_DVEC_CONTENTS(i), dvec_0 [i],
EMAC_EOL);
}

/* assign attrs for object 'obj [1]' */
Ema_Object_Attr_Set (model_id, obj [1],
  "view low gain", COMP_CONTENTS, (double) -21,
  "view high gain", COMP_CONTENTS, (double) -19,
  "gain vec", COMP_INTENDED, EMAC_DISABLED,
EMAC_EOL);

Ema_Object_Attr_Set (model_id, obj [1], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
{
  Ema_Object_Attr_Set (model_id, obj [1], "gain vec", COMP_DVEC_CONTENTS(i), dvec_1 [i],
EMAC_EOL);
}

/* assign attrs for object 'obj [2]' */
Ema_Object_Attr_Set (model_id, obj [2],
  "view low gain", COMP_CONTENTS, (double) -21,
"view high gain", COMP_CONTENTS, (double) -19,
"gain vec", COMP_INTENDED, EMAC_DISABLED,
EMAC_EOL);

Ema_Object_Attr_Set(model_id, obj [2], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
    { Ema_Object_Attr_Set(model_id, obj [2], "gain vec", COMP_DVEC_CONTENTS(i), dvec_2 [i],
EMAC_EOL);
    }

/* assign attrs for object 'obj [3]' */
Ema_Object_Attr_Set(model_id, obj [3],
"view low gain", COMP_CONTENTS, (double) -21,
"view high gain", COMP_CONTENTS, (double) -19,
"gain vec", COMP_INTENDED, EMAC_DISABLED,
EMAC_EOL);
Ema_Object_Attr_Set(model_id, obj [3], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
    { Ema_Object_Attr_Set(model_id, obj [3], "gain vec", COMP_DVEC_CONTENTS(i), dvec_3 [i],
EMAC_EOL);
    }

/* assign attrs for object 'obj [4]' */
Ema_Object_Attr_Set(model_id, obj [4],
"view low gain", COMP_CONTENTS, (double) -21,
"view high gain", COMP_CONTENTS, (double) -19,
"gain vec", COMP_INTENDED, EMAC_DISABLED,
EMAC_EOL);
Ema_Object_Attr_Set(model_id, obj [4], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
    { Ema_Object_Attr_Set(model_id, obj [4], "gain vec", COMP_DVEC_CONTENTS(i), dvec_4 [i],
EMAC_EOL);
    }

/* assign attrs for object 'obj [5]' */
Ema_Object_Attr_Set(model_id, obj [5],
"view low gain", COMP_CONTENTS, (double) -21,
"view high gain", COMP_CONTENTS, (double) -19,
"gain vec", COMP_INTENDED, EMAC_DISABLED,
EMAC_EOL);
Ema_Object_Attr_Set(model_id, obj [5], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
    { Ema_Object_Attr_Set(model_id, obj [5], "gain vec", COMP_DVEC_CONTENTS(i), dvec_5 [i],
EMAC_EOL);
    }

/* assign attrs for object 'obj [6]' */
Ema_Object_Attr_Set(model_id, obj [6],
"view low gain", COMP_CONTENTS, (double) -21,
"view high gain", COMP_CONTENTS, (double) -19,
"gain vec", COMP_INTENDED, EMAC_DISABLED,
EMAC_EOL);
Ema_Object_Attr_Set (model_id, obj [6], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
{
    Ema_Object_Attr_Set (model_id, obj [6], "gain vec", COMP_DVEC_CONTENTS(i), dvec_6 [i], EMAC_EOL);
}

/* assign attrs for object 'obj [7]' */
Ema_Object_Attr_Set (model_id, obj [7], "view low gain", COMP_CONTENTS, (double) -21,
"view high gain", COMP_CONTENTS, (double) -19,
"gain vec", COMP_INTENDED, EMAC_DISABLED,
EMAC_EOL);
Ema_Object_Attr_Set (model_id, obj [7], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
{
    Ema_Object_Attr_Set (model_id, obj [7], "gain vec", COMP_DVEC_CONTENTS(i), dvec_7 [i], EMAC_EOL);
}

/* assign attrs for object 'obj [8]' */
Ema_Object_Attr_Set (model_id, obj [8], "view low gain", COMP_CONTENTS, (double) -21,
"view high gain", COMP_CONTENTS, (double) -19,
"gain vec", COMP_INTENDED, EMAC_DISABLED,
EMAC_EOL);
Ema_Object_Attr_Set (model_id, obj [8], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
{
    Ema_Object_Attr_Set (model_id, obj [8], "gain vec", COMP_DVEC_CONTENTS(i), dvec_8 [i], EMAC_EOL);
}

/* assign attrs for object 'obj [9]' */
Ema_Object_Attr_Set (model_id, obj [9], "view low gain", COMP_CONTENTS, (double) 28.8124999999999,
"view high gain", COMP_CONTENTS, (double) 31.845394736842,
"gain vec", COMP_INTENDED, EMAC_DISABLED,
EMAC_EOL);
Ema_Object_Attr_Set (model_id, obj [9], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
{
    Ema_Object_Attr_Set (model_id, obj [9], "gain vec", COMP_DVEC_CONTENTS(i), dvec_9 [i], EMAC_EOL);
}

/* assign attrs for object 'obj [10]' */
Ema_Object_Attr_Set (model_id, obj [10], "view low gain", COMP_CONTENTS, (double) -21,
"view high gain", COMP_CONTENTS, (double) -19,
"gain vec", COMP_INTENDED, EMAC_DISABLED,
EMAC_EOL);
Ema_Object_Attr_Set (model_id, obj [10], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
    { 
        Ema_Object_Attr_Set (model_id, obj [10], "gain vec", COMP_DVEC_CONTENTS(i), dvec_10 [i], EMAC_EOL);
    }

/* assign attrs for object 'obj [11]' */
Ema_Object_Attr_Set (model_id, obj [11],
    "view low gain", COMP_CONTENTS, (double) -21,
    "view high gain", COMP_CONTENTS, (double) -19,
    "gain vec", COMP_INTENDED, EMAC_DISABLED, EMAC_EOL);

Ema_Object_Attr_Set (model_id, obj [11], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
    { 
        Ema_Object_Attr_Set (model_id, obj [11], "gain vec", COMP_DVEC_CONTENTS(i), dvec_11 [i], EMAC_EOL);
    }

/* assign attrs for object 'obj [12]' */
Ema_Object_Attr_Set (model_id, obj [12],
    "view low gain", COMP_CONTENTS, (double) -21,
    "view high gain", COMP_CONTENTS, (double) -19,
    "gain vec", COMP_INTENDED, EMAC_DISABLED, EMAC_EOL);

Ema_Object_Attr_Set (model_id, obj [12], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
    { 
        Ema_Object_Attr_Set (model_id, obj [12], "gain vec", COMP_DVEC_CONTENTS(i), dvec_12 [i], EMAC_EOL);
    }

/* assign attrs for object 'obj [13]' */
Ema_Object_Attr_Set (model_id, obj [13],
    "view low gain", COMP_CONTENTS, (double) -21,
    "view high gain", COMP_CONTENTS, (double) -19,
    "gain vec", COMP_INTENDED, EMAC_DISABLED, EMAC_EOL);

Ema_Object_Attr_Set (model_id, obj [13], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
    { 
        Ema_Object_Attr_Set (model_id, obj [13], "gain vec", COMP_DVEC_CONTENTS(i), dvec_13 [i], EMAC_EOL);
    }

/* assign attrs for object 'obj [14]' */
Ema_Object_Attr_Set (model_id, obj [14],
    "view low gain", COMP_CONTENTS, (double) -21,
    "view high gain", COMP_CONTENTS, (double) -19,
    "gain vec", COMP_INTENDED, EMAC_DISABLED, EMAC_EOL);

Ema_Object_Attr_Set (model_id, obj [14], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
    { 

Ema_Object_Attr_Set (model_id, obj [14], "gain vec", COMP_DVEC_CONTENTS(i), dvec_14 [i],
EMAC_EOL);
}

/* assign attrs for object 'obj [15]' */
Ema_Object_Attr_Set (model_id, obj [15],
"view low gain", COMP_CONTENTS, (double) -21,
"view high gain", COMP_CONTENTS, (double) -19,
"gain vec", COMP_INTENDED, EMAC_DISABLED,
EMAC_EOL);

Ema_Object_Attr_Set (model_id, obj [15], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
{
    Ema_Object_Attr_Set (model_id, obj [15], "gain vec", COMP_DVEC_CONTENTS(i), dvec_15 [i],
EMAC_EOL);
}

/* assign attrs for object 'obj [16]' */
Ema_Object_Attr_Set (model_id, obj [16],
"view low gain", COMP_CONTENTS, (double) -21,
"view high gain", COMP_CONTENTS, (double) -19,
"gain vec", COMP_INTENDED, EMAC_DISABLED,
EMAC_EOL);

Ema_Object_Attr_Set (model_id, obj [16], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
{
    Ema_Object_Attr_Set (model_id, obj [16], "gain vec", COMP_DVEC_CONTENTS(i), dvec_16 [i],
EMAC_EOL);
}

/* assign attrs for object 'obj [17]' */
Ema_Object_Attr_Set (model_id, obj [17],
"view low gain", COMP_CONTENTS, (double) -21,
"view high gain", COMP_CONTENTS, (double) -19,
"gain vec", COMP_INTENDED, EMAC_DISABLED,
EMAC_EOL);

Ema_Object_Attr_Set (model_id, obj [17], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
{
    Ema_Object_Attr_Set (model_id, obj [17], "gain vec", COMP_DVEC_CONTENTS(i), dvec_17 [i],
EMAC_EOL);
}

/* assign attrs for object 'obj [18]' */
Ema_Object_Attr_Set (model_id, obj [18],
"view low gain", COMP_CONTENTS, (double) 19.3333333333329,
"view high gain", COMP_CONTENTS, (double) 21.3684210526311,
"gain vec", COMP_INTENDED, EMAC_DISABLED,
EMAC_EOL);

Ema_Object_Attr_Set (model_id, obj [18], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
{
    Ema_Object_Attr_Set (model_id, obj [18], "gain vec", COMP_DVEC_CONTENTS(i), dvec_18 [i],
EMAC_EOL);
}
/* assign attrs for object 'obj [19]' */
Ema_Object_Attr_Set (model_id, obj [19],
   "view low gain", COMP_CONTENTS, (double) -21,
   "view high gain", COMP_CONTENTS, (double) -19,
   "gain vec", COMP_INTENDED, EMAC_DISABLED,
   EMAC_EOL);

Ema_Object_Attr_Set (model_id, obj [19], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
{
   Ema_Object_Attr_Set (model_id, obj [19], "gain vec", COMP_DVEC_CONTENTS(i), dvec_19 [i], EMAC_EOL);
}

/* assign attrs for object 'obj [20]' */
Ema_Object_Attr_Set (model_id, obj [20],
   "view low gain", COMP_CONTENTS, (double) -21,
   "view high gain", COMP_CONTENTS, (double) -19,
   "gain vec", COMP_INTENDED, EMAC_DISABLED,
   EMAC_EOL);

Ema_Object_Attr_Set (model_id, obj [20], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
{
   Ema_Object_Attr_Set (model_id, obj [20], "gain vec", COMP_DVEC_CONTENTS(i), dvec_20 [i], EMAC_EOL);
}

/* assign attrs for object 'obj [21]' */
Ema_Object_Attr_Set (model_id, obj [21],
   "view low gain", COMP_CONTENTS, (double) -21,
   "view high gain", COMP_CONTENTS, (double) -19,
   "gain vec", COMP_INTENDED, EMAC_DISABLED,
   EMAC_EOL);

Ema_Object_Attr_Set (model_id, obj [21], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
{
   Ema_Object_Attr_Set (model_id, obj [21], "gain vec", COMP_DVEC_CONTENTS(i), dvec_21 [i], EMAC_EOL);
}

/* assign attrs for object 'obj [22]' */
Ema_Object_Attr_Set (model_id, obj [22],
   "view low gain", COMP_CONTENTS, (double) -21,
   "view high gain", COMP_CONTENTS, (double) -19,
   "gain vec", COMP_INTENDED, EMAC_DISABLED,
   EMAC_EOL);

Ema_Object_Attr_Set (model_id, obj [22], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
{
   Ema_Object_Attr_Set (model_id, obj [22], "gain vec", COMP_DVEC_CONTENTS(i), dvec_22 [i], EMAC_EOL);
}

/* assign attrs for object 'obj [23]' */
Ema_Object_Attr_Set (model_id, obj [23], "view low gain", COMP_CONTENTS, (double) -21, "view high gain", COMP_CONTENTS, (double) -19, "gain vec", COMP_INTENDED, EMAC_DISABLED, EMAC_EOL);

Ema_Object_Attr_Set (model_id, obj [23], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);

for (i = 0; i < 72; i++)
{
    Ema_Object_Attr_Set (model_id, obj [23], "gain vec", COMP_DVEC_CONTENTS(i), dvec_23 [i], EMAC_EOL);
}
/* assign attrs for object 'obj [24]' */
Ema_Object_Attr_Set (model_id, obj [24], "view low gain", COMP_CONTENTS, (double) -21, "view high gain", COMP_CONTENTS, (double) -19, "gain vec", COMP_INTENDED, EMAC_DISABLED, EMAC_EOL);

Ema_Object_Attr_Set (model_id, obj [24], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);

for (i = 0; i < 72; i++)
{
    Ema_Object_Attr_Set (model_id, obj [24], "gain vec", COMP_DVEC_CONTENTS(i), dvec_24 [i], EMAC_EOL);
}
/* assign attrs for object 'obj [25]' */
Ema_Object_Attr_Set (model_id, obj [25], "view low gain", COMP_CONTENTS, (double) -21, "view high gain", COMP_CONTENTS, (double) -19, "gain vec", COMP_INTENDED, EMAC_DISABLED, EMAC_EOL);

Ema_Object_Attr_Set (model_id, obj [25], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);

for (i = 0; i < 72; i++)
{
    Ema_Object_Attr_Set (model_id, obj [25], "gain vec", COMP_DVEC_CONTENTS(i), dvec_25 [i], EMAC_EOL);
}
/* assign attrs for object 'obj [26]' */
Ema_Object_Attr_Set (model_id, obj [26], "view low gain", COMP_CONTENTS, (double) -21, "view high gain", COMP_CONTENTS, (double) -19, "gain vec", COMP_INTENDED, EMAC_DISABLED, EMAC_EOL);

Ema_Object_Attr_Set (model_id, obj [26], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);

for (i = 0; i < 72; i++)
{
    Ema_Object_Attr_Set (model_id, obj [26], "gain vec", COMP_DVEC_CONTENTS(i), dvec_26 [i], EMAC_EOL);
}
/* assign attrs for object 'obj [27]' */
Ema_Object_Attr_Set (model_id, obj [27], "view low gain", COMP_CONTENTS, (double) -21, "view high gain", COMP_CONTENTS, (double) -19,
Ema_Object_Attr_Set (model_id, obj [27], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);

for (i = 0; i < 72; i++)
{
    Ema_Object_Attr_Set (model_id, obj [27], "gain vec", COMP_DVEC_CONTENTS(i), dvec_27 [i], EMAC_EOL);
}

/* assign attrs for object 'obj [28]' */
Ema_Object_Attr_Set (model_id, obj [28],
    "view low gain", COMP_CONTENTS, (double) -21,
    "view high gain", COMP_CONTENTS, (double) -19,
    "gain vec", COMP_INTENDED, EMAC_DISABLED,
    EMAC_EOL);
Ema_Object_Attr_Set (model_id, obj [28], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
{
    Ema_Object_Attr_Set (model_id, obj [28], "gain vec", COMP_DVEC_CONTENTS(i), dvec_28 [i], EMAC_EOL);
}

/* assign attrs for object 'obj [29]' */
Ema_Object_Attr_Set (model_id, obj [29],
    "view low gain", COMP_CONTENTS, (double) -21,
    "view high gain", COMP_CONTENTS, (double) -19,
    "gain vec", COMP_INTENDED, EMAC_DISABLED,
    EMAC_EOL);
Ema_Object_Attr_Set (model_id, obj [29], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
{
    Ema_Object_Attr_Set (model_id, obj [29], "gain vec", COMP_DVEC_CONTENTS(i), dvec_29 [i], EMAC_EOL);
}

/* assign attrs for object 'obj [30]' */
Ema_Object_Attr_Set (model_id, obj [30],
    "view low gain", COMP_CONTENTS, (double) -21,
    "view high gain", COMP_CONTENTS, (double) -19,
    "gain vec", COMP_INTENDED, EMAC_DISABLED,
    EMAC_EOL);
Ema_Object_Attr_Set (model_id, obj [30], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);
for (i = 0; i < 72; i++)
{
    Ema_Object_Attr_Set (model_id, obj [30], "gain vec", COMP_DVEC_CONTENTS(i), dvec_30 [i], EMAC_EOL);
}

/* assign attrs for object 'obj [31]' */
Ema_Object_Attr_Set (model_id, obj [31],
    "view low gain", COMP_CONTENTS, (double) -21,
    "view high gain", COMP_CONTENTS, (double) -19,
    "gain vec", COMP_INTENDED, EMAC_DISABLED,
    EMAC_EOL);
Ema_Object_Attr_Set (model_id, obj [31], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);

  for (i = 0; i < 72; i++)
  {
    Ema_Object_Attr_Set (model_id, obj [31], "gain vec", COMP_DVEC_CONTENTS(i), dvec_31 [i],
    EMAC_EOL);
  }

  /* assign attrs for object 'obj [32]' */
  Ema_Object_Attr_Set (model_id, obj [32],
    "view low gain", COMP_CONTENTS, (double) -21,
    "view high gain", COMP_CONTENTS, (double) -19,
    "gain vec", COMP_INTENDED, EMAC_DISABLED,
    EMAC_EOL);

  Ema_Object_Attr_Set (model_id, obj [32], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);

  for (i = 0; i < 72; i++)
  {
    Ema_Object_Attr_Set (model_id, obj [32], "gain vec", COMP_DVEC_CONTENTS(i), dvec_32 [i],
    EMAC_EOL);
  }

  /* assign attrs for object 'obj [33]' */
  Ema_Object_Attr_Set (model_id, obj [33],
    "view low gain", COMP_CONTENTS, (double) -21,
    "view high gain", COMP_CONTENTS, (double) -19,
    "gain vec", COMP_INTENDED, EMAC_DISABLED,
    EMAC_EOL);

  Ema_Object_Attr_Set (model_id, obj [33], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);

  for (i = 0; i < 72; i++)
  {
    Ema_Object_Attr_Set (model_id, obj [33], "gain vec", COMP_DVEC_CONTENTS(i), dvec_33 [i],
    EMAC_EOL);
  }

  /* assign attrs for object 'obj [34]' */
  Ema_Object_Attr_Set (model_id, obj [34],
    "view low gain", COMP_CONTENTS, (double) -21,
    "view high gain", COMP_CONTENTS, (double) -19,
    "gain vec", COMP_INTENDED, EMAC_DISABLED,
    EMAC_EOL);

  Ema_Object_Attr_Set (model_id, obj [34], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);

  for (i = 0; i < 72; i++)
  {
    Ema_Object_Attr_Set (model_id, obj [34], "gain vec", COMP_DVEC_CONTENTS(i), dvec_34 [i],
    EMAC_EOL);
  }

  /* assign attrs for object 'obj [35]' */
  Ema_Object_Attr_Set (model_id, obj [35],
    "view low gain", COMP_CONTENTS, (double) -21,
    "view high gain", COMP_CONTENTS, (double) -19,
    "gain vec", COMP_INTENDED, EMAC_DISABLED,
    EMAC_EOL);

  Ema_Object_Attr_Set (model_id, obj [35], "gain vec", COMP_DVEC_SIZE, 72, EMAC_EOL);

  for (i = 0; i < 72; i++)
  {
Ema_Object_Attr_Set (model_id, obj [35], "gain vec", COMP_DVEC_CONTENTS(i), dvec_35 [j],
EMAC_EOL);

/* write the model to application-readable form */
Ema_Model_Write (model_id, "mont");

return 0;
}
APPENDIX B

COSINE SQUARED GAIN ANTENNA PATTERN CREATION IN OPNET
// antenna_hard.cpp : Defines the entry point for the console application.
//
#include "stdafx.h"
#include <stdio.h>
#include <math.h>
#include <string.h>
#define MAX_LEN_SINGLE_LINE 120
#define PI 3.14159265

int main()
{
    int i,theta_min,theta_max,phi_min,phi_max;
    int theta_min_int,theta_max_int,phi_min_int,phi_max_int,
    g;
    FILE *f,*fp;
    char s,filename[20];
    f=fopen("abcde.em.c","w+");
    fputs("#include <opnet.h>",f);
    fputc('n',f);
    fputs("#include <ema.h>",f);
    fputc('n',f);
    fputs("#include <opnet_emadefs.h>",f);
    fputc('n',f);
    fputs("#include <opnet_constants.h>",f);
    fputc('n',f);
    fputs("#include <opnet_emadefs.h>",f);
    fputc('n',f);
    fputs("#include <opnet_constants.h>",f);
    fputc('n',f);
    fputs("#include <opnet_constants.h>",f);
    fputc('n',f);
    theta_min_int=(theta_min/5);
    theta_max_int=(theta_max/5);
    phi_min_int=(phi_min/5);
    phi_max_int=(phi_max/5);
    printf("ok1");
    for(i=0;i<36;i++)
    {
        if(i<phi_min_int || i>=phi_max_int )
        {
            fun1(i,f);
        }
        else
        {
            fun2(i,theta_min_int,theta_max_int,g,f);
        }
    }
printf("ok2");
fp=fopen("end.txt","r");
printf("ok3");

while( ( (s=getc(fp)) != EOF) )
{
    putc(s,f);
}
printf("ok4");
fclose(f);
fclose(fp);
printf("ok5");

//opnen f3, rewind, put headders
return 0;
}

fun1(a,f2)
{
    FILE *f1;
    char c;
    f1=fopen("abcd.txt","r");
    //printf("%d",a);
    fputc(’a’,f1);
    fputs("double",f2);
    putc(’r’,f2);
    fputs("dvec_",f2);
    fprintf (f2,"%d",a);
    fputs("[] =",f2);
    while( ( (c=getc(f1)) != EOF) )
    {
        putc( c,f2);
    }
    putc(‘n’,f2);
    putc(‘n’,f2);
    fclose(f1);
}

fun2(b,tmin,tmax,gain,f4)
{
    FILE *f3;
    int t,q=1;
    int dx7;
    f3=fopen("abcde.txt","r+");
    fputs("double",f4);
    putc(‘l’,f4);
    fputs("dvec_",f4);
    fprintf (f4,"%d",b);
    fputs("[] =",f4);
    putc(‘n’,f4);
    putc(‘n’,f4);
    putc(‘r’,f4);
    putc(‘r’,f4);
    putc(‘r’,f4);
    d= floor((tmax-tmin)/2);
}
x7 = -d;

for (t = 0; t < 72; t++)
{
    q = q + 1;
    if (q < tmin || q > tmax)
    {
        fputs("-20.000000000000", f4);
    }
    else
    {
        fprintf(f4, "%f", (cos(((float)x7/d)*(90*PI/180)) * gain));
    }
}

fclose(f3);
APPENDIX C

PENCIL BEAM ANTENNA PATTERN CREATION CODE IN OPNET
// antenna_hard_2010.cpp : Defines the entry point for the console application.
//

// antenna_hard.cpp : Defines the entry point for the console application.
//

#include "stdafx.h"
#include <stdio.h>
#include <math.h>
#include <string.h>
#define MAX_LEN_SINGLE_LINE 120
#define PI 3.14159265

int main()
{
    int i,p_min_1,p_max_1,p_min_2,p_max_2,p_min_3,p_max_3,p_min_i,p_max_i,phi_min_1,phi_max_1,phi_min_2,phi_max_2,phi_min_3,phi_max_3,phi_min_i,phi_max_i;
    int theta_min_int,theta_max_int,phi_min_int_1,phi_max_int_1,phi_min_int_2,phi_max_int_2,phi_min_int_3,phi_max_int_3,phi_min_int_i,phi_max_int_i,g,number_ss;

    int aabb=0,phi_max[10],xy=0,phi_max__int[10],abcd=0;

    FILE *f,*fp;
    char s,filename[20];
    f=fopen("abcdefg.em.c","w+");
    fputs("#include <opnet.h>",f);
    fputc('
',f);
    fputs("#include <ema.h>",f);
    fputc('
',f);
    fputs("#include <opnet_emadefs.h>",f);
    fputc('
',f);
    fputs("#include <opnet_constants.h>",f);
    fputc('
',f);
    fputc('
',f);
    fputc('
',f);
    //printf("enter the number of ss's\n");
    //scanf("%d",&number_ss);
    number_ss=3;
    for(aabb=0;aabb<number_ss-1;aabb=aabb+1)
    {
        printf("enter the maximum value of phi angle of ss%d\n",aabb+2);
        scanf("%d",&phi_max[xxy]);
        phi_max__int[xxy]= (int) floor (phi_max[xxy]/5);
        xy=xy+1;
    }

    printf("enter your gain \n");
    scanf("%d",&g);
    //printf("enter the name of your antenna pattern (.pa file) without the .pa \n");
    //scanf("%s",filename);
//printf("ok1");
for(i=0;i<36;i++)
{
if( (i==0)||(i==1)||(i==(phi_max__int[abcd]-1)) || (i==(phi_max__int[abcd])) || (i==(phi_max__int[abcd]+1)))
{
    //printf("ok1");
    if(abcd<xy)
    {
        fun2(i,g,f);
        if(i==(phi_max__int[abcd]+1))
            abcd=abcd+1;
    }
}

/* interferance********************
else if(i>=phi_min_int_i && i<=phi_max_int_i)
{
    fun3(i,phi_min_int_i,phi_max_int_i,g,f);
}*/
else
{
    //printf("ok2");
    //fun2(i,theta_min_int,theta_max_int,g,f);
    fun1(i,f);
}

//printf("ok2");
fp=fopen("end.txt","r");
//printf("ok3");

while( (s=getc(fp)) != EOF )
{
   putc(s,f);
}
//printf("ok4");
fclose(f);
fclose(fp);
//printf("ok5");

//open f3, rewind, put headders
return 0;
}
fun1(a,f2)
{
    FILE *f1;
    char c;
    f1=fopen("abcd.txt","r");
    //printf("%d",a);
    fputc('
',f2);
    fputs("double",f2);
    putc('
',f2);
    fputs("dvec_",f2);
    fprintf (f2,"%d",a);
    fputs("[] =",f2);

    while( ( c=getc(f1)) != EOF)   
    {
        putc( c,f2);
    }
    putc(\n',f2);
    putc('\n',f2);
    fclose(f1);
}

fun2(b,gain,f4)
{
    //FILE *f3;
    int nq=-1;
    int d,x7;
    // f3=fopen("abcdc.txt","r+");
    fputs("double",f4);
    putc('n',f4);
    fputs("dvec_",f4);
    fprintf (f4,"%d",b);
    fputs("[] =",f4);
    putc(\n',f4);
    putc(']',f4);
    putc('}',f4);
    if(  (b==0) || (b==1)  )
    {
        for(t=0;t<72;t++)
        {
            fprintf (f4,"%d",gain);
            fprintf (f4,"%s",',');
        }
    }
    else
    {
        for(t=0;t<72;t++)
        {
            if(t==70 || t==71)
            {
                fprintf (f4,"%d",gain);
            }
            else
            {
                fprintf (f4,"%d",0);
            }
        }
    }
}
fprintf (f4, "\%s", ");

}
}

putc(\n',f4);
putc(\r',f4);
putc(\}',f4);
putc(\;',f4);
putc(\n',f4);
putc(\n',f4);

// fclose(f3);
}
}

fun3(b,p_min_i,p_max_i,gain,f4)
{
    //FILE *f3;
    int t,q=-1;
    int d,x7;
    // f3=fopen("abcde.txt","r+");
    fputs("double",f4);
    putc(\n',f4);
    fputs("dvec_",f4);
    fprintf (f4,"%d",b);
    fputs(" [] =",f4);
    putc(\n',f4);
    putc(\',f4);
    putc(\',f4);
    putc(\n',f4);

    ///<d= floor((tmax-tmin)/2);
    ///<printf("%d\n",d);
    ///</x7=d;
    ///</printf("min and%d\n",p_min_i);
    ///</printf("min and%d\n",p_max_i);
    ///</q++;

    for(t=0;t<72;t++)
    {
        /// q=q+1;
        ///if(q>=p_min_i && q<=p_max_i)
        ///{
        // printf("ok88\n");
        ///
        // printf("-20.00000000000000, ",f4);
        ///
        ///
        ///</q+q)
        ///else if(q>=p_min_1 && q<=p_max_1) || (q>=p_min_2 && q<=p_max_2) ||(q>=p_min_3 && q<=p_max_3))
        ///{
        // printf("%d\n",gain);
        // printf("\n");
        //printf("%d is x7\n",x7);
```c
//printf("%d is \n",d);
//printf("%f\n", cos (((float)x7/d)*(90*PI/180)));
//printf("\n");
// x7++;  

//printf( cos (((float)x7/d)*(90*PI/180)) * gain , f4) ;  
//fprintf (f4, ", %.", gain);
// fprintf (f4, ", %.", "");

fputs("-20.000000000000", f4);

///
///else
///{
///  fputs("0.000000000000", ",f4);
///}
/// q++;

putc('n',f4);
putc('t',f4);
putc('}',f4);
putc(';',f4);
putc('n',f4);
putc('n',f4);

fclose(f3);
```
APPENDIX D

ILP FORMULATION FOR OPNET COORDINATES
// brendan_alg_5.cpp : Defines the entry point for the console application.
//

#include "stdafx.h"
#include <math.h>
#include <stdio.h>
#include <stdlib.h>

#define no_of_RS 7
#define no_of_SS 30

int main()
{

    //int RS_num = no_of_RS-1;
    int l=0;
    int k=0;
    int la=0;
    int ne = 0;
    int br=0;
    int rw = 0;
    int nt=0;
    int ij=0;
    int b;
    int nu=0;
    int a=0;
    int z=0,y=0,x;
    int rr=0;
    int aa=0,bb=0;
    int cc=0;
    int dd=0;
    int alp=0;
    int bet=0;
    float dis_x=0;
    float dis_y=0;
    int gm=0;
    int mac_cc=0;
    int S[no_of_SS][no_of_RS];
    int temp = 0;
    int flag[no_of_SS];

    FILE *f1;

    float RS_x[no_of_RS];
    float RS_y[no_of_RS];
    float angle_frm_fun[no_of_SS];

    int Beam_sets[no_of_RS][100][100];
    int beamset_temp[no_of_RS][100][100];
    int max_third[100][100];

    float s_sets[no_of_SS];
    float BS[no_of_RS][no_of_SS];

    //int SS_num = no_of_SS-1;
    float SS_x[no_of_SS];
float SS_y[no_of_SS];
float fun_angle();
//assignment of RS
f1=fopen("var.txt","w");
RS_x[0]=2.056*200;
RS_y[0]=(5-2.88)*200;
RS_x[1]=1.92*200;
RS_y[1]=(5-2.41)*200;
RS_x[2]=2.096*200;
RS_y[2]=(5-1.986)*200;
RS_x[3]=2.526*200;
RS_y[3]=(5-1.882)*200;
RS_x[4]=2.445*200;
RS_y[4]=(5-2.973)*200;
RS_x[5]=2.875*200;
RS_y[5]=(5-2.95)*200;
RS_x[6]=3.24*200;
RS_y[6]=(5-2.84)*200;
// RS_x[1]=500;
// RS_y[1]=500;
// RS_x[1]=100;
// RS_y[1]=120;
/*
 //assignment of ss
 SS_x[0]=250;
 SS_y[0]=250;
 SS_x[1]=250;
 SS_y[1]=250;
 SS_x[2]=250;
 SS_y[2]=750;
 SS_x[3]=251;
 SS_y[3]=751;
 SS_x[4]=750;
 SS_y[4]=750;
 SS_x[5]=750;
 SS_y[5]=751;
 SS_x[6]=750;
 SS_y[6]=250;
 SS_x[7]=751;
 SS_y[7]=251;
*/
SS_x[0]=0.604*200;
SS_y[0]=(5-3.304)*200;
SS_x[1]=0.563*200;
SS_y[1]=(5-2.96)*200;
SS_x[2]=0.581*200;  
SS_y[2]=(5-2.62)*200;  
SS_x[3]=0.546*200;  
SS_y[3]=(5-2.27)*200;  
SS_x[4]=0.639*200;  
SS_y[4]=(5-2.09)*200;  
SS_x[5]=0.6911*200;  
SS_y[5]=(5-1.835)*200;  
SS_x[6]=0.685*200;  
SS_y[6]=(5-1.5)*200;  
SS_x[7]=0.883*200;  
SS_y[7]=(5-1.35)*200;  
SS_x[8]=1.07*200;  
SS_y[8]=(5-1.18)*200;  
SS_x[9]=1.3*200;  
SS_y[9]=(5-1.1)*200;  
SS_x[10]=1.55*200;  
SS_y[10]=(5-0.952)*200;  
SS_y[11]=(5-0.877)*200;  
SS_x[12]=2.12*200;  
SS_y[12]=(5-0.842)*200;  
SS_x[13]=2.387*200;  
SS_y[13]=(5-0.7724)*200;  
SS_x[14]=4.129*200;  
SS_y[14]=(5-3.345)*200;  
SS_x[15]=4.18*200;  
SS_y[15]=(5-3.69)*200;  
SS_x[16]=3.972*200;  
SS_y[16]=(5-3.955)*200;  
SS_x[17]=3.728*200;  
SS_y[17]=(5-4.135)*200;  
SS_x[18]=3.51*200;  
SS_y[18]=(5-4.26)*200;  
SS_x[19]=3.299*200;  
SS_y[19]=(5-4.367)*200;  
SS_x[20]=3.04*200;  
SS_y[20]=(5-4.28)*200;  
SS_x[21]=2.776*200;  
SS_y[21]=(5-4.315)*200;  
SS_x[22]=2.364*200;  
SS_y[22]=(5-4.547)*200;  
SS_x[23]=1.986*200;  
SS_y[23]=(5-4.53)*200;  
SS_x[24]=1.742*200;
SS_y[24]=(5-4.437)*200;
SS_x[25]=1.492*200;
SS_y[25]=(5-4.344)*200;
SS_x[26]=1.225*200;
SS_y[26]=(5-4.303)*200;
SS_x[27]=0.976*200;
SS_y[27]=(5-4.13)*200;
SS_x[28]=0.749*200;
SS_y[28]=(5-3.93)*200;
SS_x[29]=0.633*200;
SS_y[29]=(5-3.635)*200;
/*
SS_x[30]=3.14*200;
SS_y[30]=(5-0.87)*200;
SS_x[31]=2.586*200;
SS_y[31]=(5-0.876)*200;
SS_x[32]=2.455*200;
SS_y[32]=(5-0.5721)*200;
SS_x[33]=1.63*200;
SS_y[33]=(5-0.596)*200;
SS_x[34]=0.924*200;
SS_y[34]=(5-0.87)*200;
SS_x[35]=3.16*200;
SS_y[35]=(5-4.31)*200;
SS_x[36]=4.165*200;
SS_y[36]=(5-1.061)*200;
SS_x[37]=3.754*200;
SS_y[37]=(5-0.727)*200;
SS_x[38]=1.26*200;
SS_y[38]=(5-4.11)*200;
SS_x[39]=4.29*200;
SS_y[39]=(5-3.25)*200;
*/

//print max,min
fprintf(f1, "%s", "max: ");
for(ne=0;ne<no_of_RS;ne++)
{
    for(br=0;br<no_of_SS;br++)
    {
        dis_x = (SS_x[br] - RS_x[ne])*(SS_x[br] - RS_x[ne]);
        dis_y = (SS_y[br] - RS_y[ne])*(SS_y[br] - RS_y[ne]);
        fprintf(f1, "%g.%c%g", (1/sqrt(dis_x+dis_y)), '*' , br, ne,
        \n        '.');
    }
}

fseek(f1, -2, 1);
fprintf(f1, "%c", '.');
fprintf(f1,"%c%c","n","n");

//print x00<1
for(ne=0;ne<no_of_RS;ne++)
{
    for(br=0;br<no_of_SS;br++)
    {
        fprintf(f1,"%c%d%d %c%c%d%c%c","x",br,ne,',','=',1,','','n');
    }
}
fprintf(f1,"%c%c","n","n");

//print x00>0
for(ne=0;ne<no_of_RS;ne++)
{
    for(br=0;br<no_of_SS;br++)
    {
        fprintf(f1,"%c%d%d %c%c%d%c%c","x",br,ne,',','=',0,','','n');
    }
}
fprintf(f1,"%c%c","n","n");

//x00+x01 <=1;
for(br=0;br<no_of_SS;br++)
{
    for(ne=0;ne<no_of_RS;ne++)
    {
        fprintf(f1,"%c%d%d %c ","x",br,ne,','');
    }
    fseek(f1,-2,1);
    fprintf(f1," %c%c  %d%c","<','=');
    fprintf(f1,"%c","n");
}
fprintf(f1,"%c%c","n","n");

for(i=0;i<no_of_RS;i++)
{
    cc=0;
    for(j=0;j<no_of_SS;j++)
    {
        //flag1=0;
        Beam_sets[i][cc][temp]=j;
        temp++;

        for(k=(j+1);k<no_of_SS;k++)
        {
            // nu=k
            nu=k;
            // printf("%d %d %d \n",i,j,nu);
            angle_frm_fun[a] = fun_angle(RS_x[i],RS_y[i],SS_x[j],SS_y[j],SS_x[nu],SS_y[nu]);
            printf("angle b/w RS[%d] ss[%d] ss[%d] = %f\n",i,j,nu,angle_frm_fun[a]);

            if(angle_frm_fun[a]<(float)40 )
            {
                printf("2 %d %d \n",i,j,nu);
            }
            Beam_sets[i][cc][temp]=nu;
            temp++;
max_third[i][cc]=temp;
temp=0;
cc++;

// y=0;
}
printf(" \n\n");
for(i=0;i<no_of_RS;i++)
{
    for(j=0;j<no_of_SS;j++)
    {
        for(k=0;k<max_third[i][j];k++)
        {
            printf("b[%d][%d] = %d    ",i,j,Beam_sets[i][j][k]);
        }
        printf("\n");
    }
}
// ss<1;
for(i=0;i<no_of_RS;i++)
{
    for(j=0;j<no_of_SS;j++)
    {
        for(k=0;k<max_third[i][j];k++)
        {
            if(Beam_sets[i][j][k] == j)
            {
                // printf("%c%d%d %c ",s,i,l,'+');
                fprintf(f1,"%c%d%d %c%c%d%c%c ",s,i,j,'=','<','=');ss00, ss01 = 1;
            }
        }
    }
}
fprintf(f1,"%c",'n');
fprintf(f1,"%c",'n');
// ss00 + ss01 = 1;
//printf("\n\n");

for(i=0;i<no_of_RS;i++)
{
    for(j=0;j<no_of_SS;j++)
    {
        for(k=0;k<max_third[i][j];k++)
        {
```c
if (Beam_sets[i][j][k] == j)
{
    // printf("%c%d%d %c ",s,i,l,\+);
    fprintf(f1,"%c%d%d %c ",s,i,j,\+);
}
}

fseek(f1,-2,1);
fprintf(f1,"%c"\n);
fprintf(f1,"%c"");

//s00>=x10;
for(l=0;l<no_of_SS;l++)
{
    for(i=0;i<no_of_RS;i++)
    {
        for(j=0;j<no_of_SS;j++)
        {
            for(k=0;k<max_third[i][j];k++)
            {
                if (Beam_sets[i][j][k] == l)
                {
                    fprintf(f1,"%c%d%d %c ",s,i,j,\+);
                }
            }
            fseek(f1,-2,1);
            fprintf(f1,"%c"\n);
            fprintf(f1,"%c"");
        }
    }*/

for(x=0;x<no_of_SS;x++)
{
    for(alp=0;alp<no_of_RS;alp++)
    {
        for(bet=0;bet<no_of_SS;bet++)
        {
```
if(beam_sets[alp][bet] > -1 && beam_sets[alp][bet] < 1000) {
    // printf("%d",x);

    if(beam_sets[alp][bet] < 10 && beam_sets[alp][bet] == x+1) {
        S[x][alp]=beam_sets[alp][bet];
        printf(" S[%d][%d] = B[%d][%d] \n", x+1, alp, alp, bet);
    }

    if(beam_sets[alp][bet] > 9 && beam_sets[alp][bet]/10 == x+1) {
        S[x][alp]=beam_sets[alp][bet];
        printf(" S[%d][%d] = B[%d][%d] \n", x+1, alp, alp, bet);
    }

    else {
        if(beam_sets[alp][bet] > 9 && beam_sets[alp][bet]%10 == x+1) {
            S[x][alp]=beam_sets[alp][bet];
            printf(" S[%d][%d] = B[%d][%d] \n", x+1, alp, alp, bet);
        }
    }
}

for(rw=0;rw<no_of_RS;rw++) {
    for(nt=0;nt<no_of_SS;nt++) {
        // if nxt num not contain this number
        if(S[nt][rw]>9) {
            fprintf(f1, "%c%d%d %c%c %c%d%d%c%c","s",rw,la,">','=','x',S[nt][rw]/10,rw,">','=','x',S[nt][rw]%10,rw,">','=');
        } else {
            fprintf(f1, "%c%d%d %c%c %c%d%d%c%c","s",rw,la,">','=','x',S[nt][rw],rw,">','=');
        }
        // if nxt num contain this number
    }
}

/*
//if(BS[aa][bb]=1)
//printf(" %d %d has an angle of %f
",aa,bb,Beam_sets[aa][bb]);

//printf("sdf")
return 0;
}

float fun_angle(r_x,r_y,s1_x,s1_y,s2_x,s2_y)
float r_x,r_y,s1_x,s1_y,s2_x,s2_y;
{
    float final_angle[no_of_SS];
    int m=0;
    int isNaN;
    float dis_b = (float)sqrt ( ((s2_x-s1_x)*(s2_x-s1_x))+(s2_y-s1_y)*(s2_y-s1_y)) ;
    float dis_a = (float)sqrt ( ((s2_x-r_x)*(s2_x-r_x))+(s2_y-r_y)*(s2_y-r_y)) ;
    float dis_c = (float)sqrt ( ((s1_x-r_x)*(s1_x-r_x))+(s1_y-r_y)*(s1_y-r_y)) ;

    float angle = (((dis_a*dis_a) + (dis_c*dis_c) - (dis_b*dis_b))/(2*dis_a*dis_c));
    //if(s2_x ==(float)751)
    // printf("-------- %f
", angle);
    if ((float)angle != (float)1.000000 )
    {
        final_angle[m] = (float)acos((float)angle)*(float)180.0;
        final_angle[m] = final_angle[m]/(float)3.14;
    }
    else
    {
        final_angle[m] = (float)0;
    }
    if(isNaN!=0 & &(int)angle>0)
    final_angle[m] = (float)0;
    if(isNaN!=0 & &(int)angle<0)
    final_angle[m] = (float)180;

}
if ((float)angle == (float)1.000000 )
{
    if(s2_x == (float)751)
    printf("a1= %f
",angle);
    final_angle[m] = (float)0;
}

//if(s2_x == (float)751)
//printf("-------- %f
", final_angle[m]);

return(final_angle[m]);
m++;
APPENDIX E

ROUNDED CODE FOR OPNET COORDINATES
// brendan_alg_5.cpp : Defines the entry point for the console application.
//
#include "stdafx.h"
#include <math.h>
#include <stdio.h>
#include <stdlib.h>

#define no_of_RS 7
#define no_of_SS 30

int main()
{
    float rate[no_of_SS];
    int a9[no_of_SS];
    int a5[no_of_SS][99];
    double r_x[no_of_RS][no_of_SS];
    double r_y[no_of_RS][no_of_SS];
    double sum=0;
    int l=0;
    int k=0;
    int la=0;
    int ne = 0;
    int br=0;
    int rw = 0;
    int nt=0;
    int b;
    int nu=0;
    int a=0;
    int z=0;
    int rr=0;
    int aa=0,bb=0;
    int cc=0;
    int dd=0;
    int alp=0;
    int bet=0;
    float dis_x=0;
    float dis_y=0;
    int gm=0;
    int mac_cc=0;
    int S[no_of_SS][no_of_RS];
    int temp = 0;
    int flag1[no_of_SS];
    int a1[no_of_RS];
    int a2[no_of_RS];

    FILE *f1;

    float RS_x[no_of_RS];
    float RS_y[no_of_RS];
    float angle_frm_fun[no_of_SS];
int Beam_sets[no_of_RS][100][100];
int beamset_temp[no_of_RS][100][100];
int max_third[100][100];

float s_sets[no_of_SS];
float BS[no_of_RS][no_of_SS];

//int SS_num = no_of_SS-1;
float SS_x[no_of_SS];
float SS_y[no_of_SS];

double x[30][no_of_RS];
double y[no_of_RS][99];

float fun_angle();
/

//int RS_num = no_of_RS-1;
int l=0;
int k=0;
int la=0;
int ne = 0;
int br=0;
int rw = 0;
int nt=0;
int t=0;
int b;
int nu=0;
int a=0;
int z=0,y=0,x;
int rr=0;
int aa=0,bb=0;
int cc=0;
int dd=0;
int alp=0;
int bet=0;
float dis_x=0;
float dis_y=0;
int gm=0;
int mac_cc=0;
int S[no_of_SS][no_of_RS];
int temp = 0;
int flag1[no_of_SS];

FILE *f1;

float RS_x[no_of_RS];
float RS_y[no_of_RS];
float angle_frm_fun[no_of_SS];

int Beam_sets[no_of_RS][100][100];
int beamset_temp[no_of_RS][100][100];
int max_third[100][100];

float s_sets[no_of_SS];
float BS[no_of_RS][no_of_SS];

//int SS_num = no_of_SS-1;
float SS_x[no_of_SS];
float SS_y[no_of_SS];

float fun_angle();
*/
//assignment of RS
f1=fopen("var.txt","w");
RS_x[0]=2.056*200;
RS_y[0]=(5-2.88)*200;

RS_x[1]=1.92*200;
RS_y[1]=(5-2.41)*200;

RS_x[2]=2.096*200;
RS_y[2]=(5-1.986)*200;

RS_x[3]=2.526*200;
RS_y[3]=(5-1.882)*200;

RS_x[4]=2.445*200;
RS_y[4]=(5-2.973)*200;

RS_x[5]=2.875*200;
RS_y[5]=(5-2.95)*200;

RS_x[6]=3.24*200;
RS_y[6]=(5-2.84)*200;

// RS_x[1]=500;
// RS_y[1]=500;

// RS_x[1]=100;
// RS_y[1]=120;

// assignment of ss
/*
SS_x[0]=250;
SS_y[0]=250;

SS_x[1]=250;
SS_y[1]=250;

SS_x[2]=250;
SS_y[2]=750;

SS_x[3]=251;
SS_y[3]=751;

SS_x[4]=750;
SS_y[4]=750;

SS_x[5]=750;
SS_y[5]=751;

SS_x[6]=750;
SS_y[6]=250;

SS_x[7]=751;
SS_y[7]=251;
*/

SS_x[0]=0.604*200;
SS_y[0]=(5-3.304)*200;

SS_x[1]=0.563*200;
SS_y[1]=(5-2.96)*200;

SS_x[2]=0.581*200;
SS_y[2]=(5-2.62)*200;

SS_x[3]=0.546*200;
SS_y[3]=(5-2.27)*200;
SS_x[4]=0.639\times100;
SS_y[4]=(5-2.09)\times100;

SS_x[5]=0.6911\times100;
SS_y[5]=(5-1.835)\times100;

SS_x[6]=0.685\times100;
SS_y[6]=(5-1.5)\times100;

SS_x[7]=0.883\times100;
SS_y[7]=(5-1.35)\times100;

SS_x[8]=1.07\times100;
SS_y[8]=(5-1.18)\times100;

SS_x[9]=1.3\times100;
SS_y[9]=(5-1.1)\times100;

SS_x[10]=1.55\times100;
SS_y[10]=(5-0.952)\times100;

SS_x[11]=1.81\times100;
SS_y[11]=(5-0.877)\times100;

SS_x[12]=2.12\times100;
SS_y[12]=(5-0.842)\times100;

SS_x[13]=2.387\times100;
SS_y[13]=(5-0.7724)\times100;

SS_x[14]=4.129\times100;
SS_y[14]=(5-3.345)\times100;

SS_x[15]=4.18\times100;
SS_y[15]=(5-3.69)\times100;

SS_x[16]=3.972\times100;
SS_y[16]=(5-3.955)\times100;

SS_x[17]=3.728\times100;
SS_y[17]=(5-4.135)\times100;

SS_x[18]=3.51\times100;
SS_y[18]=(5-4.26)\times100;

SS_x[19]=3.299\times100;
SS_y[19]=(5-4.367)\times100;

SS_x[20]=3.04\times100;
SS_y[20]=(5-4.28)\times100;

SS_x[21]=2.776\times100;
SS_y[21]=(5-4.315)\times100;

SS_x[22]=2.364\times100;
SS_y[22]=(5-4.547)\times100;

SS_x[23]=1.986\times100;
SS_y[23]=(5-4.53)\times100;

SS_x[24]=1.742\times100;
SS_y[24]=(5-4.437)\times100;

SS_x[25]=1.492\times100;
SS_y[25]=(5-4.344)\times100;

SS_x[26]=1.225\times100;
SS_y[26]=(5-4.303)*200;
SS_x[27]=0.976*200;
SS_y[27]=(5-4.13)*200;
SS_x[28]=0.749*200;
SS_y[28]=(5-3.93)*200;
SS_x[29]=0.633*200;
SS_y[29]=(5-3.635)*200;
/*
SS_x[30]=3.14*200;
SS_y[30]=(5-0.87)*200;
SS_x[31]=2.586*200;
SS_y[31]=(5-0.876)*200;
SS_x[32]=2.455*200;
SS_y[32]=(5-0.5721)*200;
SS_x[33]=1.63*200;
SS_y[33]=(5-0.596)*200;
SS_x[34]=0.924*200;
SS_y[34]=(5-0.87)*200;
SS_x[35]=3.16*200;
SS_y[35]=(5-4.31)*200;
SS_x[36]=4.165*200;
SS_y[36]=(5-1.061)*200;
SS_x[37]=3.754*200;
SS_y[37]=(5-0.727)*200;
SS_x[38]=1.26*200;
SS_y[38]=(5-4.11)*200;
SS_x[39]=4.29*200;
SS_y[39]=(5-3.25)*200;
*/

/////////////////////////////////////////////////////////////////////
//print max,min
fprintf(f1,"%s","max: ");
for(ne=0;ne<no_of_RS;ne++)
{
    for(br=0;br<no_of_SS;br++)
    {
        dis_x = (SS_x[br] - RS_x[ne])*(SS_x[br] - RS_x[ne]);
        dis_y = (SS_y[br] - RS_y[ne])*(SS_y[br] - RS_y[ne]);
        r_x[ne][br]=dis_x;
        r_y[ne][br]=dis_y;
        fprintf(f1,"%lf %c %c%d%d%c%c%c",1/sqrt(dis_x+dis_y),"x","x",ne,br,ne,"+","+");
    }
}

fseek(f1,-2,1);
fprintf(f1,"%c",";");
fprintf(f1,"%c%c","n","n");
//print x00<1
for(ne=0;ne<no_of_RS;ne++)
{ 
    for(br=0;br<no_of_SS;br++) 
    { 
        fprintf(f1,"%c%d%d %c%c%d%c%c",x,br,ne,’<’,=,1,’
’); 
    } 
} 
fprintf(f1,"%c%c","n","n");

//print x00>0 
for(ne=0;ne<no_of_RS;ne++) 
{ 
    for(br=0;br<no_of_SS;br++) 
    { 
        fprintf(f1,"%c%d%d %c%c%d%c%c",x,br,ne,’>’,=,0,’
’); 
    } 
} 
fprintf(f1,"%c%c","n","n");

//x00+x01 <=1; 
for(br=0;br<no_of_SS;br++) 
{ 
    for(ne=0;ne<no_of_RS;ne++) 
    { 
        for(br=0;br<no_of_SS;br++) 
        { 
            fprintf(f1,"%c%d%d %c ",x,br,ne,’+’); 
        } 
        fseek(f1,-2,1); 
        fprintf(f1,"%c%c  %d%c",’<’,=,1,’
’); 
        fprintf(f1,"%c",’
’); 
    } 
} 
fprintf(f1,"%c%c","n","n");

for(i=0;i<no_of_RS;i++) 
{ 
    cc=0; 
    for(j=0;j<no_of_SS;j++) 
    { 
        //flag1=0; 
        Beam_sets[i][cc][temp]=j; 
        temp++; 
        for(k=(j+1);k<no_of_SS;k++) 
        { 
            // nu=k%no_of_SS; 
            nus=0; 
            // 
            angle_frm_fun[a] = fun_angle(RS_x[i],RS_y[i],SS_x[j],SS_y[j],SS_x[nu],SS_y[nu]); 
            printf("abgle b/w RS[%d] ss[%d] ss[%d] = %f\n",i,j,nu,angle_frm_fun[a]); 
            if(angle_frm_fun[a]<=(float)40) 
            { 
                printf("%d %d \n",j,nu); 
                Beam_sets[i][cc][temp]=nu; 
                temp++; 
            } 
        } 
    } 
}
```c
for (i = 0; i < no_of_RS; i++)
{
    for (j = 0; j < no_of_SS; j++)
    {
        for (k = 0; k < max_third[i][j]; k++)
        {
            if (Beam_sets[i][j][k] == j)
            {
                printf("\n\n%5d,%5d = %d\n", i, j, Beam_sets[i][j][k]);
                fprintf(f1,"%c%d%d %c%c%d%c%c ",'s',i,l,=,i,j,Beam_sets[i][j][k]);
                fprintf(f1,"%c",i);      
                fprintf(f1,"%c",i,l,=,i,j,Beam_sets[i][j][k]);
                fprintf(f1,"%c",i,=,i,j,Beam_sets[i][j][k]);
            }
        }
    }
}
```

// printf("%c%d%d %c ",i,l,"+ ");
// fprintf(f1,"%c%d%d %c ",i,j,"+ ");
}
}
}

for(l=0;l<no_of_SS;l++)
{
  for(i=0;i<no_of_RS;i++)
  {
    for(j=0;j<max_third[i][j];j++)
    {
      if(Beam_sets[i][j][k] == l)
      {
        fprintf(f1,"%c%d%d %c ",i,j,"+ ");
      }
    }
  }
  fseek(f1,-2,1);
  fprintf(f1,"%c%d%d>%c",l,i);
  fprintf(f1,";%c","");
}

for(l=0;l<no_of_SS;l++)
{
  for(i=0;i<no_of_RS;i++)
  {
    for(j=0;j<no_of_SS;j++)
    {
      for(k=0;k<max_third[i][j][k];k++)
      {
        if(Beam_sets[i][j][k] == l)
        {
          fprintf(f1,"%c%d%d %c ",i,j,"+ ");
        }
      }
    }
  }
  fseek(f1,-2,1);
  fprintf(f1,"%c%d%d>%c",l,i);
  fprintf(f1,";%c","");
}

x[0][0]=1;
x[1][0]=1;
x[2][0]=1;
x[3][0]=0;
x[4][0]=0;
x[5][0]=0;
x[6][0]=0;
x[7][0]=0;
x[8][0]=0;
x[9][0]=0;
x[10][0]=0;
x[11][0]=0;
x[12][0]=0;
x[0][0]=0;
x[1][0]=0;
x[2][0]=0;
x[3][0]=0;
x[4][0]=0;
x[5][0]=0;
x[6][0]=0;
x[7][0]=0;
x[8][0]=0;
x[9][0]=0;
x[10][0]=0;
x[11][0]=0;
x[12][0]=0;
x[13][0]=0;
x[14][0]=0;
x[15][0]=0;
x[16][0]=0;
x[17][0]=0;
x[18][0]=0;
x[19][0]=0;
x[20][0]=0;
x[21][0]=0;
x[22][0]=0;
x[23][0]=0;
x[24][0]=0;
x[25][0]=0;
x[26][0]=0;
x[27][0]=1;
x[28][0]=1;
x[29][0]=1;
*/
x[0][1]=0;
x[1][1]=0;
x[2][1]=0;
x[3][1]=1;
x[4][1]=1;
x[5][1]=1;
x[6][1]=1;
x[7][1]=1;
x[8][1]=0;
x[9][1]=0;
x[10][1]=0;
x[11][1]=0;
x[12][1]=0;
x[13][1]=0;
x[14][1]=0;
x[15][1]=0;
x[16][1]=0;
x[17][1]=0;
x[18][1]=0;
x[19][1]=0;
x[20][1]=0;
x[21][1]=0;
x[22][1]=0;
x[23][1]=0;
x[24][1]=0;
x[25][1]=0;
x[26][1]=0;
x[27][1]=0;
x[28][1]=0;
x[29][1]=0;
*/
x[0][1]=0;
x[1][1]=0;
x[42][1]=0;
\[ \begin{align*} 
x[43][1] &= 0; 
x[44][1] &= 0; 
x[45][1] &= 0; 
x[46][1] &= 0; 
x[47][1] &= 0; 
x[48][1] &= 0; 
x[49][1] &= 0; 
x[50][1] &= 0; 
x[51][1] &= 0; 
\end{align*} \]

\[ \begin{align*} 
x[0][2] &= 0; 
x[1][2] &= 0.0; 
x[2][2] &= 0.0; 
x[3][2] &= 0.0; 
x[4][2] &= 0.0; 
x[5][2] &= 0.0; 
x[6][2] &= 0.0; 
x[7][2] &= 0.0; 
x[8][2] &= 1; 
x[9][2] &= 1; 
x[10][2] &= 1; 
x[11][2] &= 1; 
x[12][2] &= 0.0; 
x[13][2] &= 0.0; 
x[14][2] &= 0.0; 
x[15][2] &= 0.0; 
x[16][2] &= 0.0; 
x[17][2] &= 0.0; 
x[18][2] &= 0.0; 
x[19][2] &= 0.0; 
x[20][2] &= 0; 
x[21][2] &= 0; 
x[22][2] &= 0; 
x[23][2] &= 0; 
x[24][2] &= 0; 
x[25][2] &= 0; 
x[26][2] &= 0; 
x[27][2] &= 0; 
x[28][2] &= 0; 
x[29][2] &= 0; 
\end{align*} \]

\[ \begin{align*} 
x[40][2] &= 0; 
x[41][2] &= 0; 
x[42][2] &= 0; 
x[43][2] &= 0; 
x[44][2] &= 0; 
x[45][2] &= 0; 
x[46][2] &= 0; 
x[47][2] &= 0; 
x[48][2] &= 0; 
x[49][2] &= 0; 
x[50][2] &= 0; 
x[51][2] &= 0; 
\end{align*} \]

\[ \begin{align*} 
x[0][3] &= 0; 
x[1][3] &= 0; 
x[2][3] &= 0; 
x[3][3] &= 0; 
x[4][3] &= 0; 
x[5][3] &= 0; 
x[6][3] &= 0; 
x[7][3] &= 0; 
x[8][3] &= 0; 
x[9][3] &= 0; 
x[10][3] &= 0; 
x[11][3] &= 0; 
\end{align*} \]
x[12][3]=1;
x[13][3]=1;
x[14][3]=0;
x[15][3]=0;
x[16][3]=0;
x[17][3]=0;
x[18][3]=0;
x[19][3]=0;
x[20][3]=0;
x[21][3]=0;
x[22][3]=0;
x[23][3]=0;
x[24][3]=0;
x[25][3]=0;
x[26][3]=0;
x[27][3]=0.0;
x[28][3]=0.0;
x[29][3]=0.0;
/*
x[40][3]=1;
x[41][3]=1;
x[42][3]=1;
x[43][3]=1;
x[44][3]=1;
x[45][3]=1;
x[46][3]=1;
x[47][3]=1;
x[48][3]=1;
x[49][3]=1;
x[50][3]=1;
x[51][3]=1;
*/
x[0][4]=0;
x[1][4]=0;
x[2][4]=0;
x[3][4]=0;
x[4][4]=0;
x[5][4]=0;
x[6][4]=0;
x[7][4]=0.0;
x[8][4]=0.0;
x[9][4]=0.0;
x[10][4]=0.0;
x[11][4]=0.0;
x[12][4]=0;
x[13][4]=0;
x[14][4]=0;
x[15][4]=0;
x[16][4]=0;
x[17][4]=0;
x[18][4]=0;
x[19][4]=0;
x[20][4]=0;
x[21][4]=0;
x[22][4]=1;
x[23][4]=1;
x[24][4]=1;
x[25][4]=1;
x[26][4]=1;
x[27][4]=0;
x[28][4]=0;
x[29][4]=0;
*/
x[40][4]=0;
x[41][4]=0;
\[ x[42][4] = 0; \]
\[ x[43][4] = 0; \]
\[ x[44][4] = 0; \]
\[ x[45][4] = 0; \]
\[ x[46][4] = 0; \]
\[ x[47][4] = 0; \]
\[ x[48][4] = 0; \]
\[ x[49][4] = 0; \]
\[ x[50][4] = 0; \]
\[ x[51][4] = 0; \]
\[ */ \]
\[ x[0][5] = 0; \]
\[ x[1][5] = 0; \]
\[ x[2][5] = 0; \]
\[ x[3][5] = 0; \]
\[ x[4][5] = 0; \]
\[ x[5][5] = 0; \]
\[ x[6][5] = 0; \]
\[ x[7][5] = 0; \]
\[ x[8][5] = 0; \]
\[ x[9][5] = 0; \]
\[ x[10][5] = 0; \]
\[ x[11][5] = 0; \]
\[ x[12][5] = 0; \]
\[ x[13][5] = 0; \]
\[ x[14][5] = 0; \]
\[ x[15][5] = 0; \]
\[ x[16][5] = 0; \]
\[ x[17][5] = 0; \]
\[ x[18][5] = 1; \]
\[ x[19][5] = 1; \]
\[ x[20][5] = 1; \]
\[ x[21][5] = 1; \]
\[ x[22][5] = 0; \]
\[ x[23][5] = 0; \]
\[ x[24][5] = 0; \]
\[ x[25][5] = 0; \]
\[ x[26][5] = 0; \]
\[ x[27][5] = 0; \]
\[ x[28][5] = 0; \]
\[ x[29][5] = 0; \]
\[ */ \]
\[ x[40][5] = 0; \]
\[ x[41][5] = 0; \]
\[ x[42][5] = 0; \]
\[ x[43][5] = 0; \]
\[ x[44][5] = 0; \]
\[ x[45][5] = 0; \]
\[ x[46][5] = 0; \]
\[ x[47][5] = 0; \]
\[ x[48][5] = 0; \]
\[ x[49][5] = 0; \]
\[ x[50][5] = 0; \]
\[ x[51][5] = 0; \]
\[ */ \]
\[ x[0][6] = 0; \]
\[ x[1][6] = 0.0; \]
\[ x[2][6] = 0.0; \]
\[ x[3][6] = 0.0; \]
\[ x[4][6] = 0.0; \]
\[ x[5][6] = 0.0; \]
\[ x[6][6] = 0.0; \]
\[ x[7][6] = 0.0; \]
\[ x[8][6] = 0.0; \]
\[ x[9][6] = 0.0; \]
\[ x[10][6] = 0.0; \]
for(l=0;l<no_of_RS;l++)
{
    for(i=0;i<30;i++)
    {
        printf("x[%d][%d] = %lf
",i,l,x[i][l]);
    }
    printf("\n");
}

sum=0;
for(i=0;i<no_of_RS;i++)
{
    for(j=0;j<no_of_SS;j++)
    {
        for(k=0;k<max_third[i][j];k++)
        {
            sum = sum + (x[Beam_sets[i][j][k]][i]) * (1/(sqrt(r_x[i][j]*r_x[i][j] + r_y[i][j]*r_y[i][j])));
            //printf("b[%d][%d] = %d    ",i,j,Beam_sets[i][j][k]);
        }
        y[i][j]=sum;
        printf("***** y[%d][%d]=%lf\n",i,j,sum);
        sum=0;
    }
    printf("\n\n");
}

sum=0;
//    d1=0;
//    omega1=0;

for(i=0;i<no_of_RS;i++)
{
    sum=0;
}
for(j=0;j<no_of_SS;j++)
{
    if(y[i][j]>sum)
    {
        sum = y[i][j];
        a1[i]=i;
        a2[i]=j;
    }
}
printf(" y[%d][%d] is max with value %lf
",a1[i],a2[i],sum);

for(i=0;i<no_of_SS;i++)
{
    a9[i]=0;
}

for(i=0;i<no_of_RS;i++)
{
    for(k=0;k<max_third[a1[i]][a2[i]][k++])
    {
        l=Beam_sets[a1[i]][a2[i]][k];
        // printf(" i = %d \n",l);
        a5[l][k] = i;
        // a5[22][3]=1;
        if(a9[l]==0)
        {
            rate[l] = (100/(sqrt(r_x[l][l]*r_x[l][l] + r_y[l][l]*r_y[l][l])));
            a9[l]=1;
            printf(" a[%d][%d] = %d \n",l,k,i);
            printf("\n");
        }
        else
        {
            if((100/(sqrt(r_x[l][l]*r_x[l][l] + r_y[l][l]*r_y[l][l])))>rate[l])
            {
                rate[l] = (100/(sqrt(r_x[l][l]*r_x[l][l] + r_y[l][l]*r_y[l][l])));
                printf("err new  a[%d][%d] = %d \n",l,k,i);
                printf("\n");
            }
        }
    }
}
return 0;

}

float fun_angle(r_x,r_y,s1_x,s1_y,s2_x,s2_y)
float r_x,r_y,s1_x,s1_y,s2_x,s2_y;
{
float final_angle[no_of_SS];
int m=0;
int isNaN;
float dis_b = (float)sqrt( ((s2_x-s1_x)*(s2_x-s1_x))+(s2_y-s1_y)*(s2_y-s1_y) );
float dis_a = (float)sqrt( ((s2_x-r_x)*(s2_x-r_x))+(s2_y-r_y)*(s2_y-r_y) );
float dis_c = (float)sqrt( ((s1_x-r_x)*(s1_x-r_x))+(s1_y-r_y)*(s1_y-r_y) );

float angle = (((dis_a*dis_a) + (dis_c*dis_c) - (dis_b*dis_b))/(2*dis_a*dis_c));

//if(s2_x == (float)751)
// printf("-------- %f\n", angle);
if( (float)angle != (float)1.000000 )
{
final_angle[m] = (float)acos((float)angle)*(float)180.0;
final_angle[m] = final_angle[m]/(float)3.14;

isNaN = (_isnan(final_angle[m])!=0);
if(isNaN!=0 && (int)angle>0)
    final_angle[m]=(float)0;
if(isNaN!=0 && (int)angle<0)
    final_angle[m]=(float)180;

}
if( (float)angle == (float)1.000000 )
{
    if(s2_x == (float)751)
        printf("a1= %f\n",angle);
    final_angle[m] = (float)0;
}

//if(s2_x == (float)751)
// printf("-------- %f\n", final_angle[m]);

return(final_angle[m]);
m++;
}
APPENDIX F

ILP FORMULATION FOR NP HARD COORDINATES
// brendan_5.3.cpp : Defines the entry point for the console application.

#include "stdafx.h"
#include <math.h>
#include <stdio.h>
#include <stdlib.h>
#define no_of_RS 8

int _tmain(int argc, _TCHAR* argv[])
{
    //0
    int rw1;
    int flag_extra[100];
    int beamset[8][100][100];
    int beamset_temp[8][100][100];
    int max_third[100][100];
    int countt=0;
    int couna[100];
    int coun=0;
    int omega=0;
    int fin=0;
    int post=0;
    int prnt=0;
    // char beamset_string[8];
    char a[1000];
    int t=0;
    int m_x=0;
    //0.1
    int max[8];
    int div_by;

    int ne,br,rw,nt;
    //1st
    int alp = 0;
    int bet = 0;
    //1.1
    int i[8];
    int j;
    int k=0;
    int b=0;
    int c=0;
    int d=0;
    int e=0;
    int f;
    FILE *f1;
f1=fopen("var.txt","w");

srand(rand() %10 +1 );
printf("the random numbers are \n");
//2nd
for(j=0;j<8;j++)
{
   //srand(rand(rand()));
   i[j]=rand() %10 +1;
   printf(" i[%d] = %d \n ",j+1,i[j]);
}

//3rd
//i[1]=9;
for(j=0;j<8;j++)
{
   //i[j]=rand() %10 +1;
   printf(" i[%d] = %d \n ",j+1,i[j]);
}

for(j=0;j<8;j++)
{
   k = k + i[j];
}
if(k%2 == 0)
{
   printf(" k is even, k = %d \n ",k);
}
else
{
   j=j-1;
   k=k+1;
   printf(" k is odd, k+1= %d \n ",k);
   printf(" previous i[%d] is %d ,\n ",j+1,i[j]);
   i[j] = i[j] + 1;
   printf(" now i[%d] is %d \n ",j+1,i[j]);
}

//i[0]=1;
//i[1]=2;
//i[2]=4;
//i[3]=6;
//i[4]=8;
//i[5]=10;
//i[6]=12;
//i[7]=14;
k=57;
b=k+2;
//b=59;
printf(" k+2 relays are %d \n",b);

//================================================================================
//4th
for(d=0;d<8;d++)
{
   c=k/2 -[d];
   //max is the 2nd max
   //max-3rd is the max for 3rd
   max[alp]=c+1;
alp++;

for(j=0;j<c;j++)
{
    for(e=j;e<=j+i[d]-1;e++)
    {
        beamset[d][m_x][omega]=e;
        omega++;
    }

    //printf("+++++ %d\n",omega);
    max_third[d][countt]=omega;
    countt++;
    m_x++;
    omega=0;
}

f=k/2-i[d];
//if(d==1)
     //printf("%d---\n",omega);
for(j=f;j<f+i[d]+1;j++)
{
    beamset[d][m_x][omega]=j;
    omega++;
}
//if(d==1)
    //printf("%d---\n",j);

m_x=0;
max_third[d][countt]=omega;
    countt++;
    omega=0;
    countt=0;
}

alp=0;
//5th
for(d=0;d<8;d++)
{
    c=k/2-i[d];
    //max is the 2nd max
    //max-3rd is the max for 3rd
    //printf("********%d\n",max[alp]);
    m_x=max[alp];
    alp++;
for(j=0;j<c;j++)
{
    for(e=j;e<=j+i[d]-1;e++)
    {
        beamset[d][m_x][omega]=e+k/2+1;
        omega++;
    }
    m_x++;
    omega=0;
}

m_x=0;
omega=0;

f=k/2-i[d];
for(j=f;j<f+i[d]+1;j++)
{
    beamset[d][m_x][omega]=j+k/2+1;
    omega++;
}

m_x=0;
omega=0;
}

//6
for(d=0;d<8;d++)
{
    for(bet=0;bet<max[d];bet++)
    {
        for(omega=0;omega<max_third[d][bet];omega++)
        {
            // beamset_temp[d][bet]=beamset[d][bet];
            //beamset_string[d][bet]=atoi(beamset[d][bet]);
            printf("b[%d][%d] = %d    ",d,bet,beamset[d][bet][omega]);
            //printf("b[%d][%d] = %llu    ",d,bet,beamset[d][0][0]);
        }
        printf("n");
    }
}

for(bet=0;bet<max[d];bet++)
{
    for(omega=0;omega<max_third[d][bet];omega++)
    {
        // beamset_temp[d][bet]=beamset[d][bet];
        //beamset_string[d][bet]=atoi(beamset[d][bet]);
        printf("b[%d][%d] = %d    ",d,bet,beamset[d][bet][omega]);
        //printf("b[%d][%d] = %llu    ",d,bet,beamset[d][0][0]);
    }
}
```c
prnt++;
printf("\n");
}
prnt("\n\n");

printf(\n\n);}

fprintf(f1,"%s","max: ");
for(ne=0;ne<no_of_RS;ne++)
{
    for(br=0;br<k+2;br++)
    {
        fprintf(f1,"%c%d%d%c%c%c",'x',br,ne,' ','+','
);
    }
}

//print x00<1
fseek(f1,-2,1);
fprintf(f1,"%c",";");
fprintf(f1,"%c%c\n\n\n");
for(ne=0;ne<no_of_RS;ne++)
{
    for(br=0;br<k+2;br++)
    {
        fprintf(f1,"%c%d%d %c%c%d%c%c",'x',br,ne,'<','='),1,';','
);
    }
}

fprintf(f1,"%c%c\n\n\n");
alp=0;
//print ss<1
//print ss<1
for(br=0;br<k+2;br++)
{
    for(rw=0;rw<no_of_RS;rw++)
    {
        for(nt=0;nt<(max[rw]);nt++)
        {
```
for(omega=0;omega<max_third[rw][nt];omega++)
{
    if(beamset[rw][nt][omega]==br)
        fprintf(f1,"%c%d%d
        %c%c%d%c%c",
            's',rw,nt,'<','=',1,'\n');
}
for(nt=0;nt<max[rw];nt++)
{
    for(omega=0;omega<max_third[rw][nt];omega++)
    {
        if(beamset[rw][nt+max[rw]][omega]==br)
            fprintf(f1,"%c%d%d
            %c%c%d%c%c",
                's',rw,nt+max[rw],'<','=',1,'\n');
    }
}
}
fprintf(f1,"%c%c",
    'n','n');
fprintf(f1,"%c%c",
    'n','n');
fprintf(f1,"%c%c",
    'n','n');

//ss+ss=1
//fi
n=0;
for(rw=0;rw<no_of_RS;rw++)
{
    for(rw1=0;rw1<99;rw1++)
    {
        flag_extra[rw1]=0;
    }
    for(br=0;br<k+2;br++)
    {
        for(nt=0;nt<max[rw];nt++)
        {
            for(omega=0;omega<max_third[rw][nt];omega++)
            {
                if(beamset[rw][nt][omega]==br)
                    if(flag_extra[nt]==0)
                        flag_extra[nt]=1;
                fprintf(f1,"%c%d%d
                %c%c%d%c%c",
                    's',rw,nt,+,1,'\n');
            }
        }
    }
}
for (nt=0; nt<(max[rw]); nt++)
{
    for(omega=0; omega<max_third[rw][nt]; omega++)
    {
        if(beamset[rw][nt+max[rw]][omega]==br)
            if(flag_extra[nt+max[rw]]==0)
            {
                flag_extra[nt+max[rw]]=1;
                fprintf(f1, "%c%d%d%c", rw, nt+max[rw], '+');
            }
    }
}

fprintf(f1, "%c%c\n",'n','n');
fprintf(f1, "%c"\n",=1);
fprintf(f1, "%c%c\n",'n','n');
fprintf(f1, "%c%c\n",'n','n');

//fprintf(f1, "%c%c",'n','n');
fseek(f1,-2,1);
fprintf(f1, " %c%d%c%c\n",'s',1);
fprintf(f1, "%c%c\n",'n','n');
fprintf(f1, "%c%c\n",'n','n');

//ss>ss>ss
for (br=0; br<k+2; br++)
{
    for(rw=0; rw<no_of_RS; rw++)
    {
        for(nt=0; nt<(max[rw]); nt++)
        {
            for(omega=0; omega<max_third[rw][nt]; omega++)
            {
                if(beamset[rw][nt][omega]==br)
                    fprintf(f1, "%c%d%d%c", rw, nt, '+');
            }
        }
    }
}

//fprintf(f1, "%c%c",'n','n');
fseek(f1,-2,1);
fprintf(f1, "%c%c%c%c\n",'s',=1);
fprintf(f1, "%c%c%c%c\n",'n','n');
fprintf(f1, "%c%c%c%c\n",'n','n');

fprintf(f1, "%c%c%c%c\n",'n','n');
fprintf(f1, "%c%c%c%c\n",'n','n');
\texttt{fprintf(f1, \\
"\%c,d\%d %c \\
\});
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