Optimum repeater distribution models for simultaneous users

Abstract

Although repeater and cellular network has been studied extensively, not many studies in the literature analyze the relationship between repeater coordination and the number of simultaneous users. Our main job is to make efficient use of repeaters. We build up three models, Model 1&2 try to deal with the coordination problem to guarantee different number of simultaneous users with the fewest repeaters, and the third one primarily consider space character to improve utility efficiency.

Dealing with the model one, we first assume different repeaters have different capacity. First, it uses the minimum number of repeater to cover the area of the whole zone. Second, we divide the repeater into two kinds: local ones and route ones. Finally we adopt a simple algorithm to guarantee the repeaters are fully used and a route system to connect each other. We assume a local repeater’s capacity is 20, and a route repeater’s capacity is 1000, the result is 50 local repeaters and 38 route repeaters, total with 88 repeaters to meet the requirement of 1000 simultaneous users.

When we try to fit 10000 people with the model 1, we find that the existed route system cannot satisfy the need. Then we try two kinds of methods to solve the problem. One is to add new route repeaters, and the other one is to build a new network system. Finally, we compare the two results and find that the new network system has nicer performance in terms of balanced network load and fewer repeaters. However the sensitive analysis tells us the two systems has its own strength and weakness.

Model 3 primarily deal with the space factor. Firstly, we divide the space into horizontal plane and vertical plane. Secondly, we analyze qualitatively how features of the curvature in the contour line affect the transmission. Finally, we design a simple quantitative algorithm to determine the optimal place for repeaters to locate on.

The main advantage of our approach is that the model hierarchy is very clear.

Key words: cellular, repeater, deployment, CTCSS, frequency pair
1 Introduction

Although very high frequency (VHF) is the radio frequency range from 30MHz to 300MHz [1], our model only on the Amateur radio: 2 Meters band that is from the 144MHZ to the 148MHz [1] and ignores the internal mechanism of the repeater.

The simplest system for the repeater distribution is to put the repeaters on the top of the mountains or tall towers so that it could cover the largest area. We cannot adopt this system because it cannot make sure that we have used each repeater in an economic and high efficiency way. So our main goal is to achieve high capacity within a limited frequency spectrum and cover very large area. The second goal is to use the minimum number of repeaters which can accommodate the maximum number of simultaneous users.

Our paper is organized as follows. First, we cover the entire circular area completely with the cellular topologies to get the minimum number of repeaters for the coverage. Second, we design an algorithm to get the repeater deployment system in the same cells. Then we build a pair of S-type-parallel routes to get the repeater deployment system accessible between every two cells. With the system, we can calculate the minimum number of the repeaters to accommodate the 1,000 uses simultaneously. In the 10000 users’ case, we find some problems when using the same method as the 1000 uses case because of the enormous increasing users. So we improve our system further using the Route System. With this new system, we not only successfully conquer the previous problems, but also enhance the performance of the transmission system. Finally, we research the case of mountainous area in the terms of space layer. We divide the space into to the following two aspects: one is the horizontal plane; the other is the vertical plane. In these two plans we reach a conclusion that only putting the repeater in the point having the biggest curvature can we make the fullest use of the repeater. Using this conclusion we then give out a simple and practicable algorithm to decide the placing of repeaters in the mountainous area with the help of a contour map.
2 Background

We make several clarifications of the background for the problem as follows:

- **VHF**
  
  Very high frequency (VHF) is the radio frequency range from 30MHz to 300MHz, [1]. And in this problem we study on the frequency from 145 to 148 MHz that in the range of the Amateur radio 2 Meters band [1].

- **Line-of-sight transmission**
  
  VHF signals propagate under normal conditions as a near line-of-sight phenomenon.

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**Figure 1**: the outline of this paper

**Figure 2**: Two antennae are shown, each has the same height. Line-of-sight
transmission means the transmitting and receiving antennae can "see" each other as shown. The maximum distance at which they can see each other, Distance, occurs when the sighting line just grazes the earth's surface.

- **Repeater**
  In telecommunication, the term repeater has the following standardized meanings:
  1) An analog device that amplifies an input signal regardless of its nature (analog or digital)
  2) A digital device that amplifies, reshapes, retimes, or performs a combination of any of these functions on a digital input signal for retransmission.[2]
  And in this paper, we focus on the analog device regardless of the signal's nature.

- **Mobile station**
  The mobile station (MS) comprises all user equipment and software needed for communication with a mobile network. [3]

- **Continuous Tone-Coded Squelch System (CTCSS)**
  Receivers equipped with a CTCSS circuit usually have a switch that selects normal mode or CTCSS mode. When enabled, the CTCSS radio circuit, instead of opening the receive audio for any signal, causes the two-way radio receiver's audio to open only in the presence of the normal RF signal AND the correct sub-audible audio tone (sub-audible meaning that the receiver circuitry can detect it, but is not apparent to the users in the audio output). This is akin to the use of a lock on a door. A carrier squelches or noise squelch receiver not configured with CTCSS has no lock on its door and will let any signal in. [4]
  
  With the CTCSS, the repeaters in the same or adjacent cell can share the same frequency pair without interference with each other.

### 3 Problem Setup

#### 3.1 Problem Restatement

When using the repeater to solve the line-of-sight limitation of the VHF, we must resolve the repeater's drawback: repeaters can interfere with one another unless they are far enough apart or transmit on sufficient separated frequencies or using the CTCSS. So we to solve these problems as follows:

- How to deploy the repeaters in a circular flat area?
- The definition of 'far enough apart' and 'sufficient separated frequencies'
- What to do with the adjacent repeaters?
- The minimum number of repeaters that accommodate 1,000 or 10,000 simultaneous users.
- How to deal with the case of the mountainous areas?
3.2 Terminology

Input:
- The frequency that a repeater receives.
- The frequency that the mobile station will be transmitting on.

Output:
- The frequency that a repeater transmits on.
- The frequency that the mobile station will be receiving.

The radio should display the receive frequency (the repeater's transmit frequency) when monitoring the repeater.

Offset: The difference between the repeater's output frequency and input frequency

Duplex: Duplex operation is that one station transmits on frequency A and receives on frequency B and the other station transmits on frequency B and receives on frequency A.

Frequency pair: The input and output frequencies of the repeater, and in practice the frequency pair is often replaced with the transmitting frequency. In this paper, we use the transmitting frequency (output) to replace frequency pair.

3.3 Variables and Symbols

<table>
<thead>
<tr>
<th>Symbols &amp; Variables</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>TN</td>
<td>refers to the minimum number of repeaters to accommodate all users</td>
</tr>
<tr>
<td>C</td>
<td>the maximum capacity of a repeater</td>
</tr>
<tr>
<td>R</td>
<td>the number of the repeater completely covers the circular area</td>
</tr>
<tr>
<td>M</td>
<td>the number of cells in a chosen cluster</td>
</tr>
<tr>
<td>total_user</td>
<td>refers to the total number of users in the area</td>
</tr>
<tr>
<td>local_user</td>
<td>refers to the number of users in each cell</td>
</tr>
<tr>
<td>cell_num</td>
<td>refers to the total number of cells</td>
</tr>
</tbody>
</table>
**List<repeater A>** the cluster composed of repeater A and A’s adjacent repeaters, and we sign the repeater A in the cell A

**local_repeater** The number of repeaters in local system

**route_repeater** the number of repeaters in route system

**area_radius(AR)** the radius of the circular area

**repeater_radius(CR)** the coverage radius of the repeater

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### 4 Assumptions

We make the following assumptions about the repeater coordination in this paper.

- We research the FM voice repeater, which can be found on 144MHz band. In this problem, the available spectrum is within the Amateur radio 2 Meters band; FM voice repeaters are most popular ones used in Amateur Radio, so we choose it as our research object in this paper.

- Because users of a repeater cannot transmit and receive simultaneously, the repeater operates are in full duplex mode; the mobile stations are operating in half duplex mode.

- The repeaters have equal intrinsic attributes: the maximum capacity and the coverage radius determined by their own transmit powers. The assumption makes the problem easier to understand.

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### 5 Cellular Topologies

#### 5.1 Motivation

With many complexities in the repeater deployment process, we begin by analyzing the main factors of the problem. Firstly, the number of simultaneous users the repeaters is determined by the total available bandwidth and the spectrum required for transmitting a signal.

For example: using the typical analog system, the total available spectrum is 3MHz, and the each channel need to have a bandwidth of around 20KHz including the guard band between adjacent signals to avoid undue interference. The spectrum can accommodate about 150 users.

A far more efficient system can accommodate millions of users in a limited spectrum. The most commonly used system now is the cellular topologies [5], so we choose the cellular topologies as our basic model. Then we analyze the problem in a
simplistic parts without considering the 'private line'(PL). And we can get a fully coverage on the circular area.

Secondly, we add the PL in the model to get a relatively complete result.

Finally, our methods will solve the design of the repeater deployment network to solve the problems.

5.2 Complete Coverage with Cellular Topologies

5.2.1 The cellular topologies can accommodate much more users in a limited bandwidth

- The complete coverage is divided into many cells
- Replace the single, high power transmitter with many low power repeaters
- Each repeater provides coverage only to the cell where the repeater locate, so it can reduce the interference from other signals
- The repeaters that are far enough apart may reuse the same frequency pair

Considering the assumption that the repeater has equal transmit power, we choose the hexagon shape as the simplistic model for each repeaters to fully cover the circular flat. We can easily gain the full coverage of the area in Figure2.

**Figure 3**: Complete coverage with cellular topologies: every hexagon denotes a cell, and the circle denotes the area we study.

In the Figure2, each hexagon has a repeater in the center, and the coverage area is the hexagon. It needs at least R repeater to cover the circular area. Complete coverage with R repeaters guarantees that wherever in the circular area a user can be accommodated.
5.2.2 Why we choose the hexagon?

- In order to cover the entire area with equal area and without overlap, we can choose the square, the equilateral triangle, or the hexagon.
- For a given distance between the center of a polygon and its farthest perimeter points, the hexagon has the largest area of the three.
- With the hexagon, the number of cells that completely cover the region is the fewest compared to the square and the equilateral triangle.

6 Repeater Deployment System

In this model, we build a repeater deployment system based on the cellular complete coverage. The system is composed with two parts:

- **The repeater system in the same cell named local system.** Every cell has a repeater in the center founded on the cellular system. If the repeaters cannot accommodate the users, we design an algorithm to add repeaters to exiting system one by one until to accommodate all the users simultaneously.

- **The repeater system between different cells named route system.** We build two S-type-parallel routes to make sure that every two cells are connected. Each route is unidirectional and the directions of the two are reverse. And the different cells can communicate through the routes.

6.1 Additional Assumptions

- **The repeater has two intrinsic attributes determined by its own power:** the maximum capacity and the coverage radius. Repeaters in this paper have identical intrinsic attributes.
  - Assume that the maximum capacity of a repeater is C. It is the tolerance-limit for the C users sharing the same repeater means the waiting time for the repeater is tolerable.
  - The coverage radius. We use the repeater with relatively longer coverage radius because longer coverage radius means fewer cells completely covering the entire circular area.

- **Repeaters have two extrinsic attributes (parameters):** frequency pair (transmitting frequency) and CTCSS (PL). Either of the attribute differs, the repeater is different.

- Any two cells are connected. The users in different cells can communicate each other.

- Not accounting for the distribution of the population.
• Assumptions concerning the anterior process are the same as the anterior assumptions.

### 6.2 The Algorithm for the Local System

1) We design an algorithm to achieve the repeater deployment system in the same cell as follows.
   **Step1:** complete coverage of the entire circular area needs R repeaters.
   R repeaters guarantee that wherever in the circular area a user can be accommodated.

   **Step2:** if \( C \cdot R > N \), exit the program, otherwise, enter step3

   At this time, all users in the entire circular region can be accommodated simultaneously, so it has no need to add repeaters to the existing system.

   **Step3:** Add a repeater denoted P to the cell A and the repeater locates on the same site with the repeater A.

   **Step4:** the repeater P needs to meet two conditions:
   1) P's transmitting frequency is different to that of the repeater in cluster List<repeater A>
   2) Or that, repeater P has the same transmitting frequency to the repeaters in List<repeater A>, but repeater P’s PL is different from the repeaters in List<repeater A>.

   If repeater P meets the conditions above, R+1, enter to step2; otherwise, enter step3.

2) Flow chart
The Figure 4 shows the implementation procedure of the algorithm.

3) Algorithm Analysis

The algorithm mainly based on the assumptions that repeaters have two extrinsic attributes: frequency pair (transmitting frequency) and CTCSS (PL). Either of the attribute differs, the repeater is different.

The assumptions enable us to determine the parameters: Transmitting frequency and PL. And the time complexity of the algorithm is easy to calculate, that is

\[ TimeComplexity = M \times R \log R \]
6.3 Interoperability: the Route System

We build two S-type-parallel routes to make the repeater deployment system have a good interoperability based on two considerations:

- When the users communicate in the same cell, it is necessary to ensure their priority to the repeaters.
- Considering the assumption that any two cells are connected. The users in different cells can communicate each other.

So the S-type-parallel routes only for the communications between users in different cells. And the procedure of the route system is as follows:

**Step 1:** the cellular system is the foundation. As in the Figure 2, each hexagon has a repeater in the center, and the coverage area is the hexagon.

**Step 2:** the route is connected unidirectional.

For example, the S-type-route is connected from P1(145.145.6), P2(145.6, 146.2), P3(146.2, 146.8),...P6(147.4,148) with a successive increase by 600KHz, and then with a successive decrease by 600KHz,P7(148,147.4),...P12(145.6,145) proceeding in this order until all the cells are connected. Showed in the Figure 3

**Step 3:** two pairs of repeaters exit between every two cells to guarantee any two repeaters can reach each other.

![Figure 3: An example: the unidirectional S-type-route connecting all the cells.](image-url)
Figure 6: Two pairs of repeaters between two adjacent cells.

The Figure 5 shows a unidirectional route connecting all the cells.

The Figure 6 shows two pairs of repeaters between two adjacent cells, and the transmitting direction is reverse: A to B while D to C. A pair of repeaters can send signals only in one direction; otherwise, it will cause an infinite loop circulation.

In order to avoid the interference between the repeaters in the same cell, for example, A and C, the two routes have different PL. For example, A is PL1, C is PL2. Meanwhile, every route has an equal PL to make more effective utilization.

6.4 Analysis of the Repeater Deployment System

The repeater deployment systems are divided into the local system and route system. When communicating in the same cell, users can send request to all the repeaters in the cell. While the communication in different cells can only conduct through the route system. That guarantees the priority of the users in the local cell because the majority request is in the local system.

Figure 7: big plots stand for repeaters, small plots stand for user. User can communicate in the same cell or communicate with other users in different cells. There are uplink and downlink in the system, and both of them occupy an independent repeater.

The division makes the repeater deployment system easy to understand and put into practice. And the system has a perfect trade-off between the bandwidth and the PL through the cellular topologies and the route system.
With the one-by-one-adding idea, we can get the least repeaters to accommodate users simultaneously. The algorithm guarantee the number of the repeater we get is minimum.

6.5 Mountainous Areas

In the line-of-sight transmission and reception, we build our models on the cellular topologies; while in the mountainous areas, the cellular system is inappropriate because of the uneven distribution of mountains and the mountains' blockings. So we must build a new model to solve the problem.

After a closer analysis of the case with mountainous areas, we confirm the main purpose of the new model is how to choose the position of repeaters in mountainous areas and the choice of performance about repeater.

6.5.1 Assumptions

- Only consider the signal transmitting in a straight line, ignoring the changes of the non-blocking terrain and other factors which may lead to the attenuation of radio waves
- Not accounting for the details of the mountain surface

Consider repeaters in the top of the hill which can fully covered the mountain areas, adjust measures to local conditions. High mountains and hills with wider vertical projection should use high-power repeater (longer distance of transmission). For comprehensive consideration, there exist two circumstances:
Figure 9: There should be a repeater in the mountaintop

Figure 10: The flat land in the basin area is similar to the Model one, and the fringe of basin should setup new repeaters

6.5.2 Detailed qualitative analysis

1. Horizontal projection (namely contours):
Repeater should setup in the point of biggest radius of curvature.
* If setup in the ridge line, it can transmit to most area beyond mountain areas.
* If setup in the valley, it can transmit to least area beyond mountain areas.

Proof: Draw a tangent of the point, if altitude of the point of intersection is lower than the latitude of original point, it means this point has more than half area is beyond mountain areas. Adversely, if the latitude is higher than the original’s, it means this point has less than half area is beyond mountain areas.

Figure 11: Repeater setup in the ridge line
2. Vertical section:

Three kind of mountaintop: spire dome and flat.

Figure12: kind of mountain which should take into account.

Special flat mountaintop:

Figure13: repeater setup in the center of the flat.

Figure14: repeater setup in the ridge of flat.

Because of line-of-sight transmitting, it is obvious that repeater setup in the center of the flat can cover more area, while the ridge one cannot transmit to areas which is obstruct by mountain ridge.
Figure 15: Mountaintop area has larger coverage of signal.

In the Figure 15, we can simply conclude that: signal in the mountain area is spread to much more areas. (Deep color zone is available)

6.5.3 Detailed quantitative analysis:

Using contour can calculate the space distance of any two points according to The Pythagorean.

Specific algorithm is as follows:

Step 1: mark the mountaintop as repeater.

Step 2: begin with the highest mountaintop, in proper order, using the coverage radius of a repeater as maximum distance, mark the point meet the requirement. Define it as Same Space Distance Line.

Step 3: find out the some points in the next Same Space Distance Line with bigger radius of curvature, and order them by radius of curvature.

Step 4: pick out one point, do the same as step 2.

Step 5: check whether every point the Same Space Distance Line has been covered. If not, setup a new repeater in proper position. If yes, go to step 3.

In this detailed quantitative analysis, the strengths are simple and feasible, and the weaknesses are calculation imprecise.
7 Calculation

7.1 Assumptions

1. Though we want to use as few repeaters as possible, users hope that each one can use more repeaters. We assume that the capacity of the local repeater is 20 users.

2. As communications mostly happen inside cells, we assume that the request-ratio between the local system and route system is 50:1. We assume route repeaters in the either direction (uplink/downlink)’s capacity is at most 1000;

3. We assume that the coverage radius of the repeater is 9.2 miles, so there will be 19 cells. Since this kind of repeater is very common and 19 cells can get a nice approximate circle.

4. We assume that users distribute equally among the cells.

7.2 For 1,000 simultaneous users

In this case, we can easily get:

\[ \text{total_user} = 1000 \]

\[ \text{cell_num} = 19 \]

\[ \text{route_repeater} = 38 \]

So we can get local_user as 1000/19 from

\[ \text{local_user} = \frac{\text{total_user}}{\text{cell_num}} \]

Get local_repeater as 50 from

\[ \text{local_repeater} = \frac{\text{total_users}}{20} \]

At this time: local repeater holds 20 people, (meet the requirements above)
As route repeaters work in an only one direction, so for each direction of link, the average ratio of load between all the nodes is

\[ \frac{1}{1} : \frac{1}{2} : \frac{1}{3} : \cdots : \frac{1}{17} : \frac{1}{18} : \frac{1}{19} \]
Table 2: samples of uplink and downlink

<table>
<thead>
<tr>
<th>uplink</th>
<th>downlink</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/50&gt;1/1000</td>
<td>1/950&gt;1/1000</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>1/500&gt;1/1000</td>
<td>1/500&gt;1/1000</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>1/950&gt;1/1000</td>
<td>1/50&gt;1/1000</td>
</tr>
</tbody>
</table>

In Table 2, the entire nodes meet requirements.

So we get an answer to question one as follows:

Table 3: the result of the first problem

<table>
<thead>
<tr>
<th>local repeaters</th>
<th>Route repeaters</th>
<th>Total repeaters</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>38</td>
<td>88</td>
</tr>
</tbody>
</table>

In Table 3, the result showed above is 88, including local and route repeaters.

7.3 For 10,000 simultaneous users

When $total\_user = 10000$, adopting the previous steps we can get the following:

$$total\_user = 1000$$

$$cell\_num = 19$$

$$route\_repeater = 38$$

So we can get local users as $10000/19$ from

$$local\_user = \frac{total\_user}{cell\_num}$$

Get local repeaters as $500$ from

$$local\_repeater = \frac{total\_users}{20}$$

At this time: local repeater holds 20 people, (meet requirements)

Route repeaters:
The Network System

Table 4: samples of uplink and downlink

<table>
<thead>
<tr>
<th>uplink</th>
<th>downlink</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1/500 &gt; 1/1000$ (meet requirements)</td>
<td>$1/9500 &lt; 1/1000$ (fail requirements)</td>
</tr>
<tr>
<td>$1/5000 &lt; 1/1000$ (fail requirements)</td>
<td>...</td>
</tr>
<tr>
<td>$1/9500 &lt; 1/1000$ (fail requirements)</td>
<td>$1/500 &gt; 1/1000$ (meet requirements)</td>
</tr>
</tbody>
</table>

We need to add another 9 pairs of route repeaters to meet requirements:

\[
\text{route}\_\text{cell} = 38 + 19 \times 9 \times 2 = 380
\]

Table 5: samples of uplink and downlink

<table>
<thead>
<tr>
<th>uplink</th>
<th>downlink</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1/50 &gt; 1/1000$ (meet requirements)</td>
<td>$1/950 &gt; 1/1000$ (meet requirements)</td>
</tr>
<tr>
<td>(meet requirements)</td>
<td>(meet requirements)</td>
</tr>
<tr>
<td>$1/500 &gt; 1/1000$ (meet requirements)</td>
<td>$1/500 &gt; 1/1000$ (meet requirements)</td>
</tr>
<tr>
<td>(meet requirements)</td>
<td>(meet requirements)</td>
</tr>
<tr>
<td>$1/950 &gt; 1/1000$ (meet requirements)</td>
<td>$1/50 &gt; 1/1000$ (meet requirements)</td>
</tr>
</tbody>
</table>

We now have meet all the requirements; but there are two nodes that one possesses $1/50$ uplink repeater, and another holds $1/950$ uplink repeater. This unbalance of load between nodes need to be improved seriously.

So we try to build another more balanced model: the network system.
Figure 16: The route system

Figure 16 shows the old S-type-route connecting the cell unidirectionally. When we transmit signal to some node of it, only one side of the route (uplink side or downlink side) will receive the signal. This is the reason why nodes lose balances.

Figure 17: the network system

In the Figure 17, we build a new network system. When we try to send signal to any repeater, it will transmit the signal to all the other nodes in the network.

But if the network system is built up, it has a deadly weakness: the cells in the network system are connected bidirectional which can cause an infinite loop circulation. So we make some adjustments to the network system to avoid the endless circulation. The adjustments are as follows: we build a private network for every cell with the help of PL. We name our new model the network system.
Figure 18: the network system: any of its nodes receive a signal; the signal will be transmitted to all the rest nodes.

Now we apply this new model for the previous calculation:

We have 19 nodes and each node has its own network system so we get 361 route repeaters from

$$route\_repeater = 19 \times 19$$

At this time, local repeater holds 20 users.

The ratio of load between all nodes is 1; every node in the network system holds 1/500 user. (meet requirements)

Finally we can compare the performance between the route system and the network system as follows:
Table 6: the comparison of performance in these two models

<table>
<thead>
<tr>
<th>The number of route repeaters</th>
<th>The num of user each node can hold</th>
</tr>
</thead>
<tbody>
<tr>
<td>380</td>
<td>(1/50~1/950)</td>
</tr>
<tr>
<td>361</td>
<td>1/500</td>
</tr>
</tbody>
</table>

We can get such conclusions:

1. In this case, network system saves the number of repeaters by 5% than the route system.
2. With both meeting the condition, all nodes in network system have a perfect stable load balance of unchanged 1/500 user, while the nodes of the route system hold a range number of (1/50~1/950) user.

7.4 Sensitivity and Robustness Testing

The sensitivity of the model is the effect of small parameter changes. Small changes in the results response to the small changes in the model's parameters prove the model is good. The robustness is the measure of how it performs in the extreme case. A robust model does not break down in such cases.

1. Suppose that max_route stands for the maximum number of route point every user has; \(N_0\) stands for the number of the cells; \(N_1\) stands for the largest ratio of max_route between all the users of route system; and \(N_2\) for the of the network system.

Table 7: \(N_1\) and \(N_2\) very as \(N_0\) changes

<table>
<thead>
<tr>
<th>(N_0)</th>
<th>(N_1)</th>
<th>(N_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>19</td>
<td>19</td>
<td>1</td>
</tr>
<tr>
<td>37</td>
<td>37</td>
<td>1</td>
</tr>
</tbody>
</table>

In Table 7, we can easily tell that: \(N_1 = N_0; N_2 = 1\)

This draw to a conclusion that, \(N_0\) is sensitive to \(N_1\), while \(N_2\) not. Because \(N_1\) and \(N_2\) both mean that the balanced of loading between different network node, at this point, network system performances much better than route system.

2. Suppose \(N_0\) for the number of cells; \(N_1\) stands for the number of route nodes
for route system and \( N_4 \) for network system.

<table>
<thead>
<tr>
<th>( N_0 )</th>
<th>( N_3 )</th>
<th>( N_4 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>49</td>
</tr>
<tr>
<td>19</td>
<td>19</td>
<td>361</td>
</tr>
</tbody>
</table>

In Table 8, we can easily tell that \( N_3 = N_0 \); \( N_4 = N_0^2 \)

So here we reach a conclusion that, \( N_0 \) is sensitive to \( N_3 \), while more sensitive to \( N_4 \). This means as the number of cells grows, both total amounts of the two systems grow, and especially, the network system grows even faster.

8 Strength and Weakness

**Strength:**
- The algorithm is founded on the complete coverage with cellular topologies. The cellular system is a relatively perfect model and is widely used in practice. That improves the reliability of our model.
- Account for all the main factors in the algorithm that guarantees the minimum number of the repeaters we got is reasonable and reliable.
- The main idea in the algorithm is adding the repeater to the exiting repeater system one by one until to saturation. The idea is relatively simple and the procedure is easy to realize. With the one-by-one-adding idea, we can get the least repeaters to accommodate users simultaneously.
- The cellular topologies guarantee that the non-adjacent cells do not interfere with each other; the one-by-one-adding algorithm makes sure that repeaters in the same cell do not interfere each other, either. At the same time, with the two S-type-parallel routes, the entire circular area has interoperability considering the assumption that any two cells are connected.

**Weakness:**
- The S-type-parallel routes have poor flexibility, so the increase of users will add burden to the route. If the number of users increases dramatically, the burden may exceed the routes' maximum capacity.
To the S-type-parallel route, the repeater in different cell has different burden. Analogy with the flow, the farther away from the source, the heavier burden the repeater has.

9 Conclusion and Future Work

The most significant achievement what we have got is the repeater deployment system that divided into two parts: the local system and the route system. The local system focuses on the communication in the same cell, while the route system is the connection between every two cells. The repeater deployment system is based on the commonly used cellular topologies. The idea that divides the whole system into two parts to study separately is worth learning in practice. Our work has contributed to the understanding of the repeater coordination.

We have analyzed all kinds of conditions in the mountainous areas. That has given a practical reference to confirm the location of repeaters in the mountain areas.

The limitation of our model is the connection between every two cells. The future work should focus on the connection between the repeaters in different cells.

The methods in model 1 and 2 are similar to Computer Network. Computer Network has LAN (Local Area Network) and WAN (Wide Area Network). Users in the local area network communication in the same LAN and through the WAN, different user can communicate with users in other areas. The difference between repeater and router is: Repeaters have no efficiency routing algorithms. In order to achieving the same function. We must guarantee the bidirectional can reach. Furthermore, no messages cannot transmit in the network unlimitedly and amplified, or it lead to increased the laden, so the repeater network must be established two mutual interference of communication mode, and PL tone can be used to make a difference as well as port in IP address. If a pair of same IP address, they can still communicate with different port.

References