

Impact Factor Analysis on Repeater Coordination

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Abstract—This article establishes two different population distribution models and creates new algorithms to calculate the number of the optimal Repeaters needed in allusion to two different cases that the annular mile radius of 40 planar region has 1,000 and respectively of 10,000 users. At last, we take Hong Kong as a living example to verify the reliability and practicability of the model.

Keywords-repeater;line-of-sight transmission;algorithm; optimization

1. Introduction

A repeater is a device that receives signal on an electromagnetic or optical transmission medium and regenerates the signal along the next leg of the medium[<http://searchnetworking.techtarget.com/definition/repeater>]. With the rapid development of the telecommunications industry, repeaters have become an indispensable part in assisting with short-distance transmission in global(Figure 1).

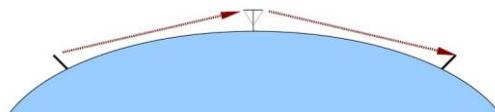


Figure 1. Line-of-sight transmission and reception through repeater

As each repeater has certain coverage radius, the main concern issue in practical project is often to determine the minimum number of repeaters to cover a maximum number of populations in a particular area with different users. Therefore, the population distribution in the local place can be the vital factor to determine the number of repeaters. In addition, the terrain may also influence the transmission by impacting the coverage radius.

Based on this situation, the key problems for the four issues are:

- How to determine the coverage radius of the repeaters?
- How to determine the population distribution in the circular flat area?
- Which algorithm to choose to determine the optimal number of repeaters?

2. Background

2.1. Key Terms & Definition

- **VHF** Very High Frequency is the radio frequency range from 30 MHz to 300 MHz. It is generally considered to be “line of sight” communications. [<http://en.wikipedia.org/wiki/Vhf>]
- **Repeater** is an electronic device that receives a signal and retransmits it at a higher level and/or higher power, or onto the other side of an obstruction, so that the signal can cover longer distances. [<http://en.wikipedia.org/wiki/Repeater>]
- **The DIRECTION of the shift** tells the repeater whether signals are transmitting at a lower frequency(-) than it receives or higher frequency(+) than it receives.

2.2. The Analyses in The Process of User Communication

Accounting for the inevitable line-of-sight propagation on the way of communication, signals need a repeater to pick them up, amplify them and retransmit them at a higher power for long-distance communication. To avoid the interference between two signals transmitting on the same frequency at the same time, the User and the repeater each have to transmit on a different frequency, with an offset of 0.6 MHz.(Figure 2)

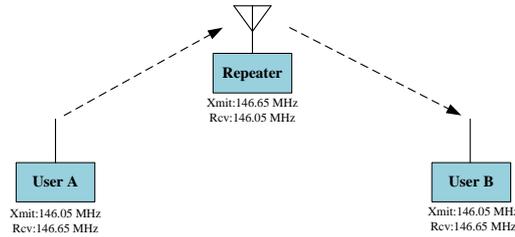


Figure 2. Two users communicate through a repeater

In addition, in order to ensure the repeater correctly responding to signals, CTCSS is installed in the User's operations. If the transmitting device doesn't send the signal with correct PL code, the repeater will not repeat the signal.

3. Indexing

Parameter	Definition
R	radius of a circular flat area
r_1	coverage radius of a repeater
f	working frequency of repeater

4. General Assumptions

For a repeater, it can only receive a particular narrow-band.

- The interference only exists in the two signals transmitting on the same frequency at the same time.
- The types for the repeater and the device of User are separately consistent.
- Without considering the signaling between repeaters.
- The coverage shape of the repeater is a circle.
- The population in the specific circular flat area has no significant change without considering the migration.
- All the repeaters in the circular area are served as civil repeater.

Users have to communicate through repeaters.

5. Model Development

We establish the logical interrelationship of the elements to show the way we approach the problems according to the common sense and current situation(Figure 4).

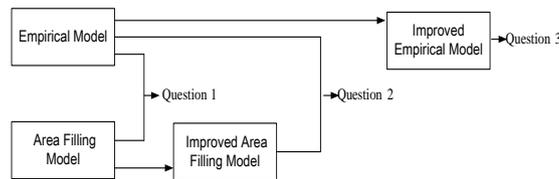


Figure 3. The logical relationships between models

The following models are based on figure 4.

Stage 1: Empirical Model for the Coverage Radius Calculation

Aiming at figuring out the coverage radius of a repeater and a sender, we select the practical engineering formula for radio wave transmission:

$$Loss(dB)=88.1+20\lg f-20\lg(h_1 \cdot h_2)+40\lg r_1$$

We take into account of the parameters involved in the formula and get the definitions(Table 1).

TABLE I. DEFINITIONS OF PARAMETERS

Parameter	Definition	Unit
$Loss$	The loss of radio wave	dB
h_1	The aerial height of operation A	m
h_2	The aerial height of operation B	m

The empirical formula limits to the conditions with the VHF signal at the frequency of 150 MHz, terrain height of about 15 m and the communication distance within 65 km.

Since the Uplink communication (transmission from operation to repeater) and the Downlink communication (transmission from repeater to operation) share the similar transmission principle, we may take the former for an example as well.

As the signal transmitting from the sender to the repeater has the maximum allowed attenuation ($SymGain$), we mainly consider the four communication elements which can obviously influence the $SymGain$:

- The transmit power of the sender ($PowerXmit$).
- The receiving sensitivity of the repeater ($SensRcv$).
- The antenna gain of the sender ($AnteGain_s$).
- The antenna gain of the repeater ($AnteGain_r$).

According to the wave propagation theory, we analyze whether the contribution of each element to $SymGain$ is positive or negative and get the equation:

$$SymGain(dB) = PowerXmit(dBm) - SensRcv(dBm) + AnteGain_s(dBi) - AnteGain_r(dBi)$$

If the system gain is equal to the loss of radio transmission, the wave energy on the communication way will reach its limit; if the system gain is less than the loss of radio transmission, it indicates that the communication may not be established. Thus, the loss of radio transmission should not be more than the system gain to ensure the communication and we take the marginal situation. So we get:

$$SymGain(dB) = Loss(dB)$$

Applying the data from existing research results, we take into account of the parameters involved in the model and get the values (Table 2).

TABLE II. VALUES OF PARAMETERS

Parameter	Value
h_1 (the radio height of sender)	1.5 m
h_2 (the antenna height of repeater)	30 m
f	146.5 MHz
$PowerXmit$	36 dBm
$SensRcv$	-116dBm
$AnteGain_s$	0 dBi
$AnteGain_r$	9.8 dBi

We use *Matlab* to do the numerical computation, and get the result:

$$r_1 = 12.47 \text{ km}$$

The above only calculate a conservative communication distance of the Uplink communication. The reason is that repeater retransmits signal at a higher power, thus, the downlink signal has the advantage over the uplink signal in terms of communication distance. Due to the two-way communication system, the conservative communication distance should depend on the uplink communication.

Stage 2: Area Filling Model Based on Graphics for 1000 users

Actually, it is impossible for repeaters to cover all the range of the circular flat area to guarantee “entire” communication in real life. Therefore, there is bound to be “dead zone”, which can neither send nor receive the signal, in the particular area. So the problem comes out to be “How many repeaters are needed to ensure that the maximum number of users can enjoy the service of the repeater?”

Aiming to confirm the minimum number of repeaters to satisfy the maximum part of users, we must clarify the distribution of 1000 users. To simplify the issue, we make some reasonable assumptions:

- The distributions of topography, climate and economy are close through the particular area.
- The distribution of 1000 users obeys uniform distribution.
- For any certain coverage ratio (α), the suitable minimum number of repeaters undoubtedly exists.

Since the population distribution is uniform, user coverage and area coverage are equivalent. On the basis of two basic graph generation algorithms (Bresenham circle algorithm & Edge fill algorithm), we propose a new algorithm to work out the minimum number of repeaters. The algorithm steps are:

- step 1:* Make a circumscribed square on the circular flat area of 64.4 km radius and discretize the square with pixels of 0.2 km side length. We signify it with an integral-point matrix (S) under the rectangular coordinates system and the coordinates of four vertices respectively are $(320, 320)$, $(-320, 320)$, $(-320, -320)$ and $(320, -320)$.
- step 2:* We use **Bresenham circle algorithm** to find out the correct pixels on the edge of circular area from matrix S . The selected pixels consist of Set C .
- step 3:* We use **edge fill algorithm** to judge whether the pixel inside the circular area or outside the area. The pixels on or within the boundary of the circle come to the Set B . The elements belonging to Set A will be stained red.
- step 4:* Repeat *step 2* and *step 3*. We can find out the pixels to describe the smaller coverage circle of 12 km ($\lfloor r_1 \rfloor$) radius. These pixels constitute Set D and will be stained yellow.
- step 5:* If a pixel is stained red first and then yellow, it should be stained green. We get the whole green pixels into Set A .
- step 6:* For a certain number of repeaters (N), we use **search algorithm** to find the maximum value of radio α and repeat it 500 times. Then, we will get a series values of α ($\{\alpha_1, \alpha_2, \alpha_3 \dots \alpha_{500}\}$) and the final value of ratio α , which equals to the maximum of $\{\alpha_1, \alpha_2, \alpha_3 \dots \alpha_{500}\}$.

Review

The area filling algorithm can be described in the form of flow chart (Figure 4).

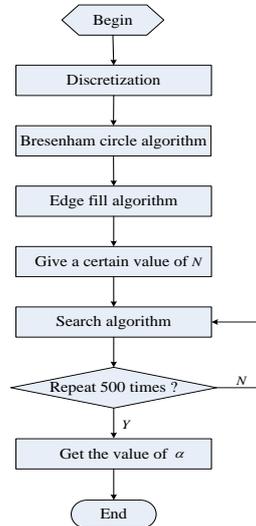


Figure 4. The flow chart of *area filling algorithm*

Combining the *edge filling algorithm* and practical situation, we set a series values of N , use Matlab to realize and we can get the results (Table 3):

TABLE III. A SERIES OPTIMAL PAIRS OF N & α (1000 USERS)

N	25	26	27	28	29	30	31
α (%)	65.5	67.5	65.8	68.4	71.0	75.9	83.7

N	32	33	34	35	36	37
α (%)	88.2	92.1	94.0	95.1	95.2	95.9

Therefore, we can find out the optimal value of N to satisfy different requirements in practice.

Stage 3: Improved Area Filling Model for 10,000 Users

In the model discussed above, we make the assumption that the population of users obeys uniform distribution since the number of users is only 1000. As the population changes to 10000, the circular area should be reasonably considered to be a city or an urban, in which there exists population center. Based on this situation, we adopt Clark Model (Figure 5) to describe the distribution of 10,000 users.

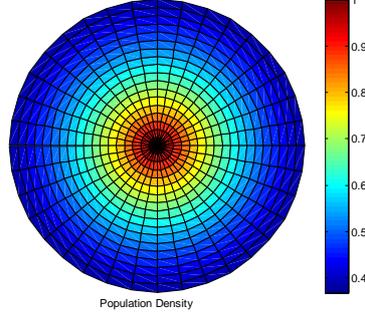


Figure 5. Population Density of Clark Model

First, we make some assumptions:

- The population center locates in the geometric center of the circle.
- The population around the population center presents Clark distribution.

Then we analyze the specific Clark population distribution for 10000 users. In accordance with theory of **Clark Model**, we have:

$$\rho = \rho_0 \cdot e^{-\frac{r}{R}}$$

where

- ρ_0 is the population density at the population center.
- ρ is the population density at the location of r kilometers from the center.
- r is the distance from the local to the center.

The purpose is still to find out the minimum number of repeaters to cover the optimal number of users. Since the population distribution has altered, every two pixels in **Stage 2** can't be treated equally. Thus, we propose an *improved area filling algorithm* to solve the problem. On the basis of Stage 2, we do these modifications:

We endow the element in Set B with weigh λ , whose value is proportional to the population density at its location. So the weight λ shares the consistent variation trend with the population density ρ . Variable λ decays exponentially with the increasing of variable r , which means the distance from the pixel center to the population center.

Assume pixel $p_i \in \text{Set } B$ and its weigh is λ_i , pixel $p_j \in \text{Set } A$ and its weigh is λ_j , so the proportion of the population covered by repeats is:

$$\alpha = \frac{\sum_{p_j \in A} \lambda_j}{\sum_{p_i \in B} \lambda_i}$$

where

$$\lambda = e^{-\frac{r}{R}}$$

We use Matlab to form the weigh matrix for each pixel, and we can get the final results(Table 4).

TABLE IV. A SERIES OPTIMAL PAIRS OF N & α (10,000 USERS)

N	25	26	27	28	29	30	31
α (%)	74.4	78.3	80.5	81.4	83.7	83.5	85.9

N	32	33	34	35	36	37
α (%)	88.4	91.2	94.9	95.7	95.7	96.2

To compare the consequence of 1000 users and 10,000 users, we make figure 6 by *Matlab*:

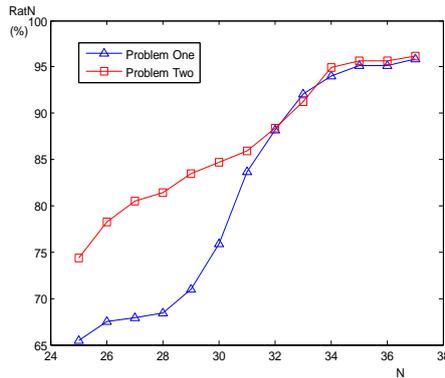


Figure 6. Contrasting results

6. Model Testing

We pick up the Repeater Coordination case in Hong Kong to testify our model. Hong Kong covers an area of 1103 km^2 . If we simplify it as a circle of radius 18.7 km and apply its actual parameters into the model of problem two, we can calculate out that Hong Kong needs 10~11 repeaters to cover about 95% users. Actually, Hong Kong has established 9 repeaters for VHF transmission. [<http://www.helloqc.net/forum/showthread.php?p=1571109>]

7. Conclusion

Our model, combined with certain existing models and algorithms, has solved the optimal repeater distribution problem with different users in quasi-smooth terrain area and the propagation defects caused by mountainous area. The *area filling algorithm* can be used for the future scientific research to solve the circle cover problem. Furthermore, from the consequence of the model testing, the model is indeed of certain instructive significance to some practical applications.

8. References

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