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SCUOLA DI INGEGNERIA INDUSTRIALE
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Radio Network Design

WMP project

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Contents

Introduction

The design of a robust and efficient Private Mobile Radio (PMR) network is critical for supporting professional users including emergency services, security personnel, and other mission-critical operations. This project mainly focuses on designing a PMR network for an area inside the city of Mashhad, in Iran, operating at a frequency of 158 MHz with ETSI Digital Mobile Radio (DMR) modulation. The network will utilize Motorola SLR5500 repeater stations and DM4000e vehicular terminals (train radios), interconnected via point-to-point microwave links to ensure seamless communication across the region.

The primary objective of this project is to utilize a minimum number of repeaters while ensuring comprehensive coverage and reliable connectivity. Key challenges include optimizing repeater placement on mountain tops or high elevations to maximize line-of-sight (LOS) coverage, designing an efficient microwave interconnection network with appropriate frequency selection and antenna specifications for repeaters, and validating the network's performance using RADIOMOBILE software.

This report will detail the network's structure, including repeater locations, transmit power, antenna configurations, and microwave link design, supported by radio coverage maps and Fresnel zone analysis. The outcomes will demonstrate a cost-effective and high-performance PMR network tailored to the geographical and technical requirements of the Mashhad region.

1 Description of the project

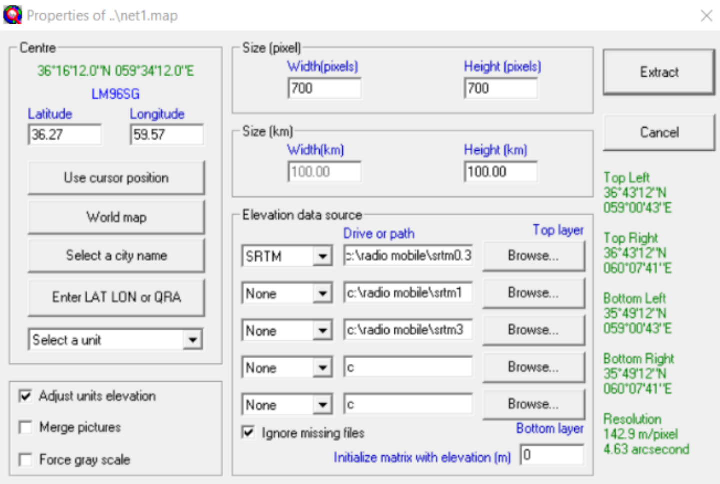
In this section the description of the project and characteristics of the network will be described.

1.1. Location and coverage requirements

As it can be seen in Fig1, an area of **100 km × 100 km square meter centered in Mashhad province, Iran is considered**. After specifying the central point latitude and longitude, the geographical view being provided by the software in Fig2. The network must ensure reliable communication for professional users (e.g., emergency services, security personnel) across this varied landscape. For the sake of reliability in connection, the network should provide at least first failure protection in physical layer; therefore, in the following, different scenarios will be considered to approach a cost efficient but reliable network for repeaters connection.

1.2. Network characteristics

Two different networks are considered in this project one VHF Net for repeaters-User connections in the frequency range of MHz and other for the microwave links in the frequency range of GHz, which because of the maximum distance 70 km between two repeaters, lower frequency for long haul is being considered. And, it is worth mentioning for low giga hertz frequency like 10 GHz, 10 dB margin is considered to overcome harsh condition like heavy raining situations.



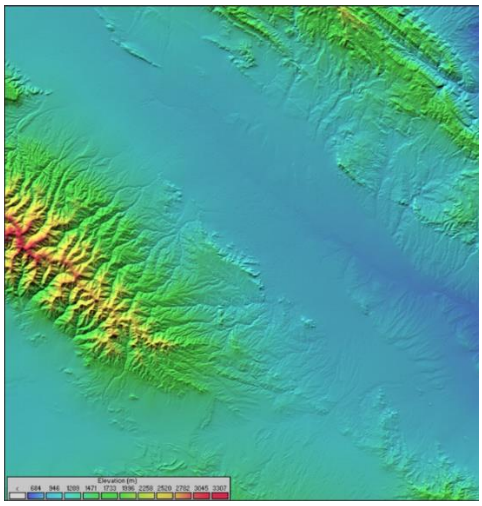


Fig1: Uploading the map of specified region

Fig2: Location of interest

1.2.1. Radio network to repeater network and vice versa

Frequency of operation: 158 MHz

Modulation type: ETSI Digital Mobile Radio (DMR)

Repeater stations (DMR): Motorola SLR5500 [1]

Repeater antenna: omni-directional with 5 dBi typical gain

Vehicular terminals (DMR): Motorola DM4000e [2]

Mobile antenna: omnidirectional with gain of 0 dB

1.2.2. Microwave network between repeaters

Frequency of operation: 10 GHz

Repeaters' interconnection: Point-to-point microwave links

Antenna: Reflector type

Microwave box: PTP 820S Licensed Microwave Radio [3]

Following which, all the systems including Mobile radios, Repeaters, and Microwave radios will be defined based on the information provided in the data sheets.

Mototrbo DM 4000e series is used for the mobile radios and as it can be seen from the datasheet of the device, the transmitted power should be between 25 and 45 and the received threshold should be 0.18 µV.

The transmit power is set equal to 35 W and Analog sensitivity equal to 0.3 µV. We also set the antenna [4] gain equal to 0 dBi and antenna height equal to 2m as requested.

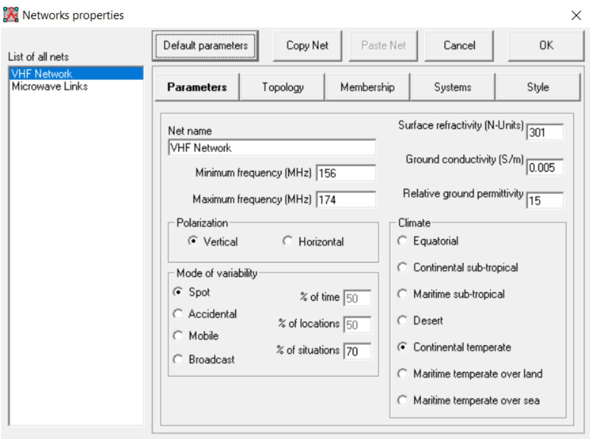


Figure 3: VHF Network

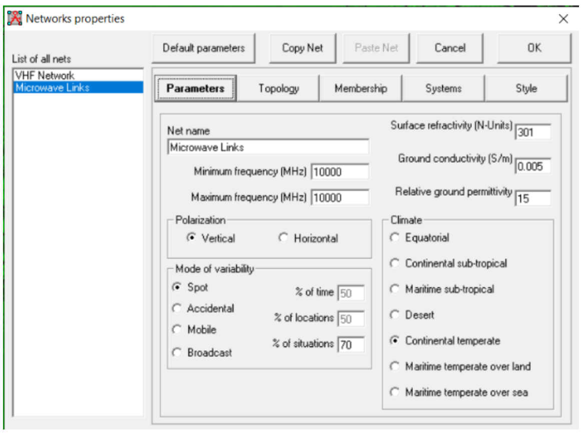


Figure 4: Microwave links

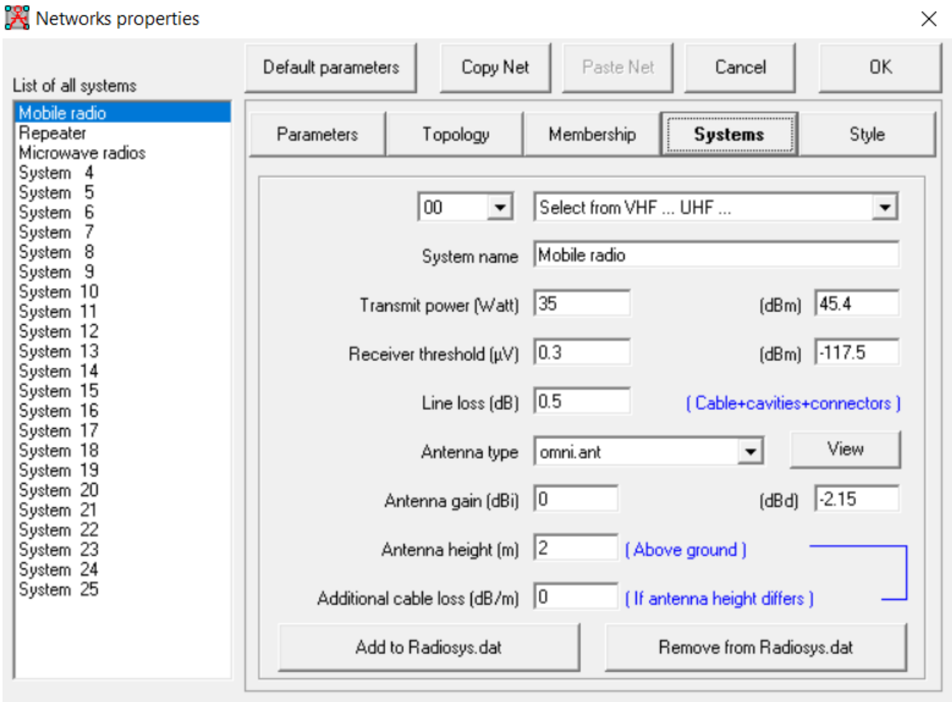


Figure 5: mobile radio properties

2 PMR network

In this section, the structure of the PMR network, including number and location of the repeaters (base stations), transmit power, type of antennas used at the base stations, coaxial cables employed, etc. will be described.

2.1. Characteristics of the repeater

As mentioned in the previous section, the properties of repeaters will be defined in the network properties. According to datasheet related to the Mototrbo SLR 5500 Repeater, the RF maximum output power and the receiver sensitivity were considered 50 W and 0.3 µV respectively.

GENERAL SPECIFICATIONS	VHF	UHF	300 MHz
Frequency Range	136-174 MHz	400-470 MHz	300-360 MHz
Channel Capacity	64		
RF Output Power	1-50 W		
Dimensions (H x W x D)	44 x 483 x 370 mm		

RECEIVER			
Frequency Range	136-174 MHz	400-470 MHz	300-360 MHz
Channel Spacing	12.5 / 20 / 25 kHz		
Frequency Stability	0.5 ppm		
Sensitivity, 12dB SINAD	0.22 uV		
Sensitivity, 5% BER	0.22 uV		

Figure 6: Repeater's datasheet

For repeater-user communication an antenna in 158 MHz is considered which has a gain of 5 dBi and is positioned on a tower with a high equal to 10 meters. Given the operating frequency, the omni-directional antenna BAN034R from BELCO Srl was selected. The chosen coaxial cable [5], RG218/U by HeluKabel, shows a loss of approximately 4.5 dB/100 meter at 200MHz. Hence, the total line loss is about 0.45 dB for an antenna 10 meters from the repeater. To find the network properties 3 types of information are quite important: the receiver sets sensitivity provided in its datasheet and equals to 0.22 micro volt (to have a good margin, it has been considered 0.3 micro volt), antenna gain, and antenna working frequency.

BAN034
BAN034R

Omnidirectional collinear Antenna

156-174 MHz

Type	BAN034	BAN034R
Frequency [MHz]	156÷174 MHz	
Impedance	50 Ω	
V.S.W.R.	<1.50	
Gain [dBi]	3	5
HPBW		
E-plane	±18°	±18°
Polarization	Vertical	
Input connector	N female	
Max power	500 W	
Survival wind velocity	180 km/h	
Wind load at 160 km/h	280 N	380 N
Dimensions [cm]	190x10x14	190x56x10
Packing type	Wooden crate	
Dimensions [cm]	200x20x20	200x40x25
Net weight [kg]	12	16
Gross weight [kg]	27	31

Figure 7: Antenna BAN034R

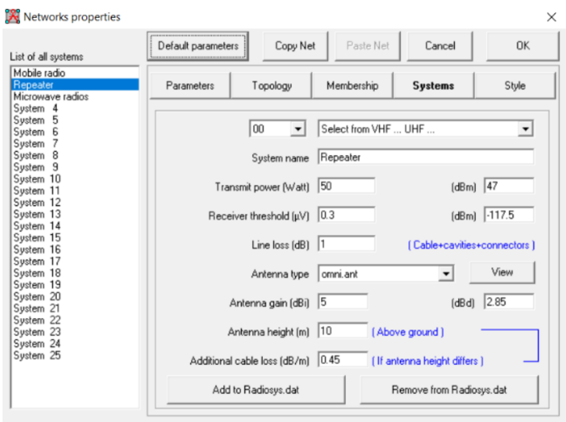


Figure 8: Repeater's properties

2.2. Implementation of repeaters

Then, we look for best positions to place repeaters to maximize the coverage over the desired region. To do so, we first find the highest altitude in each part that seems cover the area in a better way, then we place our repeaters at each place. Here we made use of 4 repeater to reach an acceptable coverage. It is worth noting that these stations positioned at altitudes of higher than 2000 meters above sea level. This method helps the signal propagate better and reach places that might be blocked by hills or other obstacles.

The figure shows the repeaters positions in space.

Repeater	1	2	3	4
Height (m)	3231	2449	2076	2868

In the next step, the coverage area of each specific repeater is explored by making use of single polar radio coverage plot.

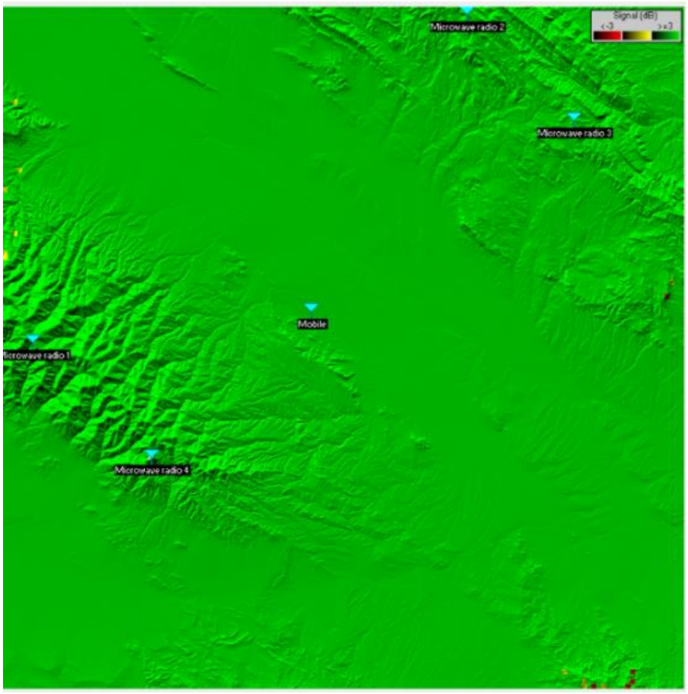


Figure 9: Repeaters position

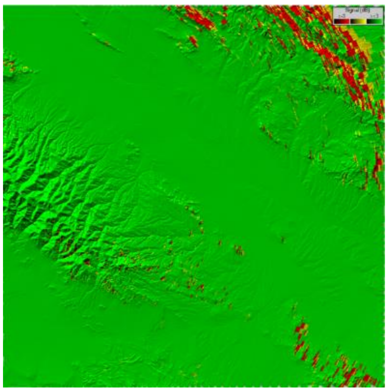


Figure 10: Repeater 1

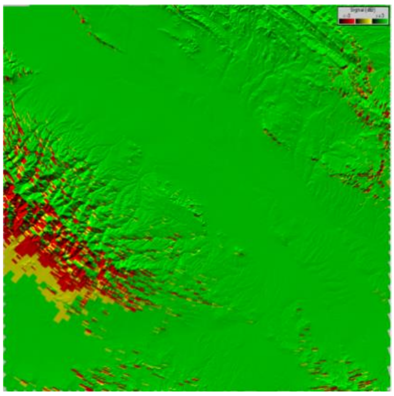


Figure 11: Repeater 2

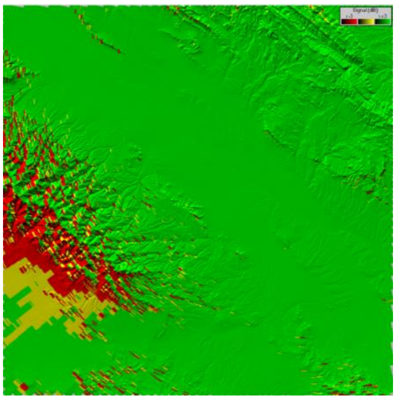


Figure 12: Repeater 3

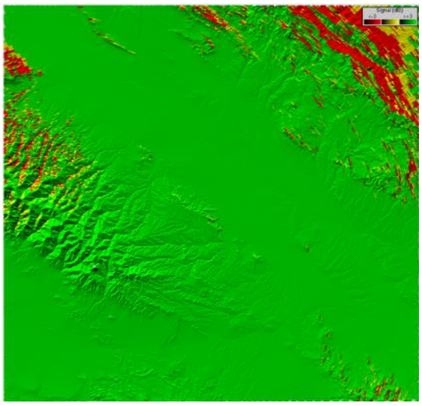


Figure 13: Repeater 4

And finally, "Combined cartesian radio coverage" plot in Radio Mobile is used to have a general view of the coverage area.

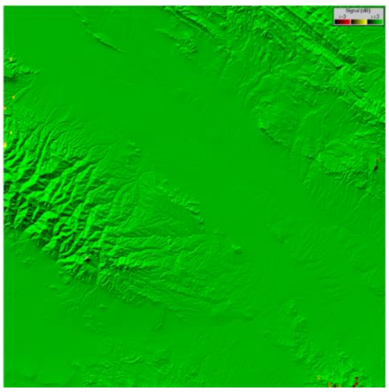


Figure 14: Combined radio coverage

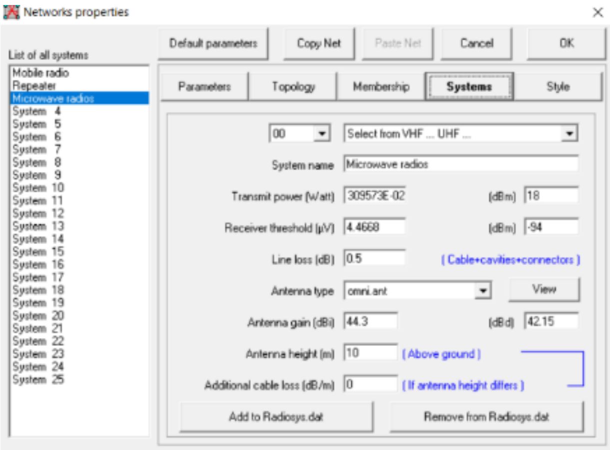


Figure 15: Microwave radios properties

As can be seen in figure 14, the area is covered with acceptable coverage. In the following the percentage of the covered area will be computed, using Python, which indicates a coverage of 99.9%

```
Green area coverage: 99.90%
```

3 Microwave network

In this section the structure of the microwave network, including number and location of the microwave radios, frequencies of operation of each link, transmit power, type of antennas used, etc. will be described.

3.1. Characteristics and implementation

we do the same procedure for Microwave radios, and we set the parameters according to the information provided in the datasheet. The details are shown in the figure 15.

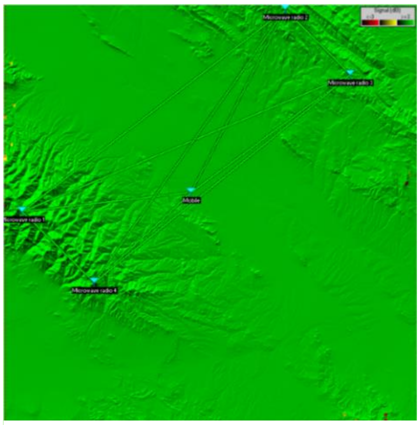


Figure 16: Microwave links

Figure 17: Antennas

For microwave communication an antenna [6] in 10 GHz is considered for the distance of 25-70 Km and frequency of 15 GHz is considered for the distance of 10-25 Km (fig. 17). which has the gain of 44.3 dBi and position on a tower with the height equal to 10 meters. To find the network properties 3 types of information are quite important: the receiver sets sensitivity provided in its datasheet and equals to 0.22 micro volt (to have a good margin, it has been considered 0.3 micro volt), antenna gain, and antenna working frequency. Then, for each repeater, one microwave link is allocated. (fig. 16)

3.2. Link analyses

For radio links to operate efficiently and consistently, it is vital that the path between antennas remains open and free from any physical barriers. Any objects that could block or weaken the signal should be avoided. Maintaining a direct, unobstructed view between transmitters and receivers is a key requirement to ensure strong and reliable network performance.

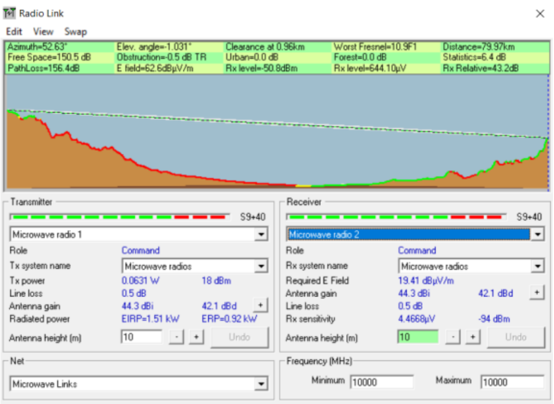


Figure 18: Repeater 1 and 2

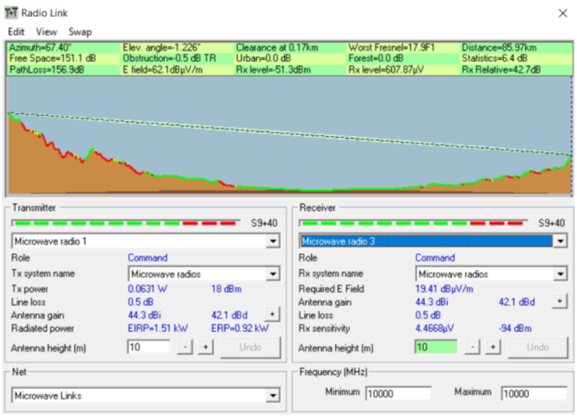


Figure 19: Repeater 1 and 3

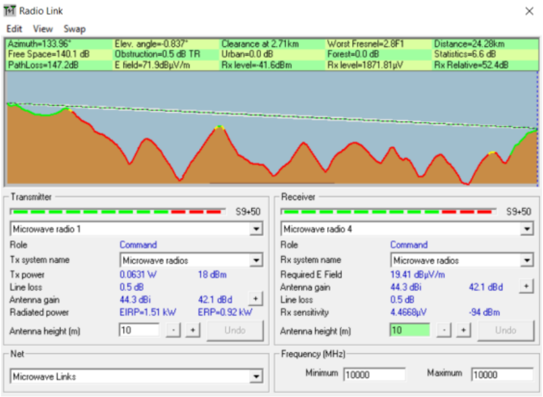


Figure 20: Repeater 1 and 4

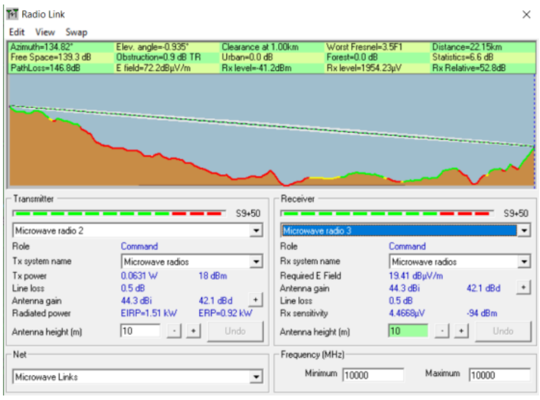


Figure 21: Repeater 2 and 3

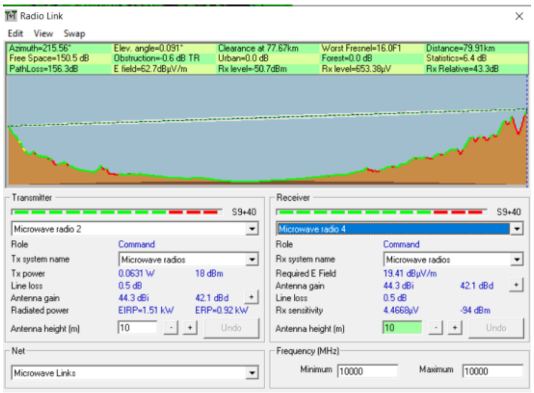


Figure 22: Repeater 2 and 4

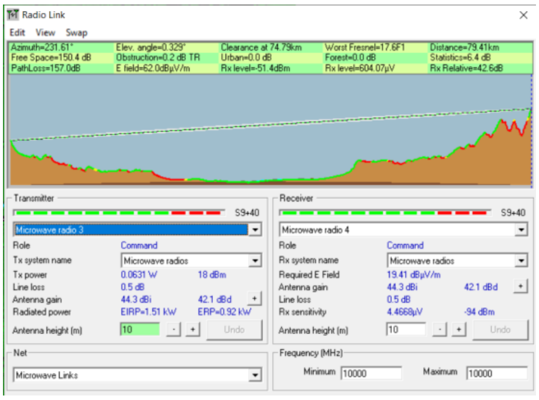


Figure 23: Repeater 3 and 4

The distance between repeaters is shown in the table below, and as it can be seen, the longest distance is almost 80 Km, and shorts distance is almost 22 Km, which are important characteristic for choosing the working frequency and antenna type for microwave network.

	RPTR 1	RPTR 2	RPTR 3	RPTR 4
RPTR 1	-	79.97 Km	85.97 Km	24.28 Km
RPTR 2	79.97 Km	-	22.15 Km	79.91 Km
RPTR 3	85.97 Km	22.15 Km	-	79.41 Km
RPTR 4	24.28 Km	79.91 Km	79.41 Km	-

3.3. Network report

The "Network Report" feature on Radio Mobile offers crucial data about the network's overall condition and functionality. In this scenario, it produces a symmetrical matrix, where each value reflects the strength of the connection between pairs of repeaters. Link quality is measured using the formula: 50 plus the signal margin in decibels (dB). As a result, any figure above 50 signifies a strong and dependable connection. To achieve efficient signal routing, antenna directions were carefully adjusted to ensure that every repeater has a clear line of sight to all other repeater stations.

As can be seen in the figure 24, all repeaters have a clear LoS visibility to each other.

3.4. Microwave Network Topology

To connect the repeaters via a microwave network, various topologies can be considered, including full mesh, star, ring, and line configurations. As shown in Figure 25, each red line represents a bidirectional link between repeaters. Establishing such a link requires two microwave outdoor units and two antennas.

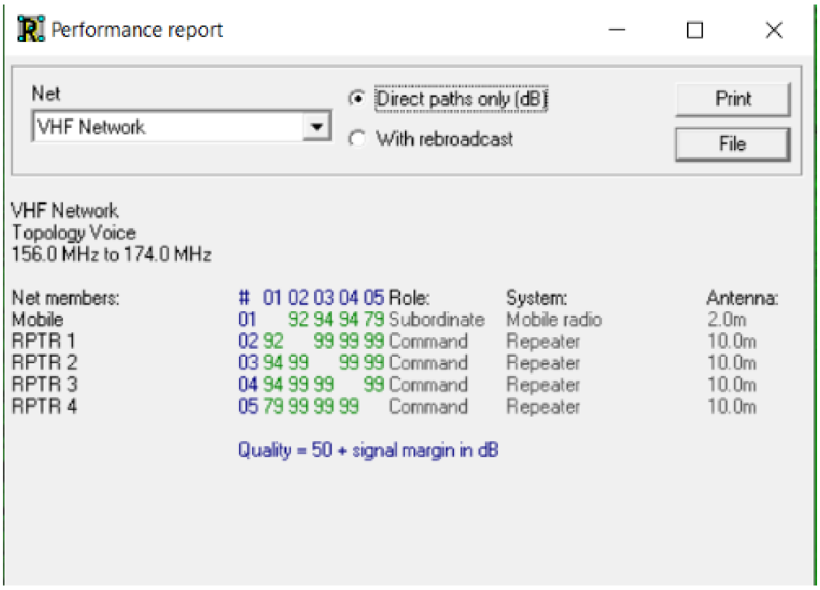
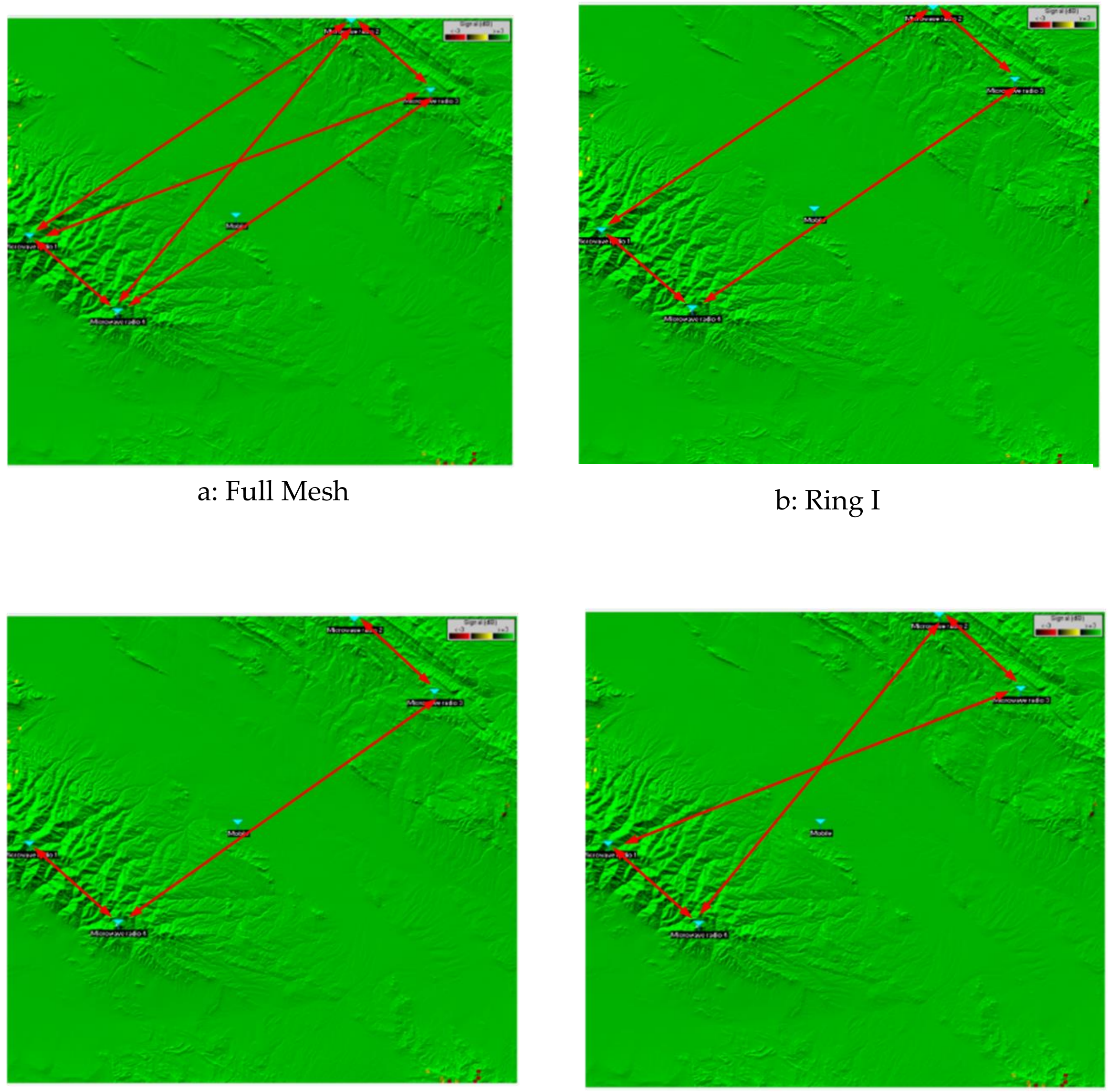


Figure 24: Network report



a: Full Mesh

b: Ring I

c: Line

d: Ring II

Figure 25: Possible Link Topologies

In a full mesh topology, six bidirectional links are required, which translate to 12 antennas and 12 microwave outdoor units. Although this setup offers high resilience—tolerating both first and second failures—it comes at a higher cost. On the other hand, a line topology requires only three links and the minimum number of antennas, but it provides no redundancy and cannot tolerate even a single point of failure.

To balance reliability and cost, we have chosen the topology illustrated in Figure 25(b). This configuration ensures tolerance against at least the first failure while minimizing the number of antennas and overall project cost.

4 Conclusion and future work

4.1. Conclusion

In this report we successfully implemented a Private Mobile Radio Network in a 100 km x 100 km square area centered around the city of Mashhad, Iran. The goal of the project was to achieve wide coverage over the region while minimizing the number of repeaters. After implementing the repeaters at their best positions, which are usually the highest altitudes, we were able to achieve an impressive coverage area of 99.9%.

4.2. Future work

Enhanced Spectral Efficiency & Interference Management

- Develop dynamic spectrum allocation techniques to optimize frequency usage in congested environments.
- Implement AI-driven interference detection and mitigation strategies to maintain reliable communication in high-density deployments.

Integration with Emerging Technologies

- Explore the use of IoT (Internet of Things) devices within the PMR ecosystem for real-time monitoring and automation in industrial applications.
- Investigate the role of AI and machine learning in predictive network maintenance, fault detection, and traffic optimization.

Energy Efficiency and Sustainable Practices

- Research energy-efficient base station designs and renewable energy sources (e.g., solar-powered repeaters) to reduce operational costs and environmental impact

5 References

[1] - Motorola SLR5500 Datasheet

[2] - Motorola DM4000e Datasheet

[3] - PTP 820S Licensed Microwave Radio Datasheet

[4] - BAN034 and BAN034R Datasheet

[5] – Coaxial Cables Datasheet

[6] – N100 082d001A Datasheet