POLITECNICO
MILANO 1863

DIPARTIMENTO DI ELETTRONICA
INFORMAZIONE E BIOINGEGNERIA

Wireless & Mobile Propagation

Academic Year 2023-24

Prof. Michele D'Amico

Project Report

Radio Network Design - D01

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Contents

List of Figures

1 Introduction

This report presents an in-depth exploration of an optional project within the "Wireless and Mobile Propagation" course, taught by Professor Michele D'Amico at Politecnico di Milano. The primary aim of this project is to cultivate proficiency in using "Radio Mobile," an advanced, free software application designed to simulate and predict radio network coverage areas. The project encompasses several critical tasks. Initially, users must configure various radio parameters and integrate ground elevation data into the software.

This data is vital for accurately simulating radio wave propagation. With the appropriate settings and parameters, "Radio Mobile" can produce detailed coverage plots for individual base stations and combinations of multiple stations, which are essential for understanding the geographic reach and performance of radio networks. The key input parameters necessary for predicting and generating a coverage map in Radio Mobile include:

- Transmitter location
- Transmitter power output
- Frequency
- Antenna type
- Antenna pattern
- Antenna gain
- Transmission line losses
- Receiver location
- Receiver antenna type
- Terrain and elevation data for the area

Radio coverage levels are displayed using various units, such as S-units, μV, dBm, and μV/m. For the purposes of this project, the universal dBm unit will be exclusively used to represent radio coverage levels. Additionally, "Radio Mobile" offers several tools that enhance its functionality. One notable tool is the "radio link" feature, which provides comprehensive information on the link status between two stations, including critical metrics such as path loss, received power, and Fresnel zones. These metrics are crucial for assessing the quality and reliability of radio links. By setting these parameters, Radio Mobile delivers a detailed and accurate representation of radio coverage, enabling users to effectively assess and optimise the performance of their radio networks.

2 Problem Statement

We are requested to design a Private Mobile Radio (PMR) Network working at VHF frequencies.

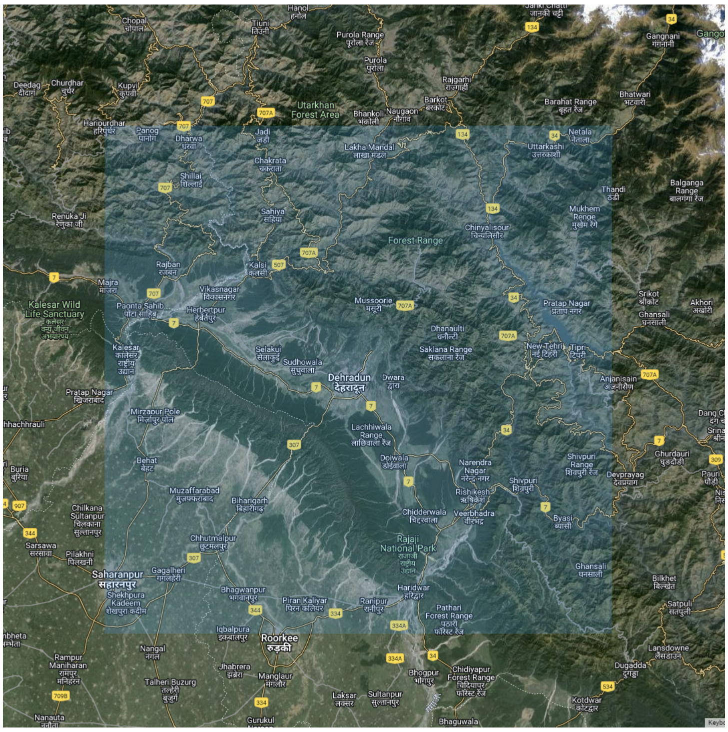


Figure 1: Area of interest - *Dehradun, India*

Specifications of the radio network are:

- Covered region: a 100 km × 100 km square area centered around the city of Dehradun, India (the centre of the area of interest, with coordinates 30° 20' 42" N, 78° 1' 44.4" E is shown in the attached map above)
- Frequency of operation: 163 MHz
- Modulation type: ETSI Digital Mobile Radio (DMR)
- Repeaters' interconnection: point-to-point microwave links at 28 GHz
- Repeater stations (DMR): Motorola SLR5500[1].
  - RF Output Power: 1-50 W
  - Sensitivity (typical): 0,22 μV
- Vehicular terminals (DMR): Motorola DM4000e[2].
  - Digital Sensitivity (5% BER) : 0.16 μV
  - RF Output Power: 1-25 W (VHF), 25-45 (UHF)

3 Design Procedure

This section elaborates on the process of radio design and steps followed to attain the results. The focus is on determining the optimal placement of repeater stations within the network. This involves identifying strategic locations that maximise coverage while minimising the overall number of stations required. The design approach grants the freedom to place stations at any suitable location, enabling the exploration of various configurations to achieve the desired coverage goals. Another thing to keep in mind point-to-point microwave links operating at 28 GHz are utilised for establishing reliable connections between the repeaters. It is important to note that the default antenna gain in *Radio Mobile* is 2 dBi. However, for the purposes of this design, we must adjust the antenna gain to 0 dBi for both handheld and vehicular antennas, as per the provided instructions.

3.1 Loading the location map

We can load the map of the desired location in 4 different ways.

- Use cursor position
- World Map
- Select a city name
- Enter LAT LON or QRA

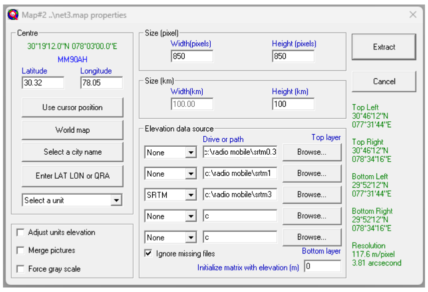


Figure 2: Map Details

Taking advantage of the city name provided, which fortunately is included in the software's database, we can conveniently select the desired city and adjust the map scale to our preferred level of detail before loading it into the *Radio Mobile* interface[3]. Once the desired city is displayed on the screen, we proceed with setting up the network properties in *Radio Mobile*.

This involves defining three distinct systems:

1. **Microwave system**: Represents the point-to-point microwave links operating at 28 GHz, responsible for connecting the repeater stations.
2. **Repeater system**: Represents the repeater stations within the network, responsible for amplifying and re-transmitting the signal.
3. **Mobile system**: Represents the mobile users or devices within the network, receiving the signal.

All relevant parameters for these systems is be obtained from their respective datasheets. For all systems, omni-directional antennas are employed. These antennas radiate signals with equal strength in all horizontal directions, making them suitable for providing coverage in all directions around the station or mobile device.

3.2 Systems

After defining all necessary data and parameters, the *"Map Properties"* section is used to place the units within the map, ensuring optimal coverage and clearance of the first Fresnel ellipsoid. The *"Elevation"* box within *Radio Mobile* provides a convenient way to determine the altitude of any selected point on the map. For network design purposes, it's crucial to designate a specific unit as *"mobile"* within the software. This allows you to visualise and analyse the coverage area from the perspective of a mobile user. The network structure in this case utilises a microwave point-to-point network operating at 28 GHz to connect the repeater stations. These microwave links effectively route the signal between the repeaters. It is important to note that stations (repeaters) can be assigned to multiple networks. In our case, we are using four repeaters which are a part of two distinct networks, **uW_28GHz** and **VH_163MHz**.

3.2.1 Microwave system

The chosen antenna for the point-to-point microwave links is the THP03275S manufactured by *Faini Telecommunication Systems*[4]. This highly directional antenna boasts a significant gain of 38 dBi in the mid-band (as illustrated in figure 3), making it ideal for point-to-point communication. Due to the narrow beamwidth, a dedicated antenna is required for each individual link. This choice ensures uniform signal transmission in all horizontal directions, facilitating efficient communication between repeaters. The selected microwave radio system for these systems is the PTP 820S from *Cambium Networks.*

Electrical Characteristics

Frequency range	27.5 - 29.5 GHz
Gain, low band	37.2 dBi
Gain, mid band	38.0 dBi
Gain, top band	38.5 dBi
Return Loss	17.7 dB
VSWR	1.3
HPBW	2.2 deg
Front to back ratio	64 dB
Isolation	NA
XPD	30 dB
Electrical Compliance	Class 3B
	ETSI 302 217

Figure 3: Microwave system antenna specifications

As per the datasheet this system operates at 28 GHz and offers a transmit power of 18 dBm and receiver sensitivity of -82.5 dBm,[5] as high data rates are not a critical requirement for this application.

PTP 820S Licensed Microwave Radio

Transmit Power (dBm)

Transmit Power	6 GHz	7 GHz	8 GHz	10-11 GHz	13-15 GHz	18 GHz	23 GHz	24 GHz UL HP	26 GHz	28-38 GHz
QPSK	28	28	28	26	24	22	20	-17	21	18
8 PSK	28	28	28	26	24	22	20	-17	21	18
16 QAM	28	27	27	26	23	21	20	-17	20	17
32 QAM	27	26	26	25	22	20	20	-17	19	16
64 QAM	27	26	26	25	22	20	20	-17	19	16
128 QAM	27	26	26	25	22	20	20	-17	19	16
256 QAM	27	26	24	25	20	20	18	-17	17	14
512 QAM	25	24	24	24	20	18	18	-17	17	14
1024 QAM	25	24	24	23	20	18	17	-17	16	13
2048 QAM	23	22	22	21	18	16	16	-17	15	12

(a) Transmitter

PTP 820S Licensed Microwave Radio

Receive Sensitivity (dBm @BER=10-6) - continued

60 MHz	6 GHz	7 GHz	8 GHz	10 GHz	11 GHz	13 GHz	15 GHz	18 GHz	23 GHz	24 GHz	26 GHz	28-31 GHz	32 GHz	38 GHz
QPSK	-84.5	-84.0	-84.0	-83.5	-84.5	-83.0	-82.5	-84.0	-83.0	-82.5	-82.5	-82.5	-82.0	-81.5
8 PSK	-80.0	-79.0	-79.0	-79.0	-79.5	-78.5	-78.0	-79.0	-78.0	-77.5	-78.0	-77.5	-77.5	-77.0
16 QAM	-77.5	-77.0	-77.0	-76.5	-77.5	-76.0	-75.5	-77.0	-76.0	-75.5	-75.5	-75.5	-75.0	-74.5
32 QAM	-74.0	-73.0	-73.0	-73.0	-73.5	-72.5	-72.0	-73.0	-72.0	-71.5	-72.0	-71.5	-71.5	-71.0
64 QAM	-70.5	-70.0	-70.0	-69.5	-70.5	-69.5	-68.5	-70.0	-69.0	-68.5	-68.5	-68.5	-68.0	-68.0
128 QAM	-68.0	-67.0	-67.0	-67.0	-67.5	-66.5	-66.0	-67.0	-66.0	-65.5	-66.0	-65.5	-65.5	-65.0
256 QAM	-64.5	-64.0	-64.0	-63.5	-64.5	-63.5	-62.5	-64.0	-63.0	-62.5	-62.5	-62.5	-62.0	-62.0
512 QAM	-62.5	-62.0	-62.0	-61.5	-62.5	-61.5	-60.5	-62.0	-61.0	-60.5	-60.5	-60.5	-60.0	-60.0
1024 QAM (strong FEC)	-59.0	-58.5	-58.5	-58.0	-59.0	-58.0	-57.0	-58.5	-57.5	-57.0	-57.0	-57.0	-56.5	-56.5
1024 QAM (light FEC)	-58.0	-57.5	-57.5	-57.0	-58.0	-57.0	-56.0	-57.5	-56.5	-56.0	-56.0	-56.0	-55.5	-55.5
2048 QAM	-55.5	-54.5	-54.5	-54.5	-55.0	-54.0	-53.5	-54.5	-53.5	-53.0	-53.5	-53.0	-53.0	-52.5

(b) Receiver

Figure 4: Specifications of microwave system - PTP820S

3.2.2 Repeater system

The Repeater and Mobile systems both operate at 163MHz, hence it requires careful consideration of both the antenna and repeater selection.

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	

Figure 5: Repeater antenna specifications

Given the operating frequency, the omni-directional antenna BAN034R from *BELCO Srl* was selected. The coaxial antenna is suitable for VHF system of frequency range of 156-174MHz,as depicted in figure 5 while featuring a gain of 5 dBi[6]. The chosen coaxial cable, LCF38-50J by *RFS - Radio Frequency Systems*, exhibits a loss of approximately 4.89 dB/100 meter at 200MHz. Hence, the total line loss is around 0.5 dB for an antenna 10 meters from the repeater.

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		
Weight	8.6 kg		
Input Voltage (AC)	100-240 Vac, 47-63 Hz		
Current (standby), 110 / 240 V	0.18 / 0.25 A		
Current (transmitting), 110 / 240 V	1.5 / 0.9 A		
Input Voltage (DC)	11.0-14.4 Vdc		
Current (standby)	0.7 A		
Current (transmitting)	9.5 A		
Operating Temperature Range	-30 to +60 °C		
Humidity	RH of 95%, non-condensing at 50 °C		
Max Duty Cycle	100%		
FCC Description	ABZ99FT3094	ABZ99FT4096	-
IC Description	109AB-99FT3094	109AB-99FT4096	-
Digital Vocoder Type	AMBE+2™		
Battery Charger Capacity	12 V, 3 A		
Connectivity	Tx (N female), Rx (BNC female), USB A receptacle, 2x Ethernet		
Supported System Types	Digital Conventional, IP Site Connect, Capacity Plus (Single Site and Multi-Site), Capacity Max, Analogue Conventional, MPT 1327		

(a) Transmitter

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		
Selectivity (TIA603D), 12.5/20/25 kHz	55 / 83 / 83 dB	55 / 80 / 80 dB	55 / 80 / 80 dB
Selectivity (TIA603), 12.5/20/25 kHz	68 / 83 / 83 dB	68 / 80 / 80 dB	68 / 80 / 80 dB
Selectivity (ETSI), 12.5/20/25 kHz	63 / 70 / 70 dB		
Intermodulation Rejection (TIA603D/ETSI)	82 / 73 dB		
Spurious Rejection (TIA603D/ETSI)	95 / 90 dB		
Audio Distortion	< 1%		
Transmitter Hum and Noise, 12.5/20/25 kHz	-45 / -45 / -50 dB		

(b) Receiver

Figure 6: Specifications of repeater system - SLR5500

For the repeater module, we were instructed (as per the problem statement) to use Motorola SLR 5500 by *Motorola Solutions*. It boasts an RF output power ranging from 1 to 50W, although for this specific system, we chose to go with an average value of 25W. Additionally, as seen in the figure 6b, it possesses a receive sensitivity of 0.16µV.

3.2.3 Mobile System

The mobile unit within the *VHF_163MHz* network, is using the DM4000E by *Motorola Solutions*, which is is configured with a transmit power of 25 W and receiver sensitivity is set to 0.18 μV. Following the problem statement, the mobile device is assumed to have an antenna with a gain of 0 dB and a low antenna height of approximately 2 metres.

	Numeric Model				Alphanumeric Model			
Model Number	DM4401e / DM4400e[1]				DM4601e / DM4600e[1]			
Band	VHF	300MHz	UHF Band 1	UHF Band 2	VHF	300MHz	UHF Band 1	UHF Band 2
GENERAL SPECIFICATIONS								
Frequency	136-174 MHz	300-360 MHz,	403-470 MHz	450-527 MHz	136-174 MHz	300-360 MHz,	403-470 MHz	450-527 MHz
Low Power Output	1-25 W	–	1-25 W	–	1-25 W	–	1-25 W	–
High Power Output	25-45 W	1-40 W	25-40 W	1-40 W	25-45 W	1-40W	25-40 W	1-40W
Channel Spacing	12.5, 20², 25 kHz							
Channel Capacity	99				1000			
Dimensions (H x W x D)	53 x 175 x 206 mm							
Weight	1.8 kg							
Power Supply (Nominal)	12 V							
Max Current Drain, Standby	0.8 A							
Max Current Drain, Receive	2 A							
Transmit Current Draw, Low Power	11 A	–	11 A	–	11 A	–	11 A	–
Transmit Current Draw, High Power	14.5 A	14.5 A	14.5 A	12 A	14.5 A	14.5 A	14.5 A	12 A

(a) Transmitter

RECEIVER SPECIFICATIONS	
Analog Sensitivity (12dB SINAD)	0.18 uV
Digital Sensitivity (5% BER)	0.16 uV
Intermodulation (TIA603D)	70 dB
Adjacent Channel Selectivity, (TIA603A)-1T	60 dB (12.5 kHz channel), 70 dB (20² / 25 kHz)
Adjacent Channel Selectivity, (TIA603D)-2T	45 dB (12.5 kHz channel), 70 dB (20² / 25 kHz)
Spurious Rejection (TIA603D)	70 dB

(b) Receiver

Figure 7: Specifications of mobile system - DM4000E

4 Data Visualisation & Outcome

4.1 Coverage Analysis

To maximise coverage within the Dehradun zone, the radio network design employs a strategic placement of four repeater stations.

4.1.1 Repeater coverage

By leveraging the natural topography of the Himalayan mountain range, these stations were positioned at altitudes of up to 3000 meters above sea level (figure 8). This approach significantly enhances signal propagation and extends coverage to areas that might otherwise be obstructed by terrain.

The figure 9 gives an idea about the microwave links and repeater positions in 3D space.

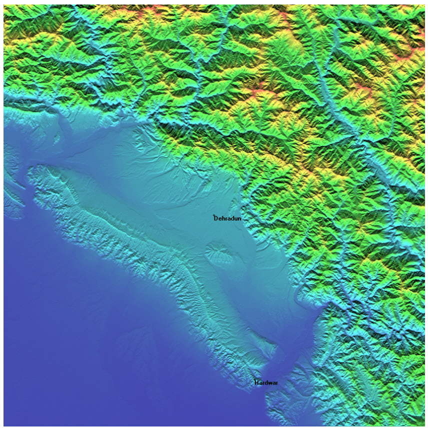


Figure 8: Target Area

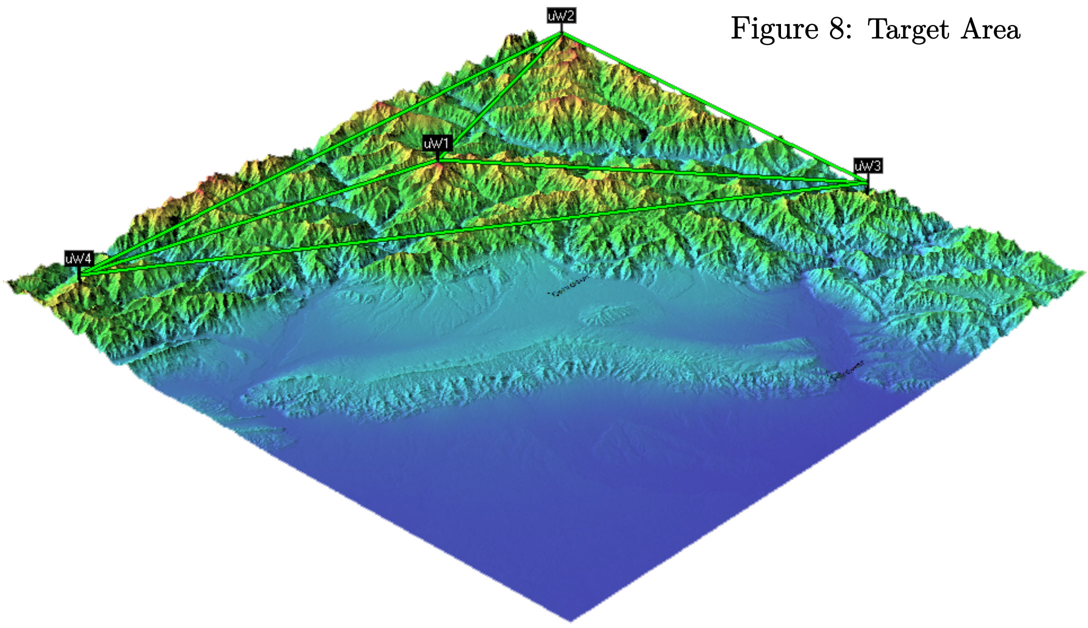


Figure 9: Microwave links of all repeaters *in 3D*

Further details regarding the specific placement of the repeaters can be found below:

Unit Name	**latitude**	**Longitude**	**Elevation**
RP1	30°35’15"N	78°09’00"E	3007.9m
RP2	30°42’46"N	78°33’59"E	3109.9m
RP3	30°09’53"N	78°30’53"E	2244.9m
RP4	30°41’49"N	77°35’33"E	2562.9m

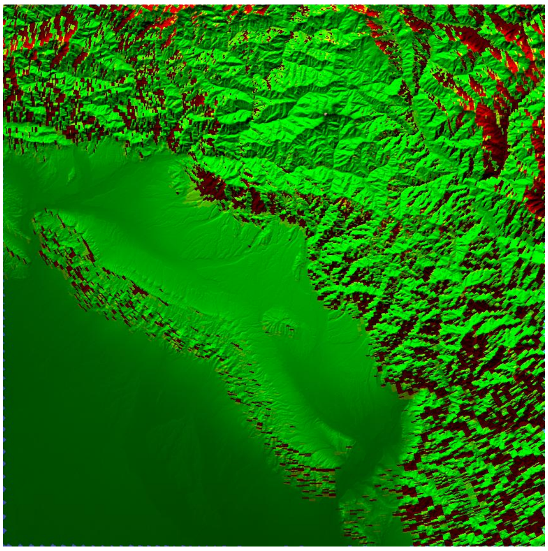
Table 1: Repeater details

To visualise the coverage area of a specific unit, we can use the *"Single Polar"* radio coverage plot.

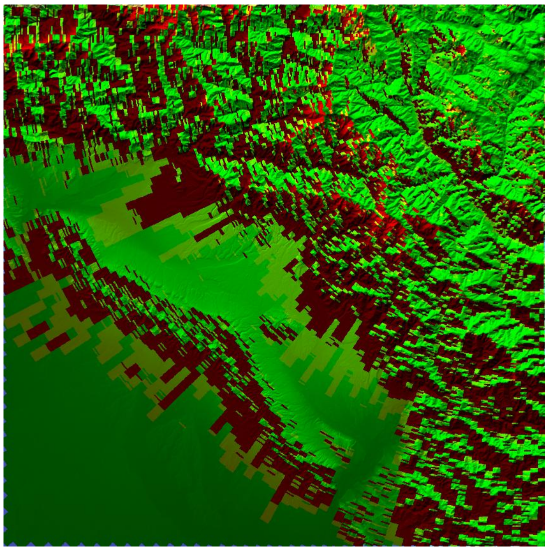
It is accessed through the following steps:

1. Go to the "Tools" menu
2. Select "Radio Coverage"
3. Choose "Single Polar"

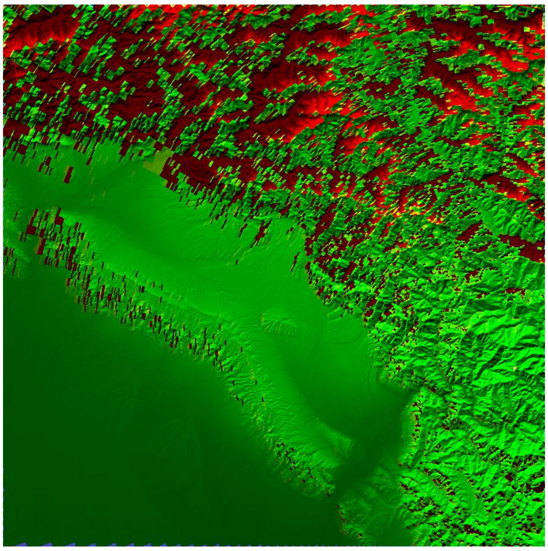
This will open a dedicated window where one can configure the plot settings and visualise the coverage area of the selected unit in a radial format. The following images show the coverage area of individual repeaters (stations):



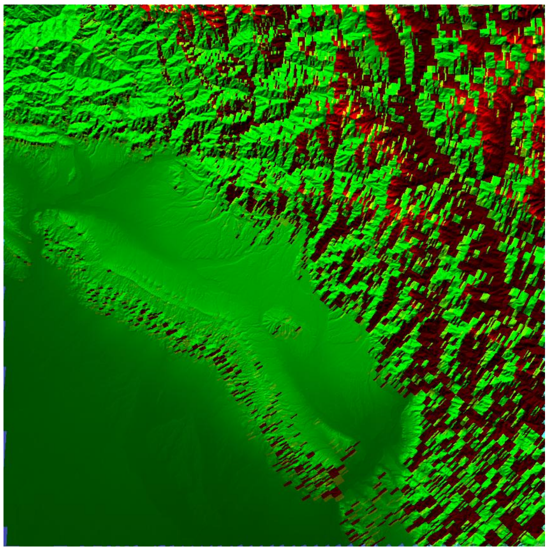
(a) RP1



(b) RP2



(c) RP3



(d) RP4

Figure 10: Single Polar Radio Coverage for all repeaters

4.1.2 Combined coverage

To generate a *"Combined Cartesian Radio Coverage"* plot in RadioMobile, follow these steps:

1. **Select Units**: In the *"Units"* tab, choose all repeaters to visualise the combined signal strength from all fixed units.
2. **Mobile Unit Selection**: In the *"Mobile Unit"* tab, select the previously defined *"Mobile_unit"* unit. This specifies the receiver for which the coverage is being calculated.
3. **Network Selection**: In the *"Network"* tab, choose the *"VHF_163MHz"* network which will cover the plot only considering the signal strength within the VHF network.
4. **Units and Draw Size**:
   - *Units*: Select "dBm" as the desired unit for displaying signal strength on the plot.
   - *Draw Size*: Set the *"Draw Size (pixel)"* to 2 to ensure maximum detail and accuracy in the coverage plot.
5. **Generate Plot**: Click the *"DRAW"* button to generate the combined Cartesian radio coverage plot.

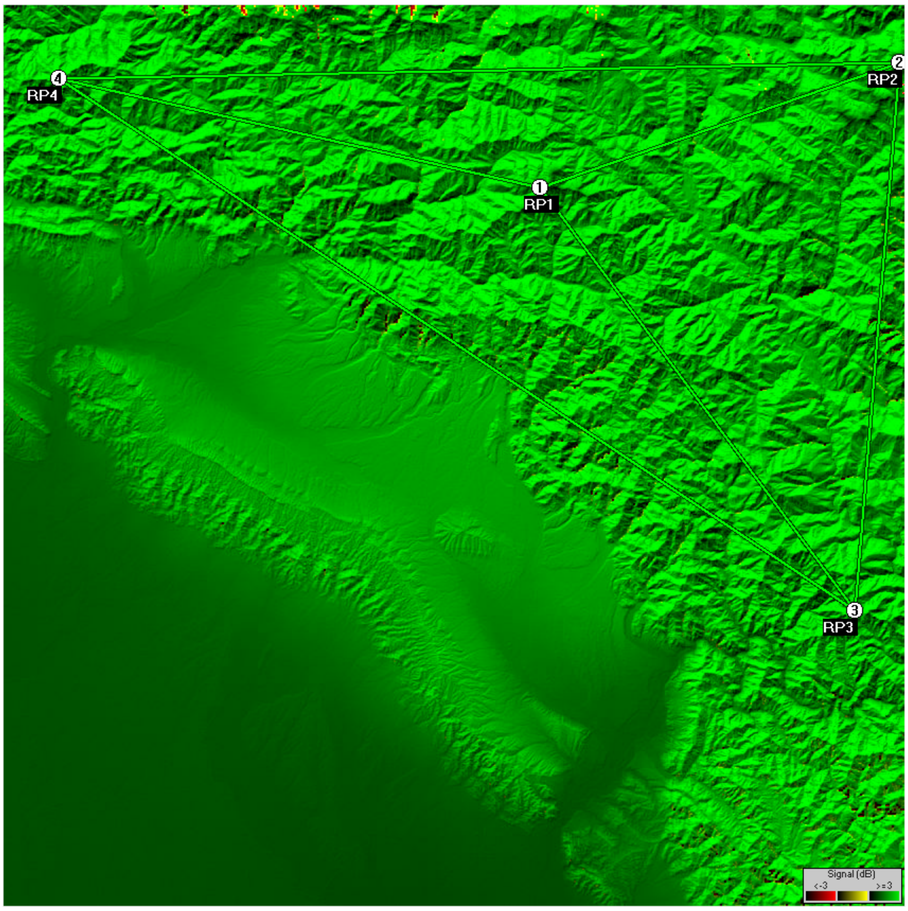
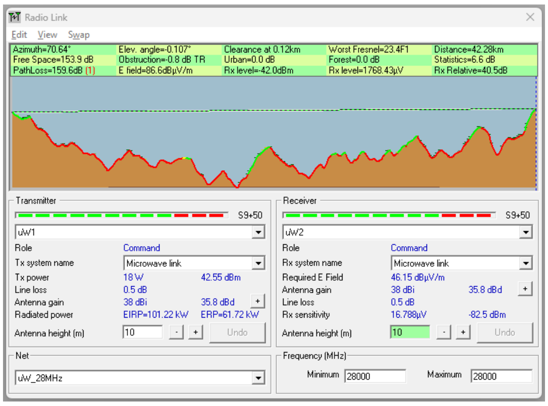


Figure 11: Combined cartesian radio coverage with links and position of repeaters

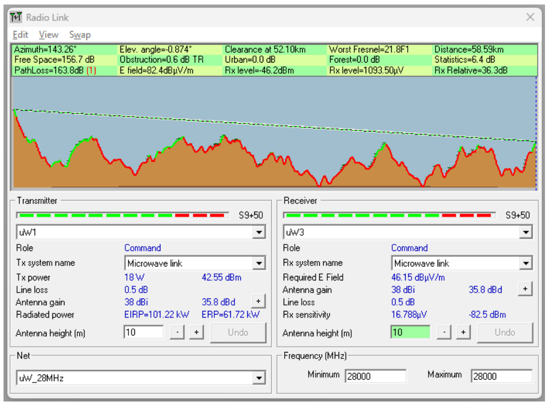
4.2 Link Analysis

4.2.1 Radio links

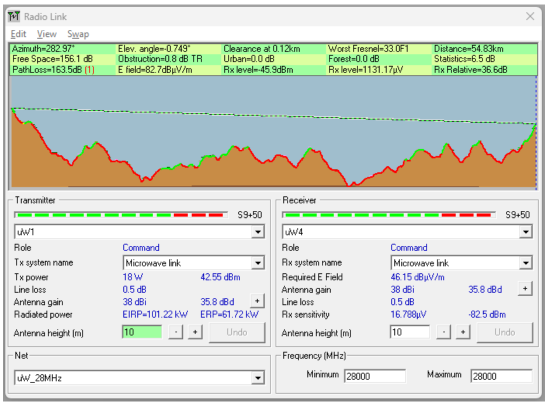
To ensure optimal performance and reliability of radio links, it's crucial to maintain a clear line-of-sight path between the transmitting and receiving antennas. This means that any potential obstructions should be minimised or eliminated along the direct path of the radio signal. According to the project guidelines, we strictly adhere to maintaining an unobstructed line-of-sight to enhance the effectiveness of our radio network.



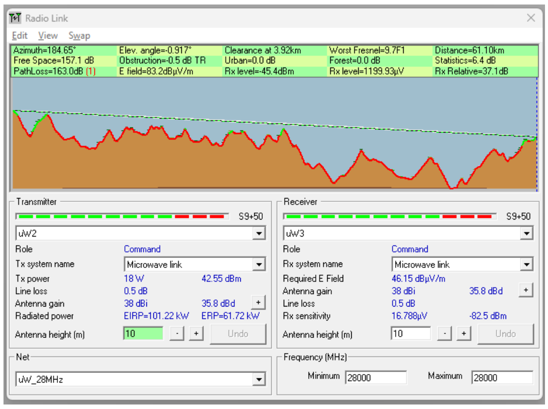
(a) RP1 and RP2



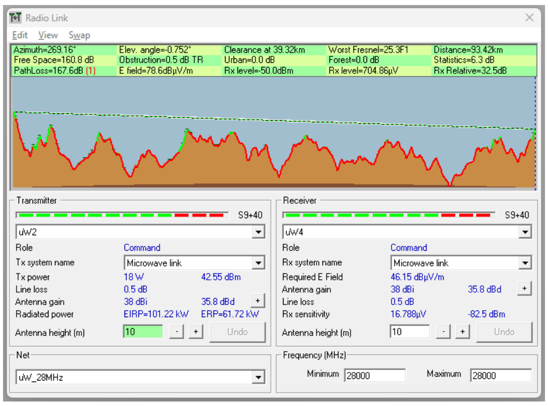
(b) RP1 and RP3



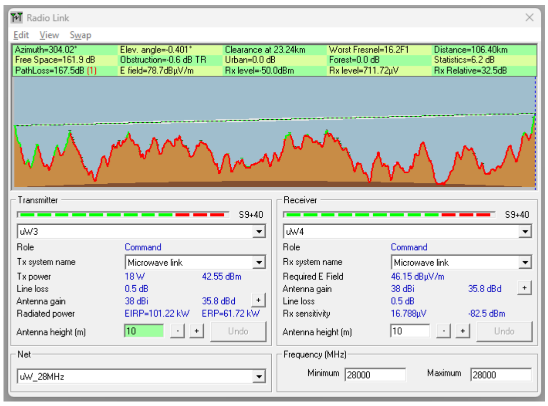
(c) RP1 and RP4



(d) RP2 and RP3



(e) RP2 and RP4



(f) RP3 and RP4

Figure 12: Microwave links between all repeaters

4.2.2 Network report

The *"Network Report"* tool in Radio Mobile provides valuable insights into the overall health and performance of the network. In this case, it generates a symmetric matrix where each number represents the quality of a specific point-to-point link between repeaters. The quality of each link is assessed and represented using a specific pattern: **50 + signal margin in dB**.

Therefore, any value exceeding 50 indicates a robust and reliable radio link. To ensure optimal routing the antenna directions were meticulously chosen to guarantee that all repeaters are visible from each individual repeater station.

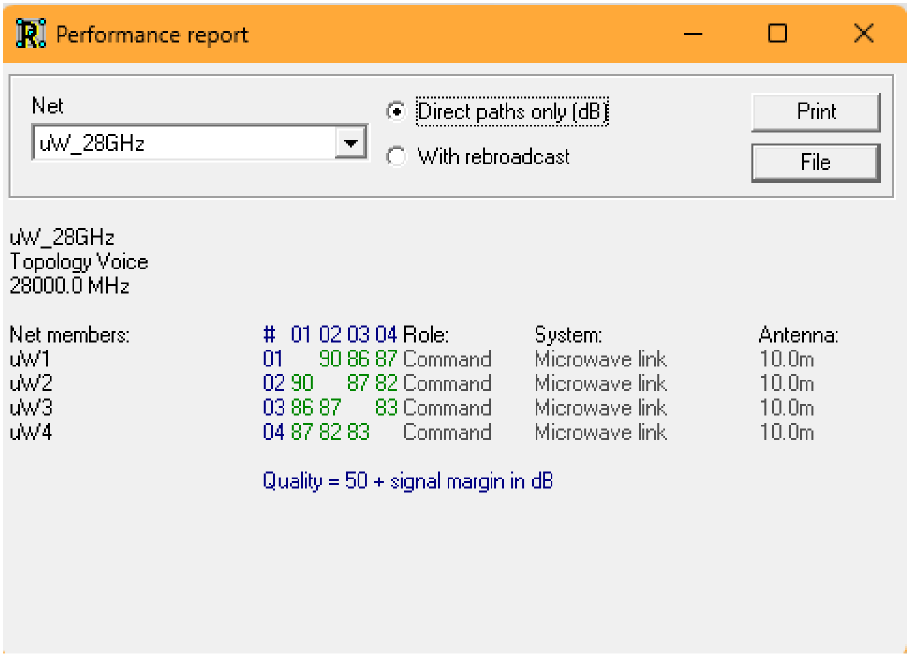


Figure 13: Performance report of the 28GHz microwave network

As depicted in the provided figure, all repeaters in the network have clear line-of-sight visibility to each other.

4.2.3 Image analysis for area coverage

To accurately determine the total area covered by the radio network, the map was reloaded with a white background. This provided a clean and uncluttered image for analysis, followed by the combined coverage simulation without any legends, ensuring only the essential signal strength data was displayed.

To determine the area covered by the radio network, a Python script was utilised (refer to A). This script employed the `extcolors` package to perform pixel-by-pixel analysis of the coverage image.

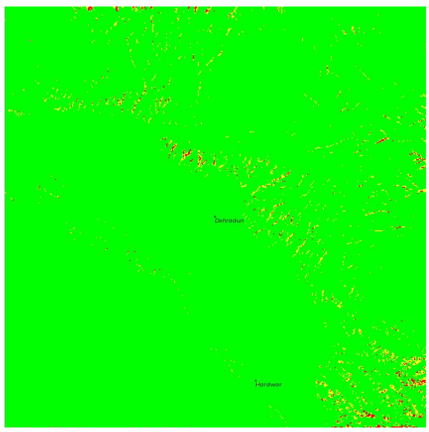


Figure 14: Image used for area analysis

5 Conclusion & Future Aspects

5.1 Conclusion

This report has presented the design and implementation of a radio network aimed at maximising coverage within the Himalayan region near Dehradun, India. The primary objective was to achieve extensive coverage while minimising the required infrastructure. This report has demonstrated the effectiveness of *Radio Mobile* software in designing and analysing such a network.

5.1.1 Simulation outcomes and key findings

- Radio Mobile provided a valuable tool for visualising and analysing the coverage area, enabling informed decision-making throughout the design process.
- By carefully planning and strategically placing four repeater stations, we were able to achieve an impressive coverage area of **98.233%**.

5.2 Future Aspects

While the current network design achieves excellent coverage, there are always opportunities for further improvement and expansion.

- As data usage and the number of users within the network grow, the existing infrastructure might need to be upgraded to handle the increased demand. This could involve using higher-bandwidth technologies, and many more ...
- As demand for reliable communication grows, the network will need to adapt to ensure continued coverage and performance. This might involve extending the network to incorporate new areas or enhancing coverage in existing locations with specific needs.

Overall, this report demonstrates the successful implementation of a cost-effective and efficient radio network solution.

A Python Code

```
import os
import extcolors

img = PIL.Image.open('/content/drive/MyDrive/Picture11.jpeg')
colors, pix_c = extcolors.extract_from_image(img)
print(colors)
color_percentages = []
for color, count in colors:
    percentage = (count / pix_c) * 100
    color_percentages.append((color, percentage))

for color, percentage in color_percentages:
    print(f"Color {color}: {percentage:.2f}%")
```

References

[1] Motorola Solutions, *MOTOTRBO™ SLR 5500 TWO-WAY RADIO REPEATER*, 2020.

[2] Motorola Solutions, *MOTOTRBO™ DM4000E DIGITAL MOBILE (DMR) TWO-WAY RADIO SERIES*, 2020.

[3] I. D. Brown, *Radio Mobile Handbook: An illustrated handbook.*

[4] Faini Telecommunication Systems Srl, *Antenna THP 03 275 S*, 2015.

[5] Cambium Networks, Ltd, *PTP 820S Licensed Microwave Radio*, 2021.

[6] BELCO Srl, *Antenna PRM VHF Omnidirectional Collinear with Reflector V Polarized*, 2024.