BSc in Computer Engineering
CMP4204
Wireless Technologies

Lecture 05

Microwave Radio

Eng Diarmuid O'Briain, CEng, CISSP

Department of Electrical and Computer Engineering,
College of Engineering, Design, Art and Technology,
Makerere University

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1. Microwave Radio

1.1 Microwave Spectrum

The microwave spectrum is defined as electromagnetic energy ranging from approximately 300 MHz to 300 GHz in frequency. Most common applications are within the 1 to 40 GHz range.

The characteristics of radio waves in this band are Point to Point (PTP). Relatively low output power directed with highly directional antenna is the norm.

2. Antennas

An Antenna or aerial is a device that acts as a transducer to transmit or receive electromagnetic waves. It is an electrical conductor or an array of conductors used to radiate electromagnetic energy or collect electromagnetic energy.

For transmission it radiates radio frequency energy from transmitter which is converted into electromagnetic energy by the antenna such that it is radiated into surrounding environment.

For reception electromagnetic energy impinging on antenna is converted to radio frequency electrical energy which is then fed to the radio receiver.

Typically the same antenna often used for both receive and transmit.

2.1 Parabolic Reflective Antenna

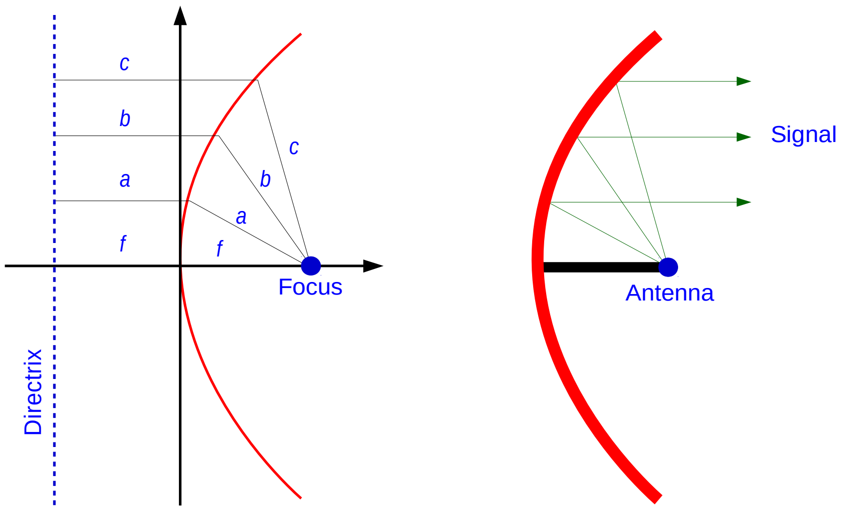


Illustration 1: Parabolic dish

To create a parabola a line called the *directrix* and a point called a *focus* is required. A parabola is formed by joining all the points (x, y) that are equidistant from both the directrix and the focus.

Parabolic Reflective Antennas are a specialised type of antenna that use the principle of the parabola. If a radio source signal placed at focus point and transmits towards the parabolic dish, then the radio waves will be reflected from parabola in parallel to axis which creates a parallel radio beam. On reception, signal is concentrated at focus, where detector is placed.

Parabolic Reflective Antennas are used for terrestrial and satellite microwave communications.

2.2 Antenna Parameters

- Frequency
- Gain (main Lobe)
- Half Power Beam Width
- Side Lobe
- Front to Back Ratio
- Polarisation
- Nulls
- Environmental Conditions

Illustration 2: Panel antenna

2.2.1 Microwave Frequency Spectrum

Letter Designation	Frequency range
L band	1 to 2 GHz
S band	2 to 4 GHz
C band	4 to 8 GHz
X band	8 to 12 GHz
Ku band	12 to 18 GHz
K band	18 to 26.5 GHz
Ka band	26.5 to 40 GHz

Illustration 3: Microwave band designations

The microwave spectrum is usually defined as electromagnetic energy ranging from approximately 1 GHz to 100 GHz in frequency.

Most common applications are within the 1 to 40 GHz range.

- Fixed Wireless Access, Local Area (FWALA) 3.5 - 3.7 GHz
- Fixed Wireless Access, Local Area (FWALA) 10.5 GHz
- Short Range Device (SRD) 17 GHz
- SRD 24 GHz
- Wi-Fi 2.4, 5 and 5.8 GHz

2.3 Antenna Gain

Antenna Gain is the amplification of the transmitted / received power where power output in particular direction compared with that produced by isotropic antenna measured in decibels (dB). The higher the gain, the longer the possible distance between the user and the base station for effective link. That allows larger cell size and requires less base stations.

2.3.1 decibel (dB)

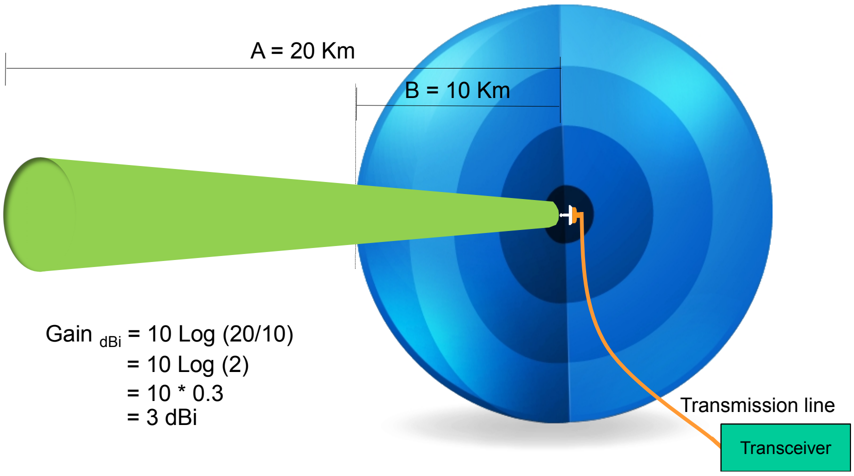


Illustration 4: Antenna gain

The decibel (dB) is a logarithmic unit that indicates the ratio of power relative to a specified or implied reference level. A decibel is one tenth of a bel, a seldom-used unit. A ratio in decibels is ten times the logarithm to base 10 of the ratio of two power quantities.

- 10 x log(Pout/Pin)

An antenna with the effective radiated power of twice the input power would therefore have a gain of 10*log(2/1) = 3dB.

The decibel symbol is often qualified with a suffix.

- dBi dB(isotropic) – the forward gain of an antenna compared with the hypothetical isotropic antenna, which uniformly distributes energy in all directions.
- dBm dBm (milliwatt) – is an abbreviation for the power ratio in decibels (dB) of the measured power referenced to one milliwatt (mW).

2.3.2 Radiation Pattern

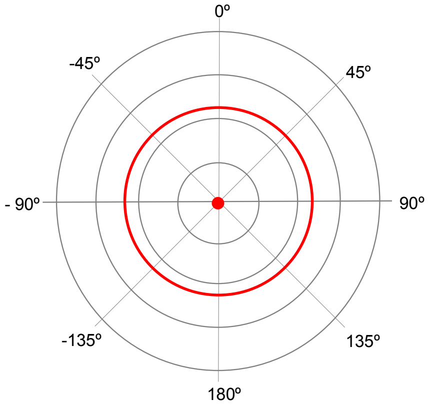


Illustration 5: Isotropic radiation pattern

The antenna radiates transmitted power in all directions however depending on the design of the antenna performance need not be the same in all directions.

For measurement of performance there is the concept of an ideal antenna called an Isotropic antenna. It is a theoretical point in space that radiates in all directions equally and gives a spherical radiation pattern.

2.3.3 Beam Width

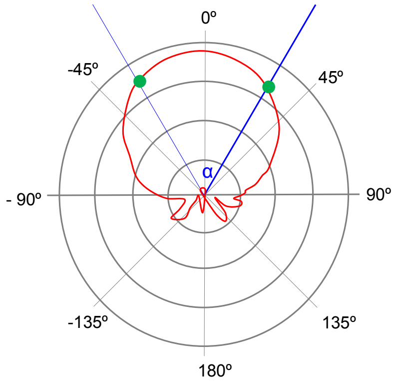


Illustration 6: Half power beam width

Half Power Beam Width (HPBW) is the angle of which the main lobe gain is higher than half of the maximum power.

The wider/narrower the HPBW is, the wider/narrower the area that can be covered with one antenna

That allows an efficient coverage design of the cell.

2.3.4 Side lobe

Side Lobes are the gain of transmitted/received signal in unwanted directions as shown in Illustration 7. The lower the side lobes levels are, the less interference received/transmitted and the network efficiency is improved.

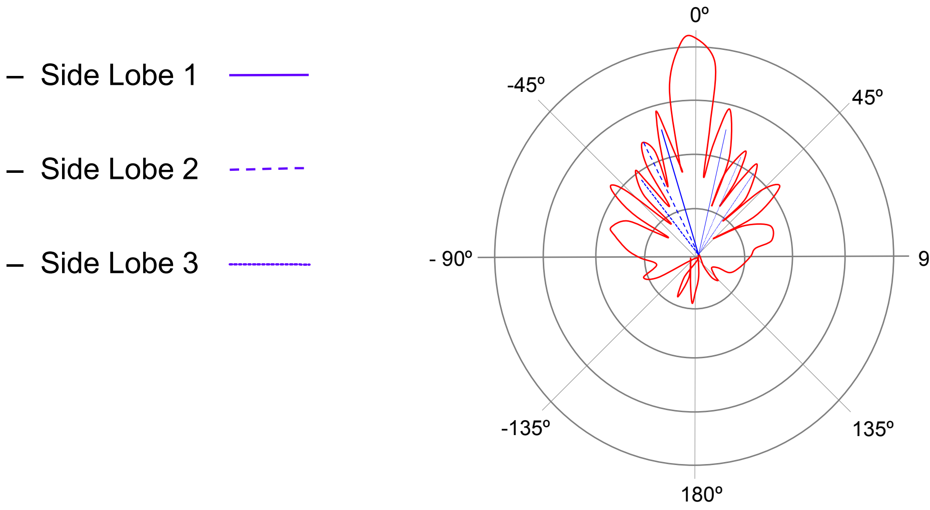


Illustration 7: Side lobes

2.3.5 Front to Back Ratio

Front to Back Ratio is the ratio between the energy radiated forward (wanted) to the energy radiated backwards (unwanted). The higher the ratio is the less interfering energy transmitted/received from/to the back. In Illustration 8 this is shown by the ratio of the front “blue” signal to the back “”green” signal.

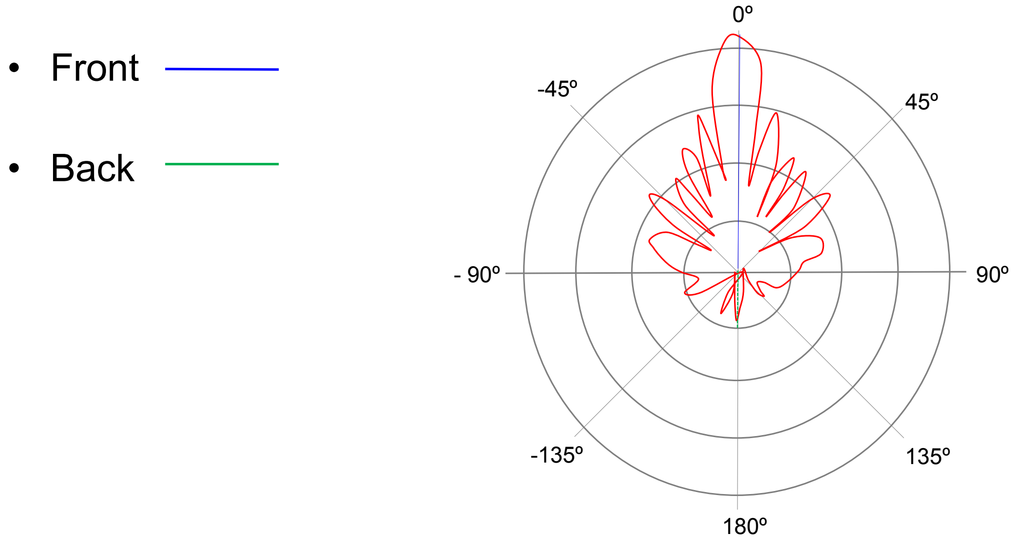


Illustration 8: Front to back ratio

2.3.6 Polarisation

- Vertical
- Horizontal

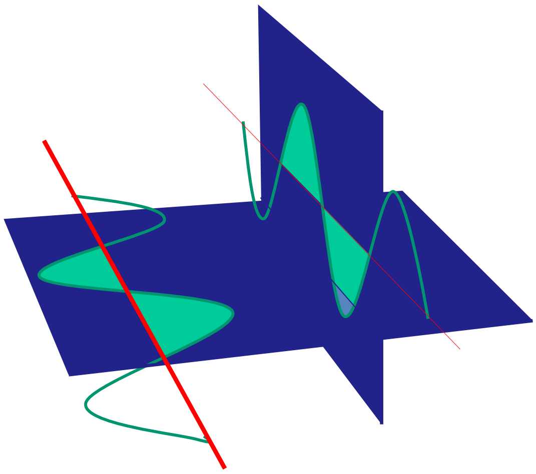


Illustration 9: Polarisation

The polarisation of an antenna is the orientation of the electric field of the radio wave with respect to the Earth's surface and is determined by the physical structure of the antenna and by its orientation. Thus, a simple straight wire antenna will have one polarisation when mounted vertically, and a different polarisation when mounted horizontally. This can be seen in Illustration 9.

2.3.6.1 Nulls

Nulls are directions where the antenna gain is very low and signal cannot be received/transmitted. With a special technique called "Null Filling" this can be used to improve the antenna coverage. This is shown in Illustration 10.

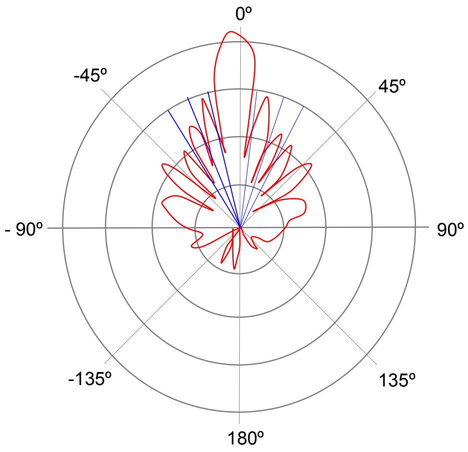


Illustration 10: Pattern nulls

2.3.7 Voltage Standing Wave Ratio (VSWR)

When a transmission line (cable) is terminated by an impedance (Antenna) that does not match the characteristic impedance of the transmission line, not all of the power is absorbed by the termination. Part of the power is reflected back down the transmission line to the radio. The forward (or incident) signal mixes with the reverse (or reflected) signal to cause a voltage standing wave pattern on the transmission line. The ratio of the maximum to minimum voltage is known as VSWR, or Voltage Standing Wave Ratio. A VSWR of 1:1 means that there is no power being reflected back to the source. This is an ideal situation that rarely, if ever, is seen. In the real world, a VSWR of 1.2 is considered excellent in most cases. At a VSWR of 2.0, approximately 10% of the power is reflected back to the radio. Not only does a high VSWR mean that power is being wasted, the reflected power can cause problems such as heating cables or causing amplifiers to fold-back.

2.3.8 Grid Antenna

5.8 GHz 27 dBi Parabolic Grid Antenna.

Illustration 11: 5.8 GHz parabolic grid

2.3.9 Jirous Antenna

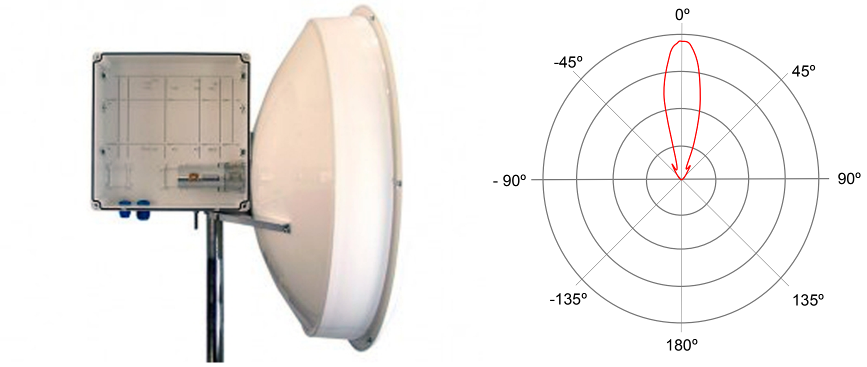


Illustration 12: Parabolic dish antenna with radome cover

<u>**Technical parameters**</u>

Frequency range:	5,45 - 5,9 GHz
Gain:	28 dBi
VSWR:	≤ 1.5
Front to back ratio:	≥ 43 dB
Beamwidth:	-3 dB 5.8°
Connector:	N - Female - JRC-29DuplEX, R-SMA - JRC-29DuplEX-SMA
Polarisation:	Dual-polarised antenna linear, horizontal and vertical
Parabola:	ø 65 cm Aluminium alloy with baking colour
Cover:	Radome, UV steady plastic ABS

3. Freznel Zone

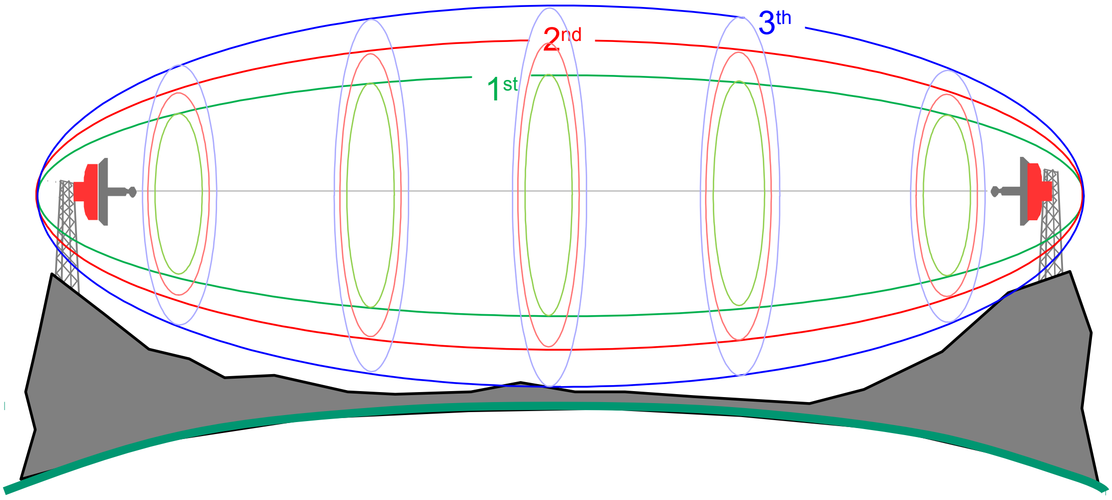


Illustration 13: Freznel zones

In order for radio waves emitted from the transmitter to reach the receiver without attenuation of power, a certain amount of space is required. The energy cannot reach the receiver via one straight line in space.

As shown in Illustration 13 the space required is a spheroid with its centre along the shortest distance between antennas called the Fresnel zone. In fact this space expands indefinitely, but the part that principally contributes to communicating the energy is called the 1st Fresnel zone.

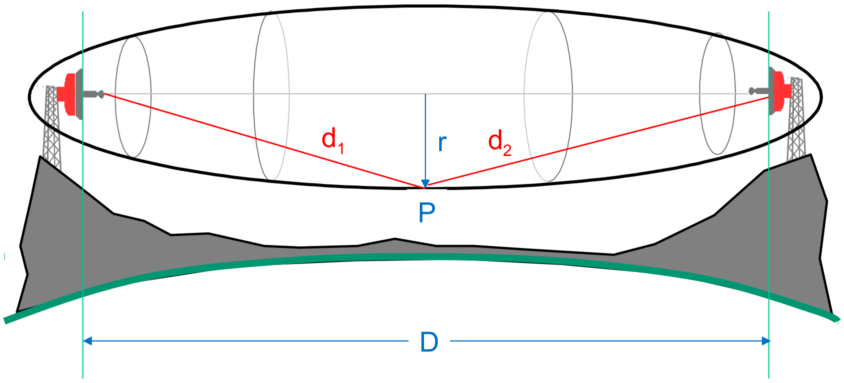
If there are obstacles inside the Fresnel zone, insufficient energy is transmitted so that received field intensity becomes weak. If the received field intensity is weak, the probability that errors will occur becomes gradually higher.

The receive sensitivity of the receiver is absolute, and propagation loss which depends on the distance travelled by the radio waves cannot be avoided. Therefore in order to prevent errors from occurring, it is important to ensure that the received radio waves are as close as possible to the theoretical value.

The first zone must be kept largely free from obstructions to avoid interfering with the radio reception.

Some obstruction of the Fresnel zones can often be tolerated, as a “rule of thumb” the maximum obstruction allowable is 40%, but the recommended obstruction is 20% or less.

Illustration 14 gives the necessary calculations for each freznel zone.



$$F_n = \sqrt{\frac{n\,\lambda\,d_1\,d_2}{d_1 + d_2}}$$

F_n = The nth Fresnel Zone radius in metres
d_1 = The distance of P from one end in metres
d_2 = The distance of P from the other end in metres
λ = The wavelength of the transmitted signal in metres

$$r = \sqrt{\frac{D}{f}}$$

r = radius in metres
D = total distance in kilometres
f = frequency transmitted in gigahertz

Illustration 14: Calculating the freznel zones

3.1 Fresnel zone disruption

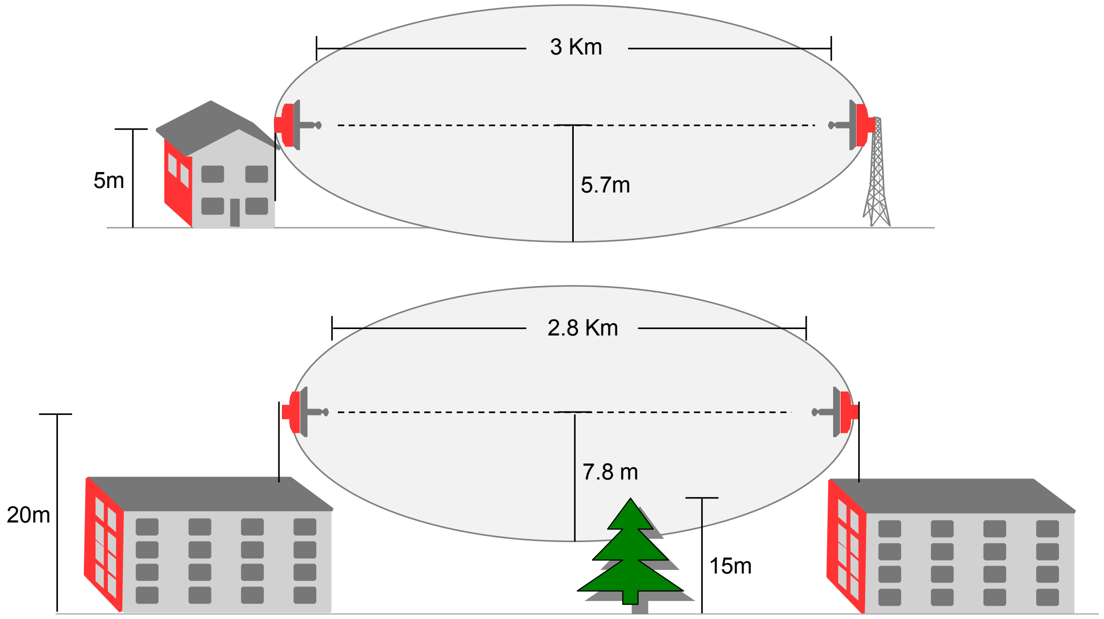
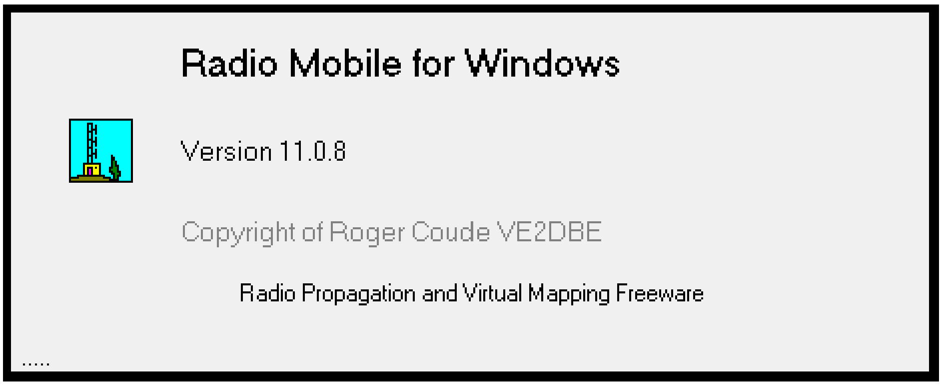


Illustration 15: Freznel zone disruption

The diagram in Illustration 15 shows two examples of freznel zone distribution. In the first example the ground between two sites is cutting the freznel zone while in the latter trees are cutting the freznel zone.

3.2 Radio Mobile



Radio Mobile for Windows

Version 11.0.8

Copyright of Roger Coude VE2DBE

Radio Propagation and Virtual Mapping Freeware

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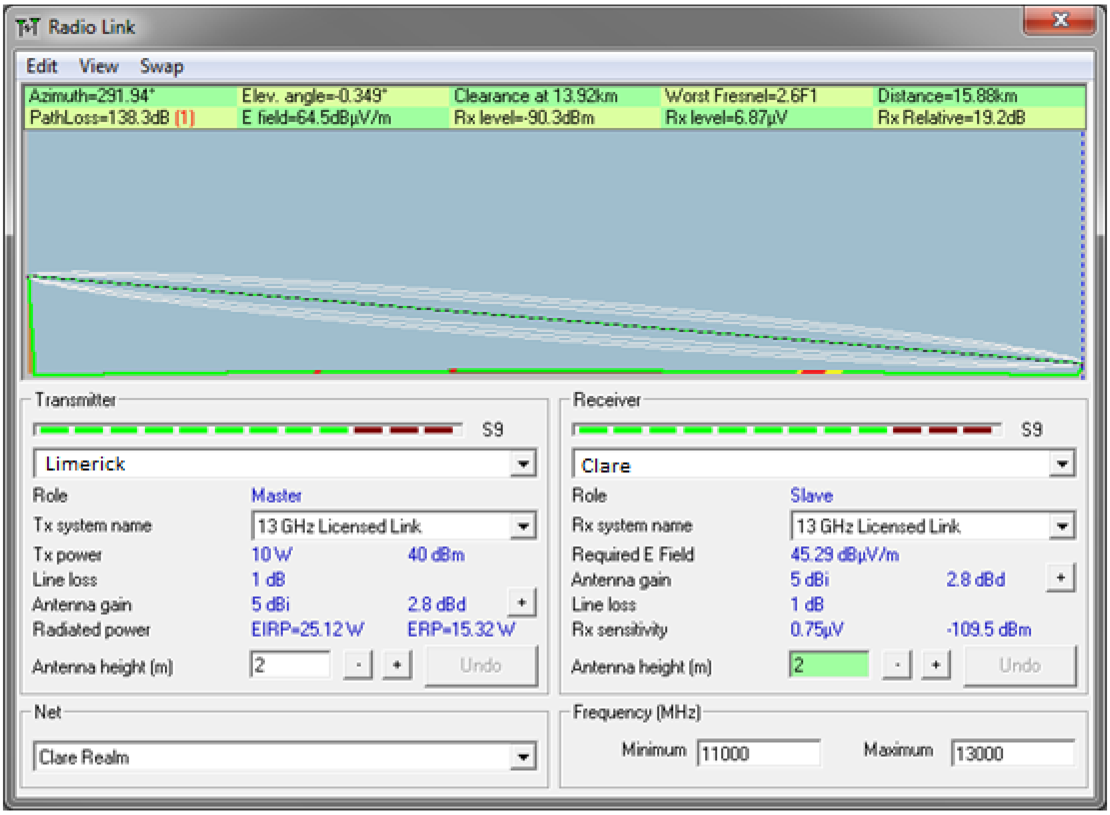
Illustration 16: Radio mobile

Install files: http://www.cplus.org/rmw/english1.html
Map Files: SRTM (Free Online)

Illustration 17 shows a plot from Limerick to a hill in Co. Clare.



Azimuth=291.94°	Elev. angle=-0.349°	Clearance at 13.92km	Worst Fresnel=2.6F1	Distance=15.88km
PathLoss=138.3dB (1)	E field=64.5dBµV/m	Rx level=-90.3dBm	Rx level=6.87µV	Rx Relative=19.2dB

Transmitter			Receiver		
		S9			S9
Limerick			Clare		
Role	Master		Role	Slave	
Tx system name	13 GHz Licensed Link		Rx system name	13 GHz Licensed Link	
Tx power	10 W	40 dBm	Required E Field	45.29 dBµV/m	
Line loss	1 dB		Antenna gain	5 dBi	2.8 dBd
Antenna gain	5 dBi	2.8 dBd	Line loss	1 dB	
Radiated power	EIRP=25.12 W	ERP=15.32 W	Rx sensitivity	0.75µV	-109.5 dBm
Antenna height (m)	2		Antenna height (m)	2	

Net: Clare Realm

Frequency (MHz): Minimum 11000 Maximum 13000

Illustration 17: Limerick/Clare plot

4. Radio Signal values

4.1 Relative Signal Strength Indicator (RSSI)

RSSI is the relative received signal strength in a wireless environment, in arbitrary units.

RSSI is an indication of the power level being received by the antenna. Therefore, the higher the RSSI number (or less negative in some devices), the stronger the signal. It is therefore a key indicator when judging the quality of a signal. The diagram in Illustration 18 gives an indication of what level of signal is useable with the greener the level the more useable. In reality signals below -75 dB are unusable. Illustration 19 demonstrates how the level can be viewed in the MikroTik.

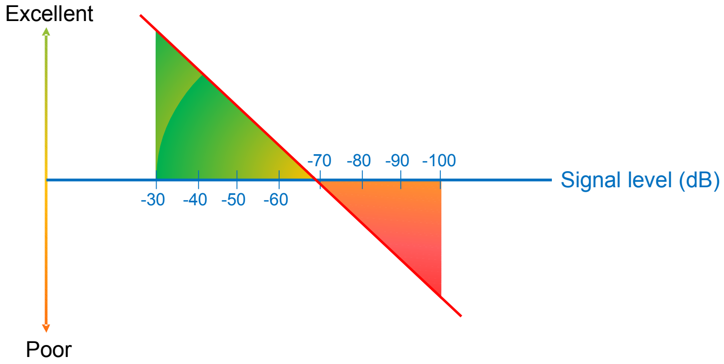
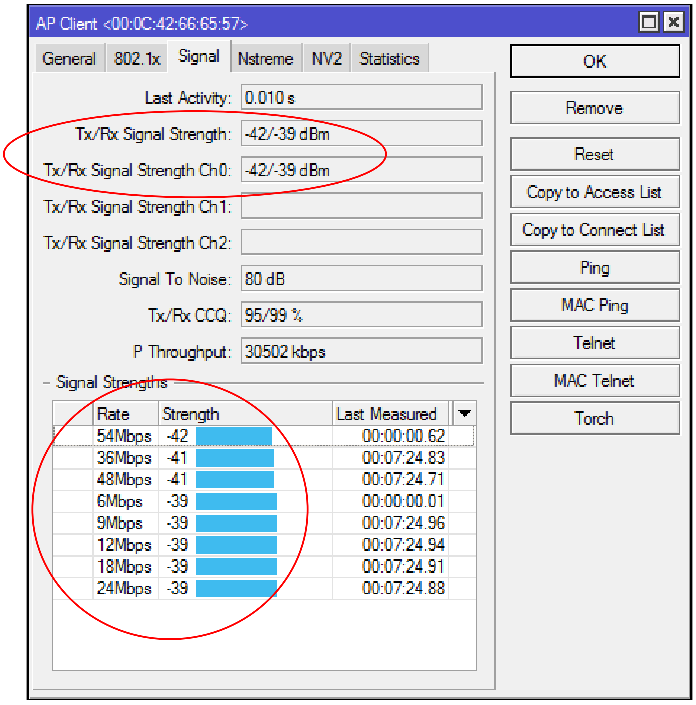


Illustration 18: RSSI



Last Activity: 0.010 s
Tx/Rx Signal Strength: -42/-39 dBm
Tx/Rx Signal Strength Ch0: -42/-39 dBm
Tx/Rx Signal Strength Ch1:
Tx/Rx Signal Strength Ch2:
Signal To Noise: 80 dB
Tx/Rx CCQ: 95/99 %
P Throughput: 30502 kbps

Signal Strengths

Rate	Strength	Last Measured
54Mbps	-42	00:00:00.62
36Mbps	-41	00:07:24.83
48Mbps	-41	00:07:24.71
6Mbps	-39	00:00:00.01
9Mbps	-39	00:07:24.96
12Mbps	-39	00:07:24.94
18Mbps	-39	00:07:24.91
24Mbps	-39	00:07:24.88

Illustration 19: Signal Strength on MikroTik

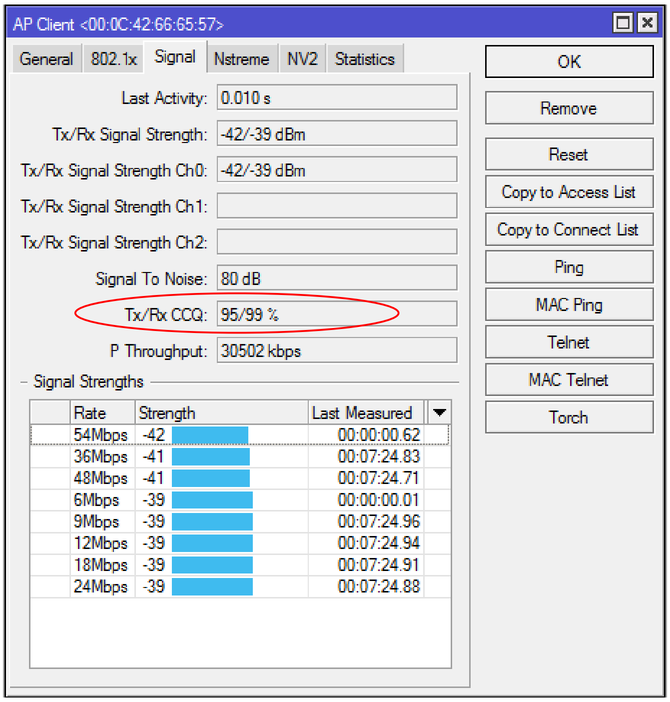
4.2 Client Connection Quality (CCQ)

CCQ is a value in percentage that shows how effective the bandwidth is used regarding the theoretically maximum available bandwidth.

CCQ is weighted average of values T_{min}/T_{real}, that get calculated for every transmitted frame:

1. T_{min} is time it would take to transmit given frame at highest rate with no retries.
2. T_{real} is time it took to transmit frame in real life.

By reviewing the Signal the Tx/Rx CCQ can be monitored as shown in Illustration 20.



Last Activity: 0.010 s
Tx/Rx Signal Strength: -42/-39 dBm
Tx/Rx Signal Strength Ch0: -42/-39 dBm
Tx/Rx Signal Strength Ch1:
Tx/Rx Signal Strength Ch2:
Signal To Noise: 80 dB
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P Throughput: 30502 kbps

Signal Strengths

Rate	Strength	Last Measured
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6Mbps	-39	00:00:00.01
9Mbps	-39	00:07:24.96
12Mbps	-39	00:07:24.94
18Mbps	-39	00:07:24.91
24Mbps	-39	00:07:24.88

Illustration 20: Viewing CCQ

One thing to note about CCQ is that it a rolling average Illustration of traffic, therefore if there is no traffic or little traffic then RouterOS cannot effectively calculate CCQ. If you run traffic over a link that is showing poor CCQ then you may see the value improve.

4.3 Noise Floor

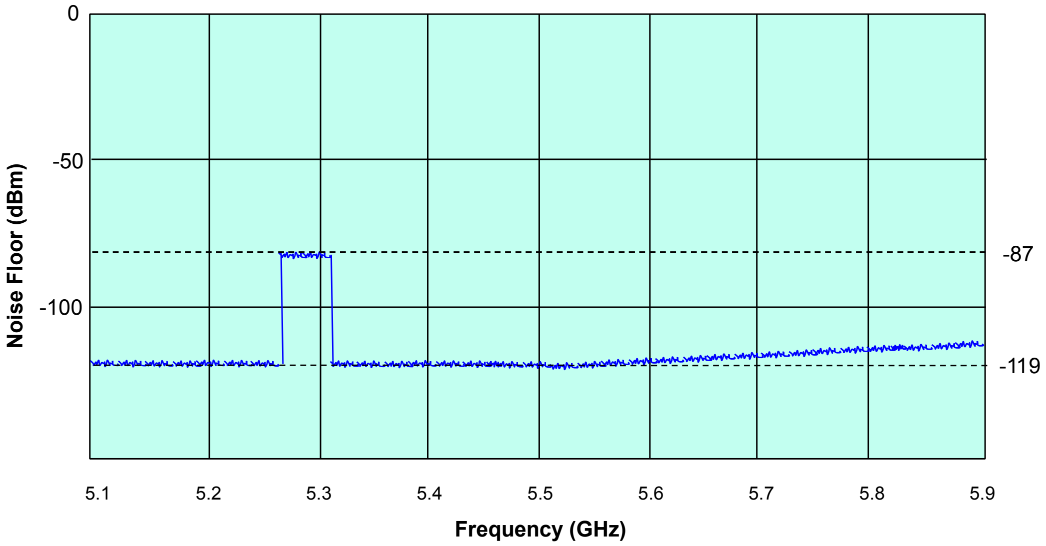
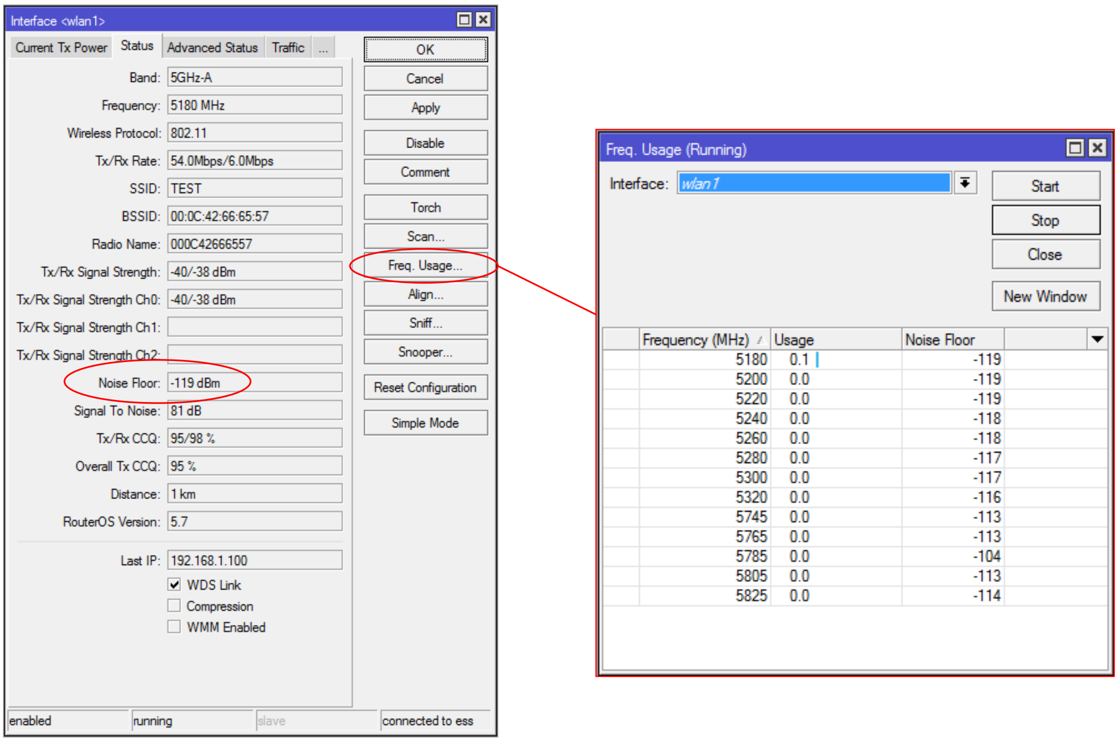


Illustration 21: Noise floor

Noise floor is the measure of the signal created from the sum of all the noise sources and unwanted signals within the radio, where the noise is defined any signal other than channel being monitored. In Illustration 21 it can be seen that the noise floor for the channel 5280 to 5320 is very high indicating that it is unsuitable for operation. It can be viewed on a channel basis as shown below in Illustration 22.



Band: 5GHz-A
Frequency: 5180 MHz
Wireless Protocol: 802.11
Tx/Rx Rate: 54.0Mbps/6.0Mbps
SSID: TEST
BSSID: 00:0C:42:66:65:57
Radio Name: 000C42666557
Tx/Rx Signal Strength: -40/-38 dBm
Tx/Rx Signal Strength Ch0: -40/-38 dBm
Tx/Rx Signal Strength Ch1:
Tx/Rx Signal Strength Ch2:
Noise Floor: -119 dBm
Signal To Noise: 81 dB
Tx/Rx CCQ: 95/98 %
Overall Tx CCQ: 95 %
Distance: 1 km
RouterOS Version: 5.7
Last IP: 192.168.1.100
☑ WDS Link
☐ Compression
☐ WMM Enabled

enabled running slave connected to ess

Interface: wlan1

Frequency (MHz)	Usage	Noise Floor
5180	0.1	-119
5200	0.0	-119
5220	0.0	-119
5240	0.0	-118
5260	0.0	-118
5280	0.0	-117
5300	0.0	-117
5320	0.0	-116
5745	0.0	-113
5765	0.0	-113
5785	0.0	-104
5805	0.0	-113
5825	0.0	-114

Illustration 22: Noise floor per channel

4.4 Antenna Adjustment

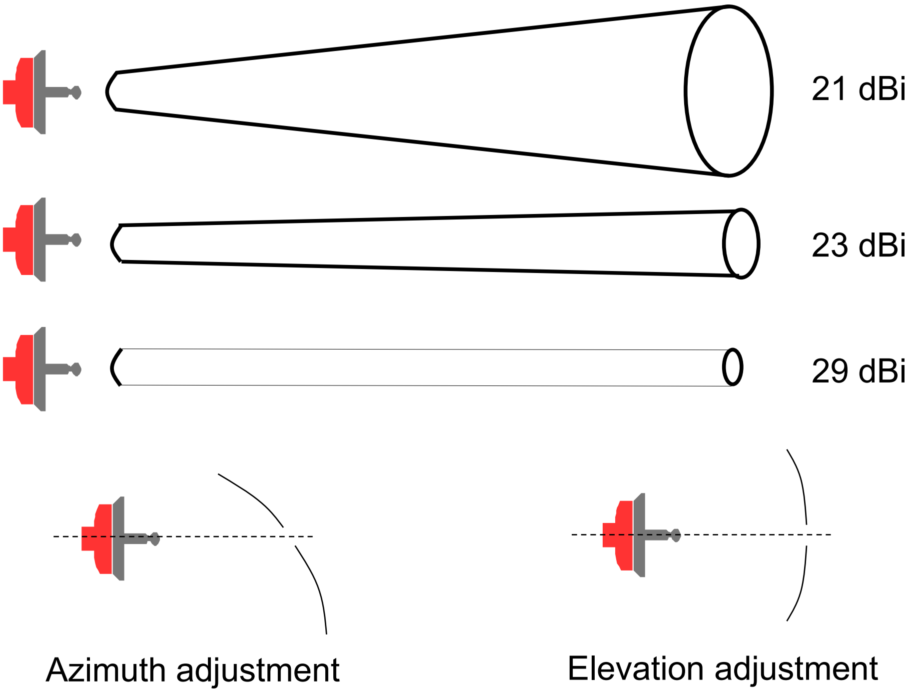


Illustration 23: Antenna gain and adjustment

Adjustment of the antenna to achieve maximum gain is essential to the provision of a superior service. Adjustment of the azimuth and elevation correctly achieves this.

Azimuth refers to the horizontal measurement of a direction.

Elevation is how far above the horizon it needs to point (up and down).

4.5 Alignment process

- Use a compass to determine the azimuth (angle to the Access Point (AP)).
- Rotate the panel 25^0 off the azimuth bearing line.

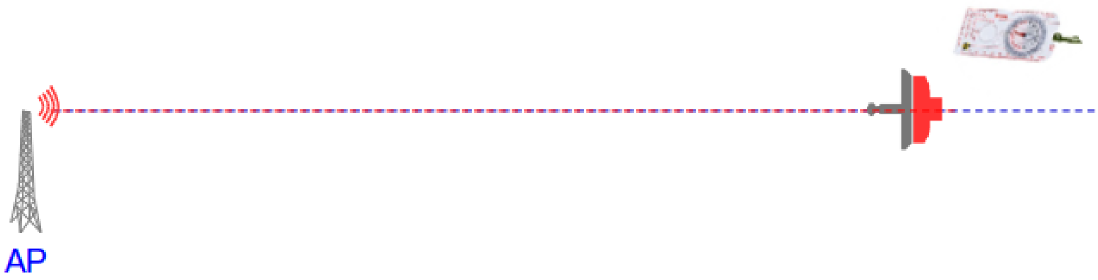


Illustration 24: Initial compass bearing

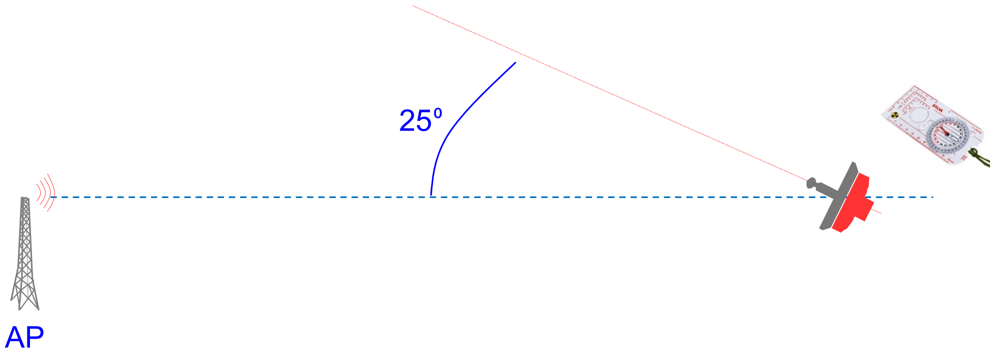


Illustration 25: Move from centre line

- Rotate through and angle for 50° to determine the angle of best RSSI. Note the bearing for the best RSSI.

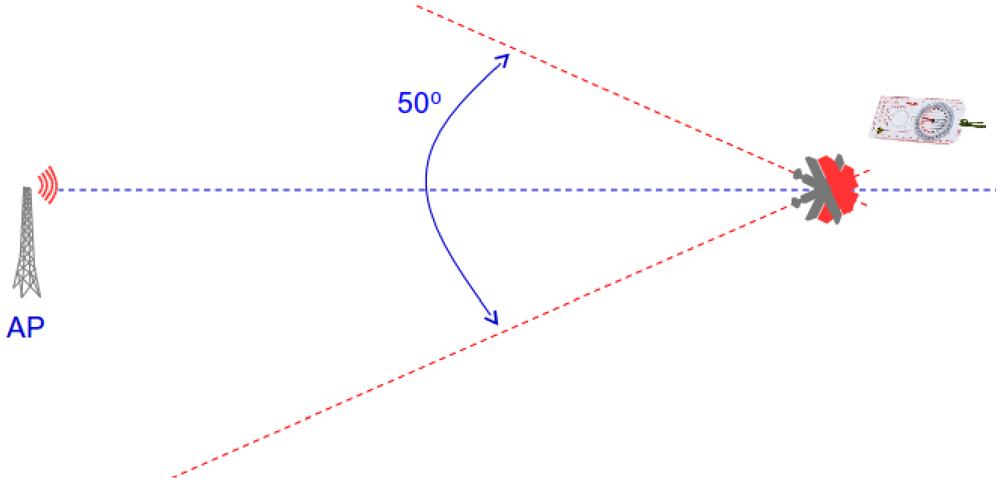


Illustration 26: Rotate through the compass bearing

4.6 Why the detailed steps for Azimuth

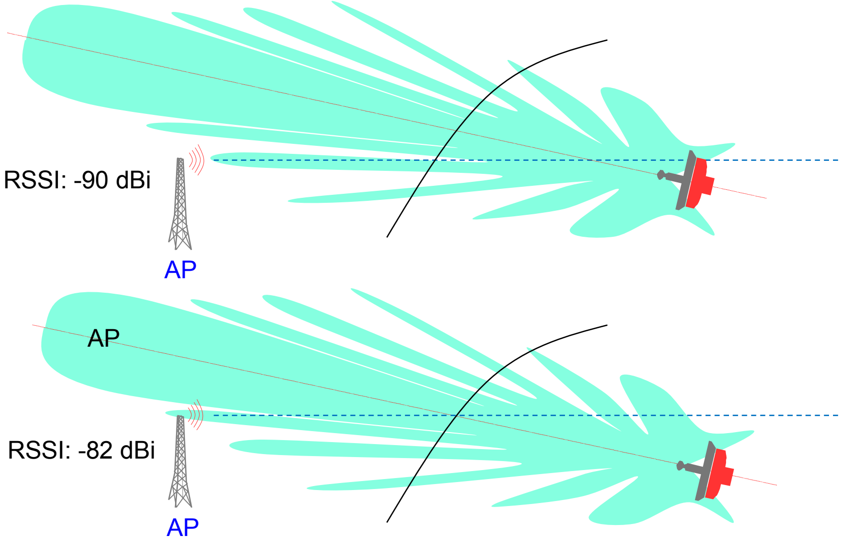


Illustration 27: Alignment and radiation pattern

It is possible that a signal can be achieved even though the centre line of the radio antenna is not in line with the Access Point. It is possible that a signal can be aligned with a side lobe. This is particularly topical with antenna with of higher gain. The process ensures that the main lobe is used and centred giving the maximum signal strength. Once complete lock down the azimuth.

4.7 Alignment – Elevation

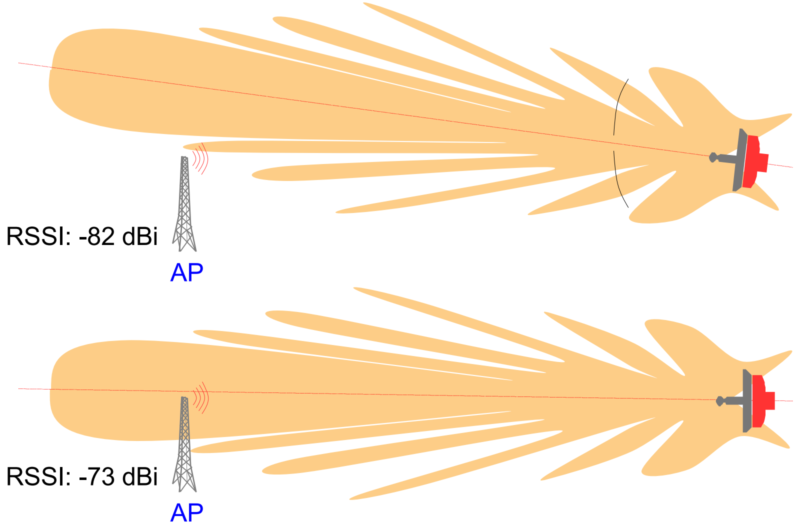


Illustration 28: Adjusting elevation

It is not enough to align the azimuth. The radiation pattern is 3 dimensional and it is just as important to adjust the elevation using a similar process to maximise signal strength.

5. Multiple In, Multiple Out (MIMO)

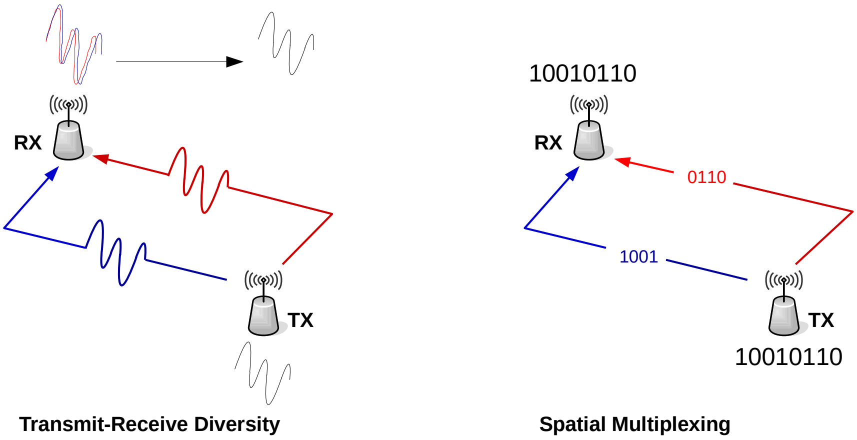


Illustration 29: MIMO functions

Multiple In, Multiple Out (MIMO) refers to an array of multiple antennas on the transmitter and on the receiver to send and receive multiple data streams simultaneously. These can be used to increase throughput giving increased spectral efficiency through spatial diversity.

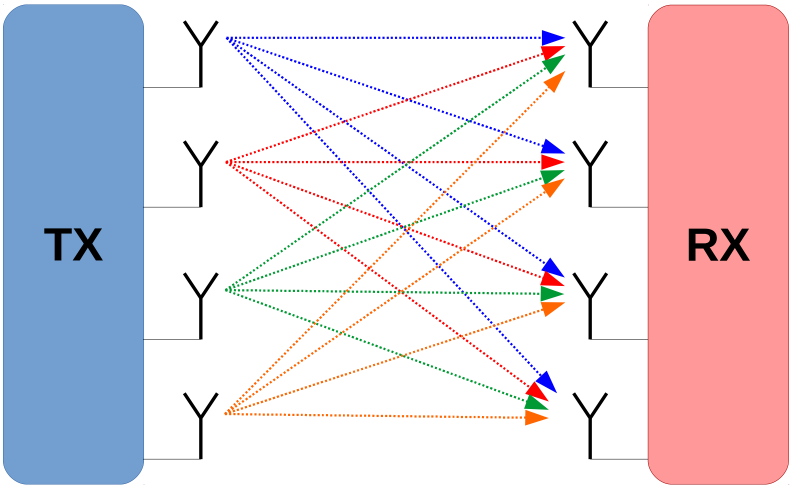


Illustration 30: 4X4 MIMO

If the spectral efficiency of a Single In, Single Out (SISO) system is in the region of 4 b/s/Hz then for a system with 4X4 MIMO with four antenna on the transmitter and four antenna on the receiver a spectral efficiency of 16.32 b/s/Hz can be achieved. This is a typical LTE solution. LTE-Advanced can even go up to 8X8 MIMO with eight transmission antennas and eight receive antennas where a spectral efficiency as high as 30 b/s/Hz can be achieved.

6. Beamforming

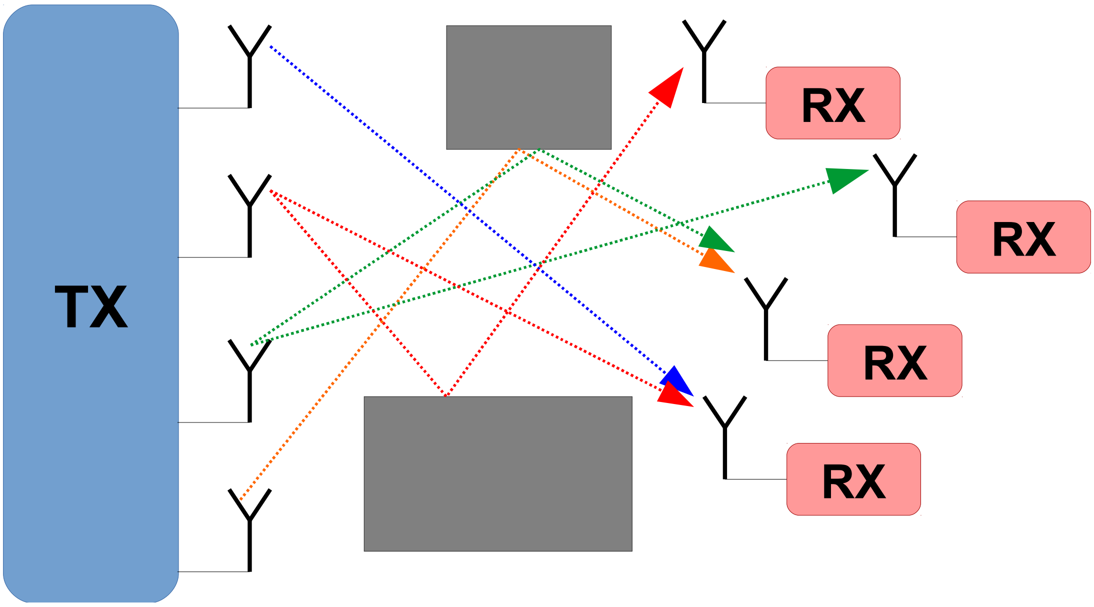


Illustration 31: Beamforming

Beamforming is a signal processing technology that is used to direct the reception or transmission (the signal energy) on a transducer array in a chosen angular direction.

It identifies the most efficient data-delivery route to a particular user, and it reduces interference for nearby users in the process. The primary problem associated with massive MIMO is how interference can be reduced while transmitting more information from many more antennas simultaneously. Each base station uses signal-processing algorithms to plot the best transmission path through the air to each user. Once plotted individual data packets can be sent in many different directions, these may be reflected off buildings and other objects in a precisely coordinated pattern as determined by the signal-processing algorithm. By managing the packets' movements and arrival time, beamforming allows many users and antennas on a massive MIMO array to exchange much more information at once.

7. Self-test Quiz

1. What are the properties of radio communications in this band ?
2. What frequency bands are generally associated with Short Range Devices (SRD) ?
3. What is antenna gain and what is the relationship between antenna gain and radio output power ?
4. What is the noise floor ?
5. What mechanism is used to ensure that an antenna is not aligned with a side lobe ?
6. If a radio link after alignment has an RSSI of -83 what do you do ?
7. What is the difference between MIMO and beamforming ?