

Radio Mobile

**Radio Propagation and Radio Coverage
computer simulation program**

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Program Operating Guide

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Radio Mobile Computer Program

The Basics and Program Operation

Copyright and Author – Radio Mobile

The Radio Mobile computer program is written and maintained by Roger Coudé, VE2DBE. The program is copyright by Roger Coudé. It is available from the Radio Mobile website, <http://www.cplus.org/rmw/english1.html>, hosted by Communications Plus and the [Mirror site \(http://www.ve2dbe.com\)](http://www.ve2dbe.com) by [Polancodeign](#)

Copyright and Author – Radio Mobile User Guide

This User Guide paper is written and maintained by Brian Henderson, P. Eng., VE6ZS as an assistance guide to using the program. The user guide is copyright 2009, Brian Henderson.

There are other descriptions of Radio Mobile installation and program use on Roger's website; however, this is simply another alternative to assist with understanding and using the program.

Introduction

Radio Mobile is a computer simulation program used for predicting the radio coverage of a base station, repeater or other radio network. Ground elevation and various radio parameters are taken into account to predict coverage around a radio site.

The paper consists of 2 parts.

1. The first part describes radio propagation in general, including the mathematics of propagation calculation.
2. The second part describes the Radio Mobile program and some of the basics and input parameters required to use it.

Radio Mobile Program Description

Radio Mobile uses the following input parameters to predict and provide a coverage map showing radio coverage:

- Transmitter location
- Transmitter power output
- Frequency
- Antenna Type
- Antenna Pattern
- Antenna Gain
- Transmission line losses, including filters and multicouplers
- Terrain and elevation data for the area

The program uses terrain elevation data from either the SRTM (Shuttle Radar Topography Mission) or the DTED (Digital Terrain Elevation Data) databases that are both available free on the Internet. Other formats for elevation are available; however, these two are the most common.

The program will produce a coloured plot of radio coverage from 1 or multiple base stations showing expected receive signal levels. Levels are displayed using any of the following units specified by the user:

- S-units
- μV
- dBm
- $\mu\text{V/m}$

Coverage contours can be displayed as either a pass/fail (above/below a user specified signal level). Coverage can also be displayed using a “rainbow” of coverage, using various colours to show various signal levels.

The program has the ability to combine this coverage prediction map together with a road or other geographic map. The plot can be quickly used to determine if communication from a specific location is possible.

Radio Coverage Basics

This section discusses some of the concepts used for radio propagation simulation and how computers analyze radio propagation and coverage. These sections are presented as background information for the reader.

Radio propagation is the study of how radio waves travel from a transmitter site to a receiver site through the atmosphere. Radio signals are affected by terrain elevation between the sites, and obstructions, including trees, buildings, etc. that

may be in between the two sites. Radio signals are also affected by atmospheric and other weather related conditions.

Radio propagation and coverage has its own language, like any other specialty.

Radio receiver Operation

The intent of any radio receiver is to receive and decode a specific signal from the many signals in the air and separate it from noise and other unwanted signals. Receiver threshold is the minimum amount of signal required for a receiver to decode and the user or listen to a message.

Example, most mobile radios have a receiver sensitivity of 0.5 μV . A signal at this level has noise along with it. If the radio is moving (mobile or handheld radio), the signal will change up and down, increasing and decreasing the background noise. Increase the signal level to 1 μV , the noise is substantially reduced and the signal is much easier for the ear to decode. Decrease the signal below 0.25 μV and it may disappear into the noise and not be understood.

Changing from 0.5 μV to 1 μV as a reference and calculation level is a 6 dB increase in power level and makes the signal much easier to understand. The signal will continue to vary up and down; however, these changes are less noticeable to the ear when listening.

Additional fade margin improves the usability of a radio system. It is not recommended to design a radio system to the complete maximum of radio performance. The result of a system designed to the maximum is that it shows very good coverage on a map, however, it is not useable at the extremities of predicted radio coverage.

The deciBel (dB)

The deciBel (abbreviated dB) is a logarithmic value commonly used for radio propagation calculations. Radio propagation works using logarithmic numbers.

Why? Radio propagation involves complicated multiplication at varying points along a radio path. A directional antenna multiplies the signal by its gain. Feed line cable divides the signal by its loss. The equations become very complex.

Taking logarithms of all gain and loss values allows them to be simply added and subtracted. When all gains and losses are identified, they can simply be added up to determine the final receive signal level. Overall mathematics is simplified by using the deciBel, abbreviated to dB.

To keep the mathematics simpler, antennas, feed line losses and insertion loss of duplexers etc. are all specified as dB values.

The Radio Mobile program works mostly in deciBels. Where input is required from a normally linear device, such as transmitter power output or receiver sensitivity, the program provides the ability to enter number in either Watts or μV (linear) or dBm (logarithmic). The program will convert these numbers to a dB value for program use.

Decibel Mathematics

The deciBel is logarithmic number that is a ratio, in this case, between 2 power levels.

The decibel is defined by the following equation:

$$\text{dB} = 10 * \log_{10} \frac{(\text{Power level 1})}{(\text{Power level 2})}$$

Note that the units in the above equation must cancel out, meaning that if the top is specified in Watts, the bottom must also be specified in Watts.

For example, linear amplifier gain may be specified in deciBels.

If input power = 75 Watts and output power = 300 Watts, the gain of this amplifier is:

$$10 * \log_{10} \frac{300 \text{ Watts}}{75 \text{ Watts}} = 6.02 \text{ dB.}$$

deciBel and Radio Standards

It is also worth noting that several standards have been established within the radio industry using the deciBel.

dBW is deciBels above a 1-Watt reference.

- A 1-Watt transmitter has an output of 0 dBW.
- A 10-Watt transmitter has an output of +10 dBW.
- A 25-Watt transmitter has an output of +14 dBW.

dBm is deciBel above a 1-milliWatt (mW) reference.

- A 1-Watt transmitter has an output of +30 dBm.

A 10-Watt transmitter has an output of +40 dBm.
A 25-Watt transmitter has an output of +44 dBm.

As can be seen, changing from dBW to dBm is simply a matter of adding or subtracting 30.

dBm can and is commonly used to specify receiver sensitivity.

0.5 μ V is equivalent to – 113 dBm
1.0 μ V is equivalent to – 107 dBm
10 μ V is equivalent to – 87 dBm

Note that dBm for receiver sensitivity is based on a voltage level in μ V, not a power level in Watts. Mathematically, this is taken into account and does make a difference to the deciBel calculations.

Propagation Modes

Line of sight is simply that – if the distant site is optically visible from the transmitter antenna location on the tower, it is considered within the coverage area. This is referred to as “optical line of sight coverage”. The optical line of sight method does not take into account reflections, Fresnel Zones or the slight bending of radio waves along the surface of the earth.

Radio path loss between 2 sights that are within line of sight uses “free space loss” only. No other loss parameters are considered.

We all know that radio waves travel in straight lines. The early mathematics of radio propagation considered that radio and light were essentially the same and travelled in the same manner. If a distant site could be seen optically, radio communication was possible. Therefore, there is an option to show optical line of sight coverage.

‘K’ factor

It was discovered by the British during early radar research (at really high frequencies, around 300 MHz in the late 1930s) and later by AT&T at Bell Laboratories, that radio waves travel a little further and actually bend with the surface of the earth. The bending is proportional to frequency. The higher the frequency, the less the bending.

VHF radio systems have better coverage than UHF systems due to the better bending of VHF frequencies.

After some extensive analysis of propagation, it was determined that if the diameter of the earth is increased by approximately 1.33 or 4/3, radio waves do travel in straight lines over this “larger” earth. The 4/3 earth radius is called the ‘K’ factor and continually shows up in radio path design and propagation theory. The earth’s curvature, as it begins to protrude into a radio path as distance between sites increases, is commonly called the earth “bulge”.

The ‘K’ factor is the difference between performing radio propagation studies as line of sight paths and actual radio paths.

It is also worth noting that ‘K’ is another of the variables that changes with atmospheric conditions. The typical value of K is 4/3. However, it can range anywhere from about 2/3 to up as high as 10. These ranges do not occur often; however, they can and have occurred on microwave test ranges.

‘K’ usually has a tendency to increase, producing less earth bulge, and less loss between radio sites. K can range up to 10, depending on atmospheric conditions.

‘K’ can also decrease. Sometimes, ‘K’ can decrease to as low as 2/3 or 0.66. Again, this does not happen often, however, can occur. Effect is an increase in signal loss and lower signal level at the receiver.

Propagation Loss

There are 2 signal losses that add together as the atmospheric and distance loss between a transmitter and receiver site. Both can be calculated between the transmitter and receiver sites.

Free Space loss

Free Space loss is the loss due to the distance between sites. It does not take into account obstructions. It assumes that the sites are completely in the clear, hence the term “Free Space”. It may also be called “line of sight loss”.

The commonly accepted equation for calculating Free Space Loss is:

$$\text{FSL (dB)} = 36.57 + 20 \cdot \log_{10} (\text{Distance in miles}) + 20 \cdot \log_{10} (\text{Frequency in MHz})$$

Diffraction Loss

Diffraction loss is the loss that results from signals being obstructed by hills, buildings, trees or other objects. Diffraction loss also results as the distance

between sites increases and the curvature of the earth obstructs the path. The earth obstruction is commonly referred to as the “earth bulge”.

Calculation of diffraction loss is very complicated and beyond the scope of this paper.

Total Loss Between Sites

Total path loss between 2 sites is calculated by adding together all the dB values including Free Space Loss and Diffraction Loss. The remaining parameters that must be added to arrive at a receive signal level are summarized here.

Provide all numbers are in deciBels as described above, this table can be filled in and the numbers added to determine receive signal level.

Transmit Power Output		dBm
Connector loss		dB
Multicoupler or filter loss		dB
Duplexer loss		dB
Feed line loss		dB
Transmit Antenna Gain		dB
Free Space Loss		dB
Diffraction Loss		dB
Receiver Antenna Gain		dB
Feed line loss		dB
Duplexer loss		dB
Multicoupler or filter loss		dB
Connector loss		dB
Calculated receive signal level		dBm
Receiver sensitivity		dBm
Fade Margin		dB

Many of these loss parameters, such as duplexer and antenna losses and gains, are available from manufacturer’s specification sheets.

Connector loss is a parameter commonly overlooked in many calculations. Depending on connector type, it can be from 0.2 to 1.0 dB per connector. Some connector types have more loss than others. It also depends on the quality of a specific connector and experience of the connector installer.

When purchasing connectors, “you get what you pay for”. Yes, ‘N’ connectors cost more. However, their loss can be significantly lower at higher frequencies. However, if improperly installed, there can be a significant increase in loss. Follow the installation guide when installing connectors.

Radio Wave Propagation

For this discussion, it is worth noting that radio waves are sine waves. They oscillate between high and low at the carrier frequency of the transmitter. Radio waves travel through the air at close to the speed of light. Since they are sine waves, they have a frequency and phase component. Phase is a specific point on the sine wave curve. All sine waves repeat themselves after 360° of arc, similar to a circle.

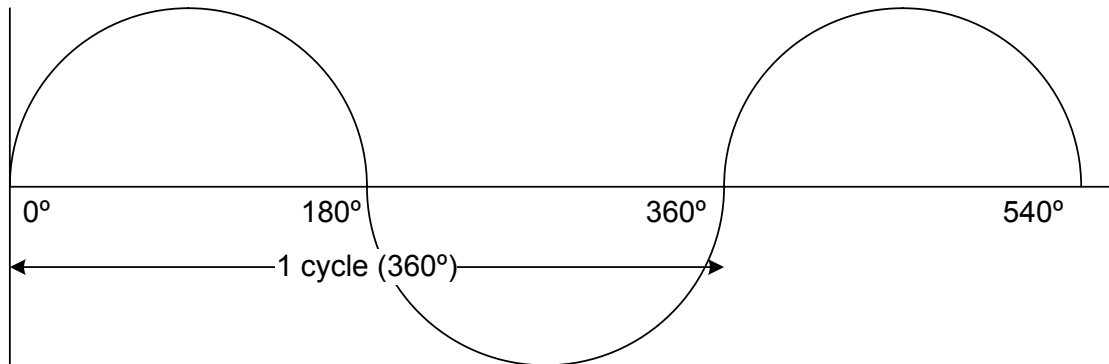


Figure 1. The Sine Wave

Fresnel Zones

Fresnel zones are used by propagation theory to calculate reflections and diffraction loss between a transmitter and receiver. Fresnel zones are numbered and are called ‘F1’, ‘F2’, ‘F3’ etc.

There are an infinite number of Fresnel zones, however, only the first 3 have any real effect on radio propagation.

What is a Fresnel zone and why is it important?

First, what is it? A Fresnel zone is a cylindrical ellipse drawn between transmitter and receiver. The size of the ellipse is determined by the frequency of operation and the distance between the two sites.

When a radio signal travels between transmitter and receiver, it can travel in several ways. It can go directly between transmitter and receiver (main signal). Signal can reflect off the ground and then carry on to the distant receiver (reflected signal). It can go left or right and be reflected back by a hill to the side of the radio path (another reflected signal).

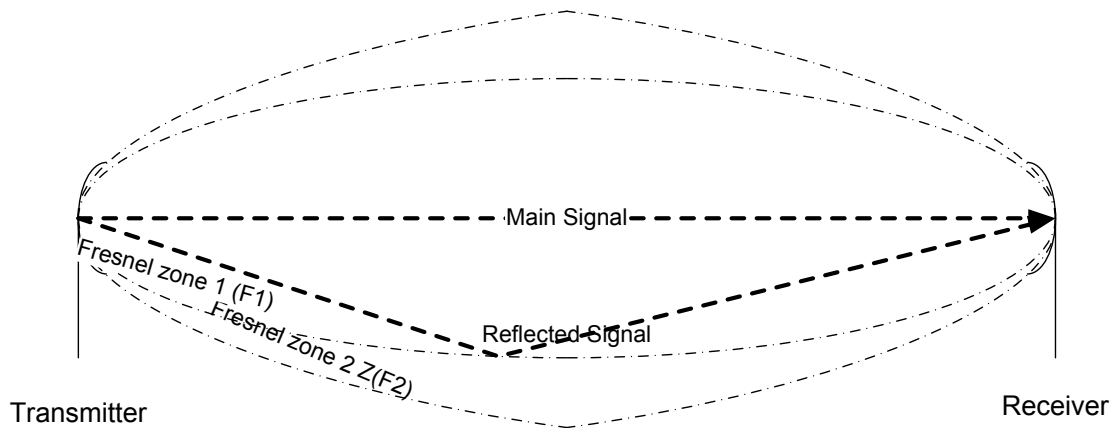


Figure 2. – First and Second Fresnel Zones

How big is it?

Fresnel zone radius describes this reflection in relation to overall radio path length. Figure 2 above shows main and reflected signals and F1 (first Fresnel zone) and F2 (second Fresnel zone). The reflection can happen at any location between the transmitter and receiver. The figure shows the reflection happening at a random location, not the centre of the path.

When a signal is reflected two things happen.

- the phase of the signal reverses and the signal changes in phase by 180° .
- Since the signal is being reflected and not going in a direct line, it travels slightly further to the reflection point and then on to the receiver. Therefore, the signal is shifted further in phase, by the difference in path length.

Over a long path, this can amount to 180° or more.

Why is this important? The receive antenna cannot differentiate between a main and reflected signal. They are both on the same frequency. It receives both main and reflected signals. It also receives any other signals within its designed frequency range.

When an antenna receives a main signal and a reflected signal, the 2 signals will combine and add together at the antenna. If they are 360° shifted (in phase), they will add together and there is no issue. However, if the signals are 180° apart (opposite phase), they will cancel and the receiver will receive nothing.

The cancelled signal is the one to be avoided.

Fresnel Zone Numbering

The specific numbered Fresnel zone describes the difference in path length between a direct signal, traveling in a straight line between 2 antennas, and a reflected signal from the calculated boundary of the specific Fresnel Zone.

Each Fresnel Zone number sequentially increases the phase reversal and adds a 180° phase shift.

The table shows the effective phase shift by reflected signals from different Fresnel Zones. It includes the 180° phase reversal from the reflected signal from the ground or other object. Adding the reflection phase reversal to the difference in path length gives the total phase shift from transmitter to receiver.

Fresnel Zone	Phase Shift	Path Length Phase Shift	Effective Total Phase Shift
Fresnel Zone 1 (F1)	1*180°	180°	360°
Fresnel Zone 2 (F2)	2*180°	360°	540° (same as 180°)
Fresnel Zone 3 (F3)	3*180°	540°	720°
Fresnel Zone 4 (F4)	4*180°	720°	900° (same as 180°)

Fresnel Zone 1 (F1)

The first Fresnel zone radius is calculated so that the difference in path length between the main signal and a reflected signal from the F1 radius distance is 180°. A reflected signal shifted by 180° of path distance plus 180° from the actual reflection point totals 360° of phase shift. The 2 signals, main and reflected, arrive at the antenna 360° apart or in phase. They will add together and actually improve receiver performance as there is a signal gain.

This reflection phase shift can happen anywhere from the calculated Fresnel zone “tube”, properly known as an ellipse.

Fresnel Zone 2 (F2)

The second Fresnel zone radius is calculated so that the path length difference between the main and reflected signals from the second Fresnel zone tube is 360° .

This is critical, since a reflected signal has an automatic 180° phase shift plus the path length difference of 360° equals a phase shift of 540° . 540° and 180° are the same phase shift in mathematics and the 2 signals will cancel, leaving no signal at the receiver.

The second Fresnel Zone, F2, is the zone of reflection that is not wanted when designing a radio path.

Fresnel Zone 3 (F3)

The third Fresnel zone has a path length difference of 540° . Add this to the 180° reflection shift; the total is 720° , and the 2 signals are in phase.

Fresnel Zone Effect

Two important effects rely on Fresnel zone calculations.

For reflection and multipath analysis, even numbered Fresnel zones (F2, F4, F6) incur a net 180° signal reflection. These are detrimental to radio propagation. Odd numbered Fresnel zones (F1, F3, F5) incur a net 360° phase shift and have little effect. Odd numbered Fresnel zones are the “good guys”.

The effect of these reflections in mobile operation can be experienced near the coverage limit of a repeater for example.

What is heard in the receiver is a rapid increase/decrease of signal, often called “picket fencing”. The rapid increase and decrease of signal from a moving radio or vehicle is called Rayleigh fading. It is a direct result of Fresnel zone reflections coming and going in and out of phase as the vehicle moves down the highway.

Point to point paths also make use of Fresnel zone calculations. For point to point paths, antenna locations are fixed and there is no rapid signal fade due to an antenna moving. There are long term effects (over several hours) that are taken into account when performing Fresnel Zone calculations.

Fresnel Zone Radius and Earth Clearance

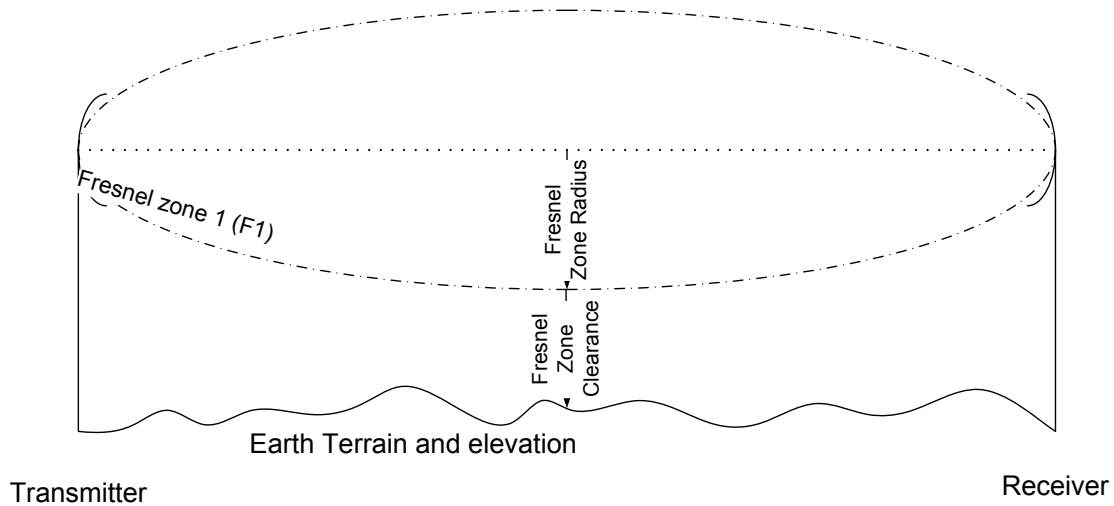


Figure 3. Fresnel Zone Radius and Earth Clearance

The diameter of the Fresnel Zone (half the diameter is the radius) of the elliptical cylinder can be calculated.

The important component of Fresnel Zone Radius is the clearance between the Fresnel zone cylinder and the surface of the earth. As shown in Figure 3, the Fresnel zone radius and Fresnel zone earth clearance are shown.

If the ratio of

$$\frac{\text{Fresnel zone earth clearance}}{\text{Fresnel zone radius}}$$

is greater than 60%, the radio path is considered “clear, line of sight” and incurs no diffraction loss.

The 60% clearance (and not 100% clearance) is due to the bending of radio waves over the surface of the earth.

This understanding of Fresnel zones and their effect helps know the how and why that radio coverage can be predicted using mathematics and computers.

Clear Line-of-Sight

When calculating path loss between radio sites, if the signal path exceeds 60% of F1 (First Fresnel zone), the radio signal is considered “clear line-of-sight” and will incur no diffraction loss.

As terrain or the earth reduces Fresnel clearance below the 60% value, diffraction loss increases.

Clear line of sight is also referred to as optical line of sight.

Point to Point Radio links

Point to point radio links are discussed later in this paper, however, it is worth noting a common design trick for point-to-point links.

Since the F2 zone is detrimental to receive signal level, antenna heights are often selected so that F1 is an unobstructed path and F2 is obstructed by a hill or the earth bulge along the path.

Any 180° reflected signals along the F2 zone are attenuated by the hill or the earth and do not reach the receive antenna to interfere and cancel the main receive signal.

Path Reliability – Point to Point Radio

Radio path reliability and fade margin were discussed in “Radio Path Fade Margin”.

Point to point radio links have more extensive analysis performed to determine radio path reliability.

The “clear line-of-sight” path was discussed in section “Fresnel Zone Effect”. A radio path must be more than 60% clear of the First Fresnel zone (F1) to incur no diffraction loss. Here is where some of the “free” calculation tools may give overly optimistic link calculations.

These propagation tools usually specify “clear line-of-sight” paths. They do not take into account diffraction loss.

Point to Point Reliability

Point to point reliability is a calculation that involves signal fade margin, distance between the sites, channel bandwidth and a myriad of other factors.

There are 2 important input parameters that involve 'K' and Fresnel zone clearance. These parameters will allow calculation of the required antenna height to achieve the Fresnel zone clearance required.

Telephone networks have long used $K=4/3$ or 1.33 and a Fresnel clearance of 60% for microwave path design. Space diversity (2 receive antenna) systems use a 100% Fresnel clearance for the higher antenna and 60% clearance for the lower antenna.

Military networks have long used $K=2/3$ or 0.66 and a Fresnel clearance of either 60% or 100%. This does give higher antennas and shorter paths and usually higher path reliability.

Care must be taken, as antennas higher up can run into reflection problems and the F2 clearance and reflected signals can become a problem when using the military design criteria.

It is always worth checking for signal reflections along a radio path. Radio mobile cannot perform reflection analysis. A program that does provide reflection calculation is Pathloss.

Radio Coverage Probability

All radio coverage is based on probability theory. Radio coverage at a specific location relative to a distant transmitter can be specified for a 50%, 90% or higher probability of successful communication. Radio coverage cannot be guaranteed 100% of the time.

Radio coverage is affected by weather and atmospheric conditions on a continual basis. Rain or snow can affect higher frequency satellite and microwave communication. Temperature inversions can affect VHF and UHF and cause reflections that either increase or decrease signal level at a distant site.

Because of these variables, radio networks rely on a parameter called "Fade Margin". Fade margin is the safety factor used to determine the level of probability of successful radio communication. Fade margin is the additional signal, above a receiver threshold, that is not necessary for communication, however, is necessary for reliability prediction.

Radio Path Fade Margin

The following is an approximate list of common fade margins and probability numbers. Other factors do influence fade margin, including path distance and

frequency, however, these numbers give a reasonable appreciation of fade margin.

Percentages refer to time period, as in “50% of the time, signal will be at or greater than the calculated value”.

50%	6 dB
90%	10 dB
99%	20 dB
99.9%	30 dB
99.99%	40 dB

Obviously, the higher the fade margin, the higher the probability that a usable communication signal will be received, and the smaller the coverage area displayed to maintain this fade margin.

For most mobile systems, a fade margin of 6 to 10 dB is acceptable. Critical systems such as police, fire and ambulance may require higher reliabilities and require higher fade margins during system design.

It is worth noting that cellular radio systems and to a limited extent, public trunked radio systems use fade margins of the order of 10 to 20 dB. To keep cellular and trunked telephones small, antennas are small and inefficient; therefore, more signal level is required to maintain a reliable communication path from a cell site to a cellular telephone.

Coverage for mobile radios will always be greater than for a handheld radio. The difference is due to the smaller and lower gain antennas and smaller capture area of the handheld antenna. Handheld radios also have a lower transmit power than mobile radios.

Geographic Coordinate Systems

Radio Mobile has the ability to operate using 4 different coordinate systems. All of these locate a radio or user at a unique location on the earth's surface.

Better descriptions of these coordinate systems are available from Wikipedia on the Internet and other sources. Simple descriptions of the coordinate systems are presented here.

Radio Mobile input makes use of the following coordinate systems:

- Latitude and Longitude (Lat and Long), default and always used
- Maidenhead Locator System (Maidenhead) or QRA
- Military Grid Reference System (MGRS)

- UTM Universal Transverse Mercator

MGRS Military Grid Reference System is based on and is similar to UTM coordinates.

Radio Mobile initially defaults to using Latitude and Longitude and the QRA (Maidenhead Locator System).

The alternate coordinate system can be changed under “options”. Select “Options”, “Coordinates” and any of the above 4 coordinate systems can be set as the alternate. Latitude and Longitude remain always available.

Note also that the status bar at the bottom of the page will show up to 3 coordinate systems of where the cursor, as displayed on the map, is located. Simply check off the boxes of the coordinate systems desired.

When moving the cursor around on the map, the display continually shows cursor location and elevation in metres at the cursor point. Note that the X-Y reference, if selected, shows the cursor location in pixels, selected when the size of the map (in pixels) is chosen for map display during map extraction. Pixels and map resolution are defined under “Map Properties” when extracting a map.

The X-Y reference 0, 0 point is the top left corner of the map.

Earth Reference Points

Also, note that in order to represent the round earth on a flat map, there are a number of reference survey points selected on the earth for various coordinate systems. The earth is not a perfect sphere. The technical term is “oblate spheroid”. There are a number of ellipsoids used to represent actual points on the earth using the survey reference points.

- The most common ellipsoid is Clarke, 1866 (of Lewis and Clarke).
- Numerous geographic reference datums are used as survey reference points.
- Canada uses both North American Datum, 1927 (NAD27), located west of Kansas City. This datum is more or less the geographic centre of the 48 States.
- Canada is in the process of upgrading to North American Datum 1983 (NAD83). This reference datum uses a different ellipsoid to represent the shape of the earth and is based on satellite imagery. The reference point is virtual (not a real point) and derived by mathematics.
- The UTM coordinate system and other locations use an ellipsoid and reference point defined by the World Geographical Standard, 1984

(WGS84). WGS84 is the reference ellipsoid used by the GPS navigation system.

These locations cause slight shifts in reference points of a map and shift in location of a specific point on the surface. The shifts are small and for the most part have limited effect on calculation or display of radio coverage.

Surveyors are concerned about the 200 m to 300 m differences between the various reference points; however, radio coverage is not significantly affected.

Latitude and Longitude

Latitude and Longitude is probably the most widely known method of locating a point on earth.

The world is divided into horizontal “slices”. These are lines of Latitude. The equator is at 0°, the north pole is at 90° North and the South Pole is at 90° South.

Points are measured north and south of the 0° equator and are referred to as North and South Latitude. Each degree is divided into 60 minutes (′), each minute is divided into 60 seconds (″), just like a clock.

The world is divided into vertical “segments” (like an orange). These are lines of Longitude. The 0° “meridian” passes through Greenwich, England (now a suburb of London, England). The 180° meridian lies in the Pacific Ocean, east of Asia.

Points are measured east and west of the 0° meridian and are referred to as East and West Longitude. Each degree is divided into 60 minutes (′), each minute is divided into 60 seconds (″), just like a clock.

The intersection of Latitude and Longitude defines a specific unique location on the earth.

A location on the earth appears as

51° 2′ 43.63″ N, 114° 3′ 26.14″ W.

One minute of Longitude at the equator is defined as 1 Nautical mile. However, the actual distance between lines of Longitude decreases with distance, as the earth tapers north or south of the equator, requiring the map scale to continually change as the lines of longitude merge at the North and South poles.

The disadvantage to Latitude and Longitude is that distances and map scales change, depending on the latitude of the location. Further north or south, the lines of Latitude represent different horizontal distances on a map.

Sometimes Latitude and Longitude are specified in “Decimal Degrees” and do not show minutes or seconds of arc. A location may be specified as 51.1234 N and 114.0456 W.

Most computer programs, including Radio Mobile, will accept latitude and longitude entered as decimal degrees. It will convert these numbers into the format used for calculation.

Note also that Radio Mobile latitude and longitude defaults are specified as:

Latitude	Positive numbers are North Latitude, north of the equator, Negative numbers are South Latitude, south of the equator.
Longitude	Positive numbers are east of 0°, east longitude Negative numbers are west of 0°, west longitude

Maidenhead Locator System

The Maidenhead Locator system locates amateur radio stations into grid squares on earth using a minimum number of characters. The intent is that these characters can be easily sent and exchanged using short transmissions of voice or Morse code.

The format of the Maidenhead system is XY45xy. Alternating characters X, 4, x combine to represent Longitude and Y, 5, y combine to represent Latitude.

The Maidenhead system divides the earth into 10° (north south or latitude) by 20° (east west or Longitude) grid squares. Latitude begins counting at the South Pole; Longitude begins counting at 180° West. There are no negative numbers using the Maidenhead system.

Longitude is presented first, beginning at 180° W, with letter ‘A’. Letters increment sequentially to letter ‘R’ that completes the zone circle around the earth.

Latitude is the next character and begins counting at the south Pole with the letter ‘A’. Zones are lettered south to north (south to north pole) using letters ‘A’ through ‘R’.

Single digit numbers appear next. First digit is again Longitude and divides the 20° zone into 2° squares. Second digit is Latitude and divides the 10° zone into 1° squares. Each grid square is 1° by 2°.

Another pair of lowercase letters (usually) further divides a grid square into sub squares. Each grid square is divided by 24 into 2.5’ by 5’ sub squares. Letters

'a' through 'x' show these sub squares. The same convention is used, first letter is longitude; second letter is latitude.

A location using the Maidenhead locator system appears as

DO21xb.

Universal Transverse Mercator (UTM)

UTM coordinates are completely metric coordinates and define a location on earth by Easting and Northing (E and N). Coordinates are based on latitude and longitude, however, the distance scale does not change.

The earth is divided into 60 vertical Zones around the equator. Each zone has a longitude width of 6°. Zones are sequentially numbered from west to east, beginning at the 180° meridian of longitude in the Pacific Ocean. A UTM coordinate will always quote the zone number.

Eastings are measured in metres east of a specific zone boundary. Northings are measured in metres north or south of the equator. Note also that the zone will be followed by a letter. Letters are assigned every 8° moving north from 80° South Latitude, beginning with letter "C" (Letters I and O are omitted). The equator is at "N", Canadian locations may be at "T", "U" or "V".

Letters indicate the approximate location and are used to indicate if a location is north or south of the equator. A negative UTM coordinate does not appear. The equator is

A UTM coordinate appears as

706,277 E, 5,658,780.9 N, Zone 11U.

Most topographic maps show UTM coordinates on the map, making a location easy to find. Canadian National Topographic System (NTS) maps show Eastings and Northings in blue and include 1-kilometre grid lines to locate a specific point on the map.

Note that there are exceptions to this description. Within the north and south polar areas, a slightly different system is used, also defined in the UTM standard. These exceptions are described in other references, including Wikipedia.

Military Grid Reference System (MGRS)

The Military Grid Reference System is based on the UTM system. It is the system used by NATO to specify a location on the earth. Radio Mobile can accept location input using the MGRS coordinate.

The MGRS locator system relies on grid squares defining a 100,000 m or 10 km square on the earth's surface. It is similar to and based on UTM coordinates, however, letters are used to indicate the location of these squares on the earth.

UTM zones are divided into 100,000 m slices and lettered from west to east using letters A through Z, omitting 'I' and 'O'. At the equator, each UTM zone requires 8 letters. Lettering is repeated when the end of the alphabet is reached. As distance from the equator increases north or south, letters are dropped from the end of the alphabet (since the lines of longitude get closer together).

North or south of the equator, squares are lettered 'A' through 'V' (omitting 'I' and 'O') in odd numbered zones. In even numbered zones, lettering begins at 'F'. After the letter 'V' the letters repeat. Letters begin at the bottom of the square and sequentially increase moving north.

The offsets allow unique lettering of each 100,000 m grid square.

Following the grid square letters are a series of numbers: 2, 4, 6, 8 or 10 digits. These numbers are the metric UTM coordinates and are the Easting and Northing numbers.

The number of digits specifies how accurate a location is. The series of numbers is split equally (even number of digits) for Easting and Northing respectively and specifies a location to the following accuracy:

- 1+1 digits specify distances to 10,000 m (10 km)
- 2+2 digits specify distances to 1,000 m (1 km)
- 3+3 digits specify distances to 100 m
- 4+4 digits specify distances to 10 m
- 5+5 digits specify distances to 1 m

A typical Military Grid Reference System location appears as:

11U QS 06277 58781

Elevation Data and Elevation Maps

Elevation data is available in many printed and paper forms (printed maps), however, has only been recently available in electronic form for use by computers. First, a little history of paper maps.

In Canada, elevation data continues to be available on topographic contour maps, either in 1:50,000 or 1:250,000 scales, produced by the Geological Survey of Canada. These maps show elevation contour lines at 25 or 50 feet intervals (older maps, not yet converted to metric) and 10 or 20m intervals (newer maps). Other countries have similar topographic maps in similar scales.

Most of the Canadian contour maps were made from aerial photography pictures taken in the late 1940s and early 1950s. Over time, these maps have been updated to show city growth and other changes. However, it is not uncommon to see dates from the 1970s on current contour maps. Since elevation contours have not changed much in 50 years, this is not considered a problem.

Contour maps are available for some countries, the USA uses a 1:24,000 scale standard. Some countries do not have contour maps, or do not release them to the general public.

Last resort are Aeronautical "WAC" charts (World Aeronautical Charts) that show all land areas of the world. Contour intervals are at either 100 or 500 feet only. Scale of WAC Charts is usually 1:500,000, which gives very low resolution.

Digital Terrain Elevation Data (DTED)

During the late 1980s Canada began leading the way with electronic maps that could be interpreted and used by computer. They developed the Digital Terrain Elevation Data or "DTED" series of maps for northeastern Alberta, near Cold Lake. These were expanded and now cover most of Canada.

The original maps took "spot" elevations every 500 m from a 1:250,000 scale map (1 cm = 2.5 km, or 1 inch = 6.3 miles).

The second generation of maps averaged the elevation over that same 500 m square and provided the single elevation number for each 500 m square.

It was reasonably well known among radio people that within a 500 m horizontal distance, larger hills were often missed and the original DTED maps were not that accurate. They were not trusted for radio path design, specifically microwave point-to-point links. They were used, however, for early coverage plots of radio systems.

Newer DTED maps are now spot elevations taken every 100 m. In mountainous areas, they can still miss some of the peaks.

DTED maps are available from www.geobase.ca. It is required to register to download DTED maps, however, maps are easily downloaded once registered. Select "Digital Elevation Data" from the menu.

The data is downloaded by selecting maps from a map of Canada.

Files are “zipped” files and must be unzipped for use. PKZip, 7-Zip or other programs may be used to decompress the files.

Shuttle Radar Topography Mission (SRTM)

In 2001, NASA took the initiative to map the elevation of the earth. They took radar images of the earth every 3 seconds of arc around the earth from the Space Shuttle. This works out to an average of 90 m intervals. In the USA they went to 1 second of arc, or about 30 m on the ground.

There are now 2 versions of these electronic maps available on the Internet. Version 1 was the original, Version 3 is corrected and fills in a number of blanks and errors from the original data.

SRTM data is considered more accurate than DTED, although there are “holes” in SRTM data, and DTED is good to use as a second, backup alternative.

Note also that for Canada and other northern countries, latitudes north of 60 degrees north are not included. They may be purchased from a supplier called “Lurodata”.

Latitudes in the far south are also not available. However, the following website may be used to download data for approximately 80% of the earth’s surface.

<ftp://e0srp01u.ecs.nasa.gov/srtm>

Locations are listed by continent. SRTM data is provided in 1° by 1° squares on the earth’s surface. Select the newest version (currently version 2), the SRTM version (currently version 3) and the continent required.

Files are “zipped” files and must be unzipped for use. PKZip or other programs may be used to decompress the files.

Using downloaded Elevation Data

When data is downloaded, it must be stored in a specific file on your computer. Radio mobile must be programmed to look at this file to obtain elevation data.

Radio mobile can also automatically search for required files. It will download the file it needs to calculate the path or coverage required. Disadvantage of this is an Internet connection is required when performing radio calculations. “Stand

alone” path calculations cannot be performed unless the data has been previously downloaded.

The location of elevation data files is defined in the Map Properties window. See section “Maps and Map Properties” for a description of setting the digital elevation file locations.

Radio Mobile Program Installation

There are already several available descriptions on how to install the Radio Mobile program and where to obtain elevation data from the Internet. This document outlines how to use the program and how to make it produce useable coverage maps.

Program Use and Operation

Data Entry and Format

Radio Mobile data input is strictly in metric units. Elevations are in metres, distances are in kilometres. Cable lengths and tower heights are in metres. All program input parameters are metric and cannot be changed to display British units.

If feet and miles are the preferred working units, there is a conversion section available in the program. Under the tools menu, there is a menu called “metric conversion”. It is also available by typing Ctrl ‘m’.

Clicking on the “units” box scrolls through a number of metric conversions, including feet to metres, miles to kilometres, dB/foot to dB/metre.

File Structure

When Radio Mobile is installed (Windows operating system), it is installed in a directory called “Radio Mobile” at the top level of the “C:” drive (default file location).

Within the “Radio Mobile” directory is a folder called “Networks”. Initially, there will be 4 Network folders created within the Networks folder:

- Network 1
- Network 2

- Network 3
- Base network

Base Network is a first example and has default input parameters that are used when the program is opened for the very first time.

When the program is closed, the program will ask to save 3 files in the current default directory. There are no options offered when closing Radio Mobile as to where these files are saved. The 3 files are:

- *.net
- *.map
- *.jpg

These 3 files are used the next time the program is opened to set the operating parameters for the Radio Mobile program.

It is suggested that each time a new coverage map is required for a different geographic area, that a new network folder be created to store the data and coverage information for a site or group of sites.

When a new network and coverage map is created, using the “file” command, manually “Save Network As” and define the name of the network and select the file location. The option is then given as to where files for that network are stored. When the storage location is selected as the newly created directory, all files for that coverage plot will be saved in this new location. This becomes the new default file storage location for that specific network.

This assists with your own file management to keep all files relating to that network in their own folder.

When exiting the program, the 3 files will be saved in the new default directory.

If it is required to work on a different network, from the File menu, “Open Networks” and navigate to the correct folder holding the Network files required. This will become the new default file storage location, until changed again to a different network.

Program Start and check for Program Updates

Either start the program using the desktop icon or from the Start menu, Programs, “Radio Mobile”.

Once the program is running, click on “Help” and “Check for Web Update”. The program does get updates, changes and revisions regularly, might as well ensure the latest version is running.

When starting Radio Mobile, the last Network worked on will be opened in the display window. If that network is not today’s task, either Open another network or create a new network as directed in this User Guide.

Radio Mobile Input Parameters

Before a coverage plot can be produced, 3 main input parameters must be defined for the Radio Mobile program. In addition, a map of the area of coverage must be defined, along with the map size, resolution and limits. This map is then extracted from the elevation database and used as a background for the coverage plot. See Section “Maps and Map Properties”

These parameters can be defined in any order; however, all must be defined before a coverage plot can be produced.

The 3 parameter names default to:

- Net 1, Net 2, Net 3
- System 1, System 2, System 3
- Unit 1, Unit 2, Unit 3

As the various input parameters for the program are defined and have specific data entered, the default names can be changed to better describe the network and various radios, units, systems and the operating parameters.

Label names can be changed for any of the following input parameters:

- Network
- System
- Unit

Make use of the label fields, it makes it so much easier to look at the program next week or next month and remember the setup for a specific network and coverage plot.

The 3 parameters are defined:

Net or Network defines an overall radio group and set of operating parameters. It includes the base stations, mobiles, handhelds, etc. within a radio network. It also defines the frequency band for the network.

System Defines the specific operating parameters of any radio Unit. This includes transmitter power, receiver sensitivity, line loss and antenna height, type and gain.

Unit Each radio in a network is a Unit. This includes base stations, repeaters, mobiles and handhelds. Unit parameters define the geographic location of a radio.

Maintain association between the various devices in the program, when entering data. The program cannot check for input data errors.

For example, a VHF network will have VHF mobile, handheld or base station Units entered. Systems must be defined for each of the units within a network. However, if incorrect system parameters are programmed, such as incorrect antenna gain for a 900 MHz system instead of a VHF system, the program cannot recognize this error.

Systems for a mobile, handheld and base station or repeater units will be different and must all include realistic VHF parameters.

A common mistake is to define antenna cable loss the same for VHF or UHF systems. Cable loss increases at higher frequencies. Enter the correct System operating parameters and association between units for each Network.

Maps and Map Properties

Maps in Radio Mobile refer to elevation and terrain data. Maps are specified by size in kilometres. Maps can be square or rectangular.

Geographic maps and marrying with road and other maps are discussed later; see Section “Combining with Geographic and/or Roadmap”.

When a map is extracted, the map is presented as a “rainbow” colour scale map. The rainbow of colours represents elevations across the map. This rainbow can be turned “on” or “off” leaving behind a grey scale of elevations. At the top left of the map (use sliders along the side and bottom to get to the top left) is a legend showing elevation in metres and corresponding colour.

Select “File” and “Picture Properties” to change the map display from rainbow to grey scale. The grey scale can also be turned “on” in the Map Properties window by checking the box “Force grey scale” at the lower left of the window.

Generally, when plotting coverage, the grey scale type map is preferred. Radio signal levels are displayed using the same rainbow colour scale. Therefore, to

avoid confusing elevation colours with signal level colours, leave the map as a grey contrast map.

Rivers and waterways along with high hills and/or mountains can be easily seen and identified on the elevation map. Rivers show as a trench or valley, mountains show as peaks and up slopes.

Step 1 Extract an elevation map for the area of interest, where the coverage map will be produced. Click on “File”, “Map Properties”. A window will open showing the map parameters of the map. Values must be modified for the coverage area of interest.

Step 1a Select the centre of the map. This can be selected a number of ways.

Use Cursor position – cursor is not yet defined, will give a default value. If a map is open, the current cursor position can be used as map centre.

World map – brings up a world map. Position cursor over the area of interest, and then click once. This location is set as the centre of the map.

Select City Name – database of cities around the world is contained within Radio Mobile. Select a city as the centre of the map. If other locations have been previously added to the city database, they will continue to be available as a city for setting as the centre of the map.

Enter Lat and Long or other coordinate (QRA, Military Grid Reference or UTM) – enter Latitude and Longitude directly. Alternatively, enter the 6 character Maidenhead Locator System square (also called the ARRL grid square), Military Grid Reference System (MGRS) or UTM coordinate.

Select a unit – If radio unit locations are defined within the coverage being developed, any unit can be selected and set as the centre of the map.

Step 1b Check off the “Adjust Units Elevation box”. As units are defined for use and display within the program, their elevation will automatically be extracted from the map. Otherwise, unit elevations must be entered manually as part of Unit Properties.

Step 1c Merge pictures allows merging a geographic map along with elevation data at this step. Although the merge can happen at this point, the map picture does become very cluttered and difficult to read. It is preferable to extract the map showing elevation only, place the coverage on it and then merge in the geography and/or roadmap. More is described later under “Producing a Coverage Map”.

Step 1d Force grey scale – The map extracted defaults to a rainbow colour scale showing elevations on the map. Check this box to show elevations

as a grey scale for elevation data. When a coverage plot is produced, it can show the same rainbow of colours defining signal levels.

The choice can be made here – extract the map as a grey scale format and leave the colours for radio signal levels. Contrast and brightness of the grey scale may be adjusted later to better show signal coverage on top of the grey scale map. There are also other places to make the change to grey scale if needed.

Alternatively, coverage can be defined using the Pass/Fail criteria above or below a specified signal level. See the section on “Style” for further description. Colours can then be left showing terrain elevation. Coverage is plotted on the map using a single colour.

Coverage plot colours can be selected to not obscure the terrain and geography shown on the produced map.

Step 1e Set the size of the map. Map size is specified in 2 ways. Width and height (pixels) define the quality of the map when printed out. The larger the number of pixels, the higher the quality and resolution of the map when it is printed.

Note also that the size in pixels will define the shape of the map, square or rectangular.

Step 1f Set size of the map in kilometres. Only one of the dimensions can be specified, the other will be calculated to maintain correct map ratio and geographic perspective. The dimension refers to the overall width or height shown by the map when extracted.

Step 1g Set file locations of the elevation database(s) source. First set the format of the database, SRTM, DTED, BIL, etc. Using the Browse button, set the correct file location in the computer where your database map files are stored.

The first line becomes the first option where the program will look for elevation data. The second line is the second option. One way of operating uses SRTM as the first option and DTED as the backup. More than 3 different elevation databases is probably overkill.

Obviously, the location you are on the earth may govern what computer mapping data is available for elevation data. SRTM is probably the most universal.

Step 1h Ensure “ignore missing files” is checked. There are holes and missing spots in elevation databases. If the program encounters one of these holes, execution will stop.

Step 1i Extract the elevation map. An elevation map will be displayed based on the input parameters and location supplied. Radio coverage will be overlaid on top of this map.

Find Peak and Low Elevation

A convenient feature offered on any map is to find the highest elevation point. Under “View” “Find peak elevation” or “ctrl f”. The cursor will be set to the highest elevation value on the map. This may be useful for radio site selection.

A similar feature allows finding the lowest elevation on the displayed map. Under “View” “Find lowest elevation”.

Network

A Network is the overall collection point for the base stations, mobiles, handhelds, etc. within a radio group. For each single or combined site coverage plot, all pieces of the puzzle are collected together in a “Network”.

Each network can be thought of as a coverage “Project”, possibly in a different geographic area or for a different client or customer.

If, for example, coverage of 5 repeaters in a city will be plotted, all must be defined and be members of the same common “Network”.

The Network defines the frequency band for radio coverage. If a coverage plot is required for both a VHF and UHF system, they must be defined as different Networks; each network defined as a different frequency band.

Note that you may use the same “units”, base stations, mobiles and handhelds in these different networks. It is quite possible to name Net 1 as “VHF” and Net 2 as “UHF”. These can be used to provide coverage maps for different frequency bands for the same area and using the same mobile or base station units to show coverage.

A mobile radio unit, for example, may have the same power output and receiver sensitivity at VHF and UHF frequencies, however, the antenna and feed line loss will be different.

Step 2 Create a New Network – defines the database sizes and quantities available for the completely New Network. Defaults are:

Nets	25
Units	50
Systems	25

These sizes are defined when a Network is created. Default numbers are large enough for most applications, however, there are always exceptions. If more components, base stations, mobiles etc. are required, it must be defined at this stage.

If a Network has already been created, it may be opened using “Open Network”. If changing coverage areas or moving to another coverage project, opening a new network will change to the next project.

Changing and viewing Networks

Open ‘Tools’ and click on ‘Network Manager’. Networks, Systems and Units can all be viewed in this window. The relationship between the Network, System(s) and Unit(s) can be viewed, i.e. the members of a given network are shown in a table.

Example, for a defined VHF network, specific Systems and Units are associated with that specific Network.

Other Networks may have other Systems and other Units associated with them.

This is useful when checking for errors. It is easy to determine from this Network Manager that a Unit, defined as a VHF Mobile radio is actually associated with a System called a UHF base station, leading to an error in coverage area.

At the top of the Network Manager screen is the maximum number of Networks, Systems and Units defined in the current Network File.

If more Networks, Systems or Units are required, the maximum numbers can be redefined. Enter a corrected number in the appropriate box and click on “Apply”.

Network Properties

Step 3 Open Network Properties and begin defining and entering data to the one or more nets. Click on “Parameters” to access the nets.

Step 3a Input parameters for each net. Change the name of the net to the specifics of that particular coverage plot e.g. “VHF” or the overall name of the group of repeaters, customer or user.

Step 3b Enter the frequency range in MegaHertz. Note that 2.4 or 5.8 GHz systems should be entered as “2400” or “5800” respectively. The program mathematics operates using MHz.

Step 3c Enter polarization – polarization does affect coverage slightly and must be entered as the correct value.

Step 3d Mode of Variability – This refers to probability and fade margin. The Radio Mobile program defaults to 50% reliability of coverage. Depending on the service that uses this radio system, reliability can be specified as a higher number, with correspondingly small coverage areas.

Step 3e Select “Mobile” and change parameters for % of time and % of situations accordingly. Both parameters should be set to the same percentage. The percentage refers to fade margins described earlier.

E.g. Standard Commercial Radio Service is acceptable at 50%. Ambulance or Fire Service should increase this number to 90% and possibly higher. Numbers below 50% may give a coverage plot that is overly unrealistic and may require a handheld user to “pick a site” for consistent communication.

Step 3f Additional Loss – Can be added if operating inside a dense city or dense forest. This is partly open to judgement of operating parameters. Dense cities include Toronto, Montreal, Vancouver or Calgary. Density of the city is related to the number of tall buildings around a transmitter site. A smaller centre will have less building density and correspondingly smaller effect. The city parameter adds loss for buildings that are not on topographic maps, however, will reduce coverage in the downtown city core, as would be expected.

Forest increases humidity (deciduous trees) and/or becomes an obstruction (coniferous trees). A high density of trees around a radio site will reduce coverage if radio waves must travel through trees between transmitter and receiver. If the antenna is installed on a tower that is taller than the surrounding trees, effect will be minimal.

However, as radio waves travel and get closer to the ground as the earth bends, they begin to go through trees and are attenuated. If trees are known to exist, it is best to include them when performing a coverage calculation.

Note that deciduous trees only affect coverage when there are leaves on the trees. In winter, coverage will improve in a deciduous forest. Remember that leaves reappear in the spring, again reducing coverage.

Specific example, pine tree needles are about the same wavelength as 850 MHz cellular signal frequencies. There is a significant decrease in expected cellular coverage in a pine forest that was discovered in the early days of cellular telephones.

Step 3g Surface Conductivity, Ground conductivity and Relative Ground Permittivity are defaults and are applicable to most of Canada. Exceptions are coastal regions, complete over water paths or in the Arctic. The Geological Survey of Canada is a good source for these numbers if producing coverage maps for these areas.

Step 3h Climate – Most of Canada is “Continental Temperate”. If coverage is in a maritime area, desert, Arctic or high humidity equatorial region, select the correct option.

Topology

Topology refers to the overall system layout and communication methods and architecture of a radio network.

Voice networks are expected to transmit messages so that others can hear them the first time. Repeat transmissions are used in the real world, simply because a user requests a repeat voice transmission. It is normally expected that a voice message is transmitted only once.

Voice communication is similar to being in a very noisy room, trying to carry on a conversation. If a person constantly has to repeat a statement because it cannot be heard above the noise in the room, communication is not reliable.

Computers, on the other hand, do not care about repeat message transmission. Until a message is received with no errors, a computer can ask for a message re transmission as many time as required to “get the message through”.

There are 2 other topology methods available within Radio Mobile.

Data Net, Star Topology has 1 master station communicating with several distant outstations. Outstations are “slaves” and only respond when information is requested from them. They cannot initiate a message on their own. Some data transmission protocols have available a Report By Exception (RBE) mode, that allows a slave station to originate a message. Communication is usually polled by the master station.

The biggest thing to keep in mind is that there is no collision detection or “traffic cop” maintaining order among message traffic. If a collision occurs, a message

will be corrupted and the Master station has to poll all the outstations to find out any missed message traffic.

Data Net, Cluster (Node/Terminal) is similar to an Ethernet network with routers. Essentially, any radio unit is assumed to be capable of communicating with any other radio unit. A node in the system can act as a repeater when necessary. Messages are addressed and rely on a network to get a message through using any available nodes.

Radio Mobile will calculate paths, using as much iteration as necessary, to find the shortest successful path between units. If no path is found after the maximum number of iterations is reached, a link will be shown in red.

Step 4 Select the radio network technology being used.

- Voice Net
- Data Net, Star topology
- Data Net, Cluster

Membership

Membership defines 2 parameters.

First, it defines all the active units that are part of a specific network. Place a check mark in the active units for this particular calculation. This is useful if a coverage plot is required plus or minus one or more specific sites. It allows the difference in coverage area to be displayed plus or minus 1 or more sites simply by checking or not checking the sites within a network.

Each network defines a frequency band. If two different networks are defined, for example, one for VHF, the second for UHF multiple coverage maps can be created, one for each band or network.

Ensure that the correct Units are selected as members of the correct Network.

Second, membership identifies the System associated with each unit. A system contains the specific operating parameters for a unit. A system specifies Transmit power, receiver sensitivity, transmission line loss, antenna type, gain and height.

Each unit must have an associated System, defining the complete operating parameters for that unit.

As an example, VHF and UHF radios have different operating parameters, antenna gains, cable losses etc. and therefore must be defined as different “Systems”.

Step 5 Define the membership of various units within each network. It is best to work on 1 network at a time. Select a network and check off the units that are members of that network.

Step 5a Define the communication relationship for each radio unit. The section allows for activating various radios and sites within a network, depending on the coverage plot and calculation required. Each active “unit” must have a checkmark.

Note that it is often wanted to have a coverage plot of mobile coverage and handheld coverage. If a mobile and handheld unit are defined, coverage can be plotted by checking the mobile unit as “active” and producing a mobile coverage plot. Then uncheck the mobile unit, check a handheld unit as “active” and a coverage plot for a handheld can be calculated and displayed.

Coverage may be shown as originating from a base station or repeater transmitter site and a mobile or handheld radio as the receiver. A reverse calculation can also be performed using the base station as the receiver and the mobile or handheld radio as the transmitter site.

This is useful when balancing “talk out” with “talk in” capability.

Step 5b Define repeater radio units as “Command”.

Step 5c Define mobiles, handhelds and fixed base stations that communicate with repeaters as “Subordinate”

Step 5d Define data repeaters in a mesh data network as “rebroadcast”.

Step 5e Place check marks in the active units that are being used for coverage calculations. Any unit not checked as being “active” in this screen will not be calculated as an active site. Note that a unit may appear on the map as a reference location point, however, it may not be used for calculations.

Step 5f Define the system to be used for each radio unit. Systems can be named the same as a radio unit so that it is easier to relate the two.

Step 5g Define the antenna height, if it is different than as specified by the system parameter. Antenna height is usually defined as part of system parameters, however, an override is available here, if required. It is

sometimes desired to plot the coverage from a site using several antenna heights. The override feature can easily be used for each of these heights.

Systems

A “System” defines the specific operating parameters for a given radio unit. Operating parameters include:

- Transmitter power output,
- Receiver sensitivity and threshold level
- Antenna type
- Antenna gain
- Antenna pattern
- Feed line and other losses

It is easiest to change the default system name to a system named for each associated radio unit. Radios may have the same power output; however, antenna height, gain, cable loss, multicoupler, duplexer and filter loss may be different for each radio unit. Therefore, a specific system or multiple system sets of parameters may be defined for each radio unit.

Mobile and handheld radio units have different parameters. Handhelds have a lower antenna gain and no feed line loss. Mobile radios may have a $\frac{1}{4}$ wave antenna, a $\frac{5}{8}$ or a higher gain collinear antenna.

Cable loss for all systems will vary with frequency of operation.

Step 6 The system variables define the operating parameters for each radio unit in the network. This includes base stations, repeaters, mobiles, handhelds, etc.

Step 6a Change the System name to correspond with the associated radio unit.

Step 6b Enter transmit power output in Watts or dBm. The corresponding value will be automatically calculated.

Step 6c Enter receiver threshold sensitivity in either μV or dBm. The corresponding value will be automatically calculated.

Step 6d Enter total feed line loss between transmitter and antenna. Remember to include:

- Coaxial cable loss – varies with frequency and length of cable

- Duplexer used
- Multicoupler if used
- Any additional filters used that may be in line between transmitter or receiver and antenna
- Connectors – for type ‘N’ connectors, 0.5 dB is typical per connector. UHF connectors have higher loss; include 1.0 dB each for these connectors.

Step 6e Antenna type – enter the type of antenna used. Several types are available from the library in Radio Mobile. Omni antennas have a perfectly circular pattern. Cardioid and ellipse antennas better represent the usual 210C4 or 310C4 offset dipole antennas used for VHF and UHF systems. Other directional antennas are available when required.

Step 6f Antenna gain is available from the manufacturer. VHF and UHF systems usually specify antenna gain in dBd (gain relative to a dipole). Microwave and spread spectrum systems usually specify gain as dBi (gain relative to an isotropic radiator). Ensure the correct field and value are entered; the corresponding gain value will be automatically calculated.

Step 6g Enter antenna height in metres.

Step 6h Additional cable loss may be added if not included in the line loss field. Remember this cable loss is entered as dB/m and will be multiplied by antenna height to determine total cable loss.

Step 6i System data can be added to or removed from the Radio Mobile system database. If multiple systems are calculated, with similar system parameters, the system file can be stored in the program library for later use.

Style

Style defines the way a coverage plot is presented.

Coverage can be shown using 2 methods. Coverage can be shown using a pass/fail criteria, based on receiver threshold (sensitivity) or it can be shown using multiple colours (referred to as “rainbow” in the program) showing the variation of calculated signal levels around the map. Actual method is selected in the program as part of the input parameters before calculating radio coverage.

The Style box is for use with the pass/fail coverage criteria described below.

Step 7 Select method of showing “Line of Sight” coverage – 2 ray method (using 2 lines).

Step 7a Select the pass/fail criteria for coverage display. Program default is coverage greater or less than 3 dB different than receiver threshold.

As an example, if receiver threshold is -90 dBm, then,

- Signals larger than -87 dBm (-90 +3 dB) are shown in green
- Signals between -87 dBm (-90 +3 dB) and -93 dBm (-90 -3 dB) are shown in yellow
- Signals less than -93 dBm are shown in red

The 3 colours can be individually turned “on” or “off”.

Step 7b The 3 dB criteria can be modified to any value required. Set the difference in signal level from the receiver threshold. It can be set to any number from the 3 dB default.

Step 7c When finished entering all these parameters, click on “OK” to close the Network Properties window.

Units

A “Unit” is a radio. All base stations, repeaters, mobile or handheld radios are referred to as a “Unit” by the program.

Unit labels default to Unit 1, Unit 2, etc. When defining the various units for a specific application, change the name to a site name, “base station”, “mobile”, “handheld”, etc.

Radio Mobile calculates using latitude and longitude as positive and negative numbers. Anytime latitude and longitude locations are entered, there is a box to allow changing to the correct hemisphere of the world. There is a box in the Latitude column that says “N”. Click on the box, it will be changed to “S”.

Longitude works similarly. A box displays “E”. Click on the box; it will change to “W”.

Latitudes and Longitudes continue to be displayed as plus (+) and minus (-) numbers. Ensure the correct hemisphere is selected.

Radio mobile uses the convention:

- North Latitude is positive (+)
- East Longitude is positive (+)
- South Latitude is negative (-)

West Longitude is negative (-)

Step 8 Open “File”, Unit Properties Menu.

Step 8a Change the label of the various units, 1, 2, 3, etc. to identify the various units that are in the radio network. Names can be as simple as “base station”, mobile, etc., or they can be site names of repeaters. Names should be unique and define the function of each radio unit.

Elevation of the radio unit will be automatically filled from the terrain maps once the location of the unit is set and the map is defined.

Step 8b Position of any radio unit can be copied and pasted to a new radio unit. Use the “copy” and “paste” icons to do this.

Step 8c Specify the location of each unit. There are 5 ways to define the location of a unit.

- Enter Latitude and Longitude directly – if the Latitude and Longitude is known, they can be directly entered. Ensure that lat and long is entered as either north or south latitude and east or west longitude.
- Place unit at cursor position – when a map is extracted from the database, the cursor may click and identify a position anywhere on that map. Any unit can be defined at the location of this cursor position. This is handy if a mobile unit is simply represented someplace on the map.

The remaining 3 options assume that a unit has a defined location by one of the 2 methods above.

- Place cursor at unit position – if the unit already has a defined location, the cursor can be moved to that unit location.
- Add unit to cities.dat – Radio Mobile has a database of cities. The location of any unit can be added to this database.
- Get unit from cities.dat – A unit can be located at any city in the database, including previously stored unit locations.

Step 8d Style refers to the label and icon identifying the specific unit.

- **Enabled** specifies whether or not the radio unit will be displayed on the map.
- **Transparent** makes the text label transparent so that other details can be read through the printing. Careful selection of colours will allow the label to continue to be displayed in readable format.
- **No Label** turns off the label text entirely.

- **Left, Centre and Right** move the text label in relation to the icon.
- **Back colour** is the background colour for the text label.
- **Fore colour** is the print colour for the text label.
- The slider at the bottom allows changing the size of the icon on the map.
- The small + symbol to the right of the slider allows the icon to be changed to a different icon or picture. The icon can be changed to be a car (mobile), handheld radio or numerous other icons.

Step 8e Buttons to the right control the display and order of radio units, sort the list, etc.

Note that once units are shown on a map, double clicking on any displayed unit will bring up the Unit Properties menu and changes can be made to each unit if required.

Any radio unit can be displayed on a map or coverage area by clicking on “View” and “show networks”. Three options are presented,

- “All” displays all units and the links between them.
- “Units” shows only the units.
- “Lines” shows the lines linking units together.

Step 8f When unit properties have been defined, click “OK” to close the Unit Properties window.

Showing Units and Links

After the Network, Systems and Units are defined and the map extracted, they should be displayed on the map to verify that the map is the correct size for the units within the coverage area.

Click “View”, “Show Networks”. Three options are offered.

All – Shows both the units and links connecting all enabled units together.

Units – Shows the units as they are positioned on the portion of the map shown. Note that if the map area was originally defined as too small for the defined units, units that are “off the map” will not be displayed. Be aware that you may have to use horizontal and vertical scroll bars to see the entire map and all of the units.

Note that under Unit Properties, it is possible to “enable” a unit. Removing the checkmark disables that unit for calculations and coverage.

Again, this is useful, if different units have been defined, for VHF and UHF systems. Different mobile radios (Units) may have been defined, each having the correct antenna gain, cable loss and radio parameters for the respective systems.

Lines – Shows links only between all enabled units.

Producing a Coverage Map

The map displayed is an elevation map. Next step is to overlay radio coverage on top of that map.

Elevation maps show elevation using a rainbow colour scale. When coverage is plotted, the 2 colour scales will get mixed up and colours showing elevation and coverage cannot be differentiated.

Two choices here.

The program has the ability to change the map to a “grey scale” and will automatically request this change before calculating radio coverage. It is best to show elevation in grey if rainbow coverage is requested. Coverage signal levels can then use the rainbow of colours to show signal levels, rather than elevation.

If coverage is plotted using pass/fail criteria and a specific defined signal level, elevation and coverage colours will not be “mixed up”, as coverage will be shown as a single colour only.

Grey Scale

When the program requests a change to the grey scale, it may or may not produce a useable result. The grey may hide some details and not display others in a manner that is visible and useable.

The grey scale can be changed and modified by changing the contrast, brightness and illumination source. This may take some experimentation, however, will eventually produce a better result.

Step 9 modify the grey scale parameters. Under the File menu, click Picture Properties. The 3 main parameters that can be changed are contrast, brightness and light azimuth.

Contrast and brightness are similar to setting parameters on a black and white picture.

Light azimuth is the direction of illumination by a virtual sun. Shadows on the black and white image can be moved to suit the overall map display by changing the azimuth of the virtual light source.

All of these may take some experimentation, depending on the terrain and parameters of the specific map.

The picture defaults to a grey scale so that coverage may use the colour rainbow to display coverage. Elevation can be displayed as a colour rainbow if coverage is displayed as a solid colour overlaid on the map.

Other Display Options

There are numerous other display options that may be changed using this screen. Experiment with the program and its display to produce what is wanted.

- Cities can be displayed.
- Elevation can be changed back to the rainbow display.
- Elevation contours can be added to the map at various intervals, either 10 m or 30 m contours can be shown.
- Stereo display is more for cartographers examining a printed map with stereo glasses to show a 3D image.

Add Radio Coverage

Step 10 Select Tools, Radio Coverage and select either “Single Polar” or “Combined Cartesian”. First, check if the “Draw” option is available as an operating button. If it is greyed out, one of the input parameters is missing, a unit is not “enabled” or membership is not correctly defined. Coverage cannot be calculated until the error is found and corrected.

Step 10a Select a mobile unit. This is where coverage can be shown for a defined mobile unit, or a defined handheld unit.

Step 10b Select a Network. Here is where different networks for VHF or UHF coverage can be selected.

Polar Coverage

Step 11 Two options are available for coverage calculation. Note that coverage will be sequentially calculated for each base station unit selected, defined as “Command” and “turned on” in the Membership menu. This is

often a reason why the “Draw” option may be greyed out, the correct base station is not selected. For coverage to be calculated, each unit in the calculation must be defined as “enabled” under “Unit Properties”.

Step 11a Single polar coverage calculates coverage using radial lines centred on each selected base station. As the distance from the base station increases, the distance between radial lines increases and resolution is reduced. This coverage calculation is faster to perform, but resolution is reduced at the extremities of the coverage plot.

Combined Cartesian coverage calculates signal levels using an X-Y coordinate system. Resolution is the same all over the map, however, the calculation process takes significantly longer.

Polar coverage can be used for a “quick and dirty” plot, Combined Cartesian can be used for the detailed and final map.

Step 11b Select the link direction. Either plot coverage from base station transmitter to mobile receiver or from mobile transmitter back to the base station. The worst case of either direction can also be selected. See description under “Other notes about Coverage Plots”.

Step 11c Select the type of plot. Contour line will show a contour for a specific signal level. This contour line surrounds the coverage area greater than the level specified in the Threshold display field.

“Fill” fills in the successful coverage area based on pass/fail coverage discussed earlier. Acceptable coverage is shown in yellow and no coverage is shown in red. (Default settings). Fill colour can be changed by clicking on the “Color” button.

Step 11d Select threshold display type. Four options are offered:

- S-Unit – may use the IARU Region 1 standard values. Note that S-Units can be changed under the Options menu to Radio Mobile default values, or specific criteria set can be programmed to calibrate your own “S-meter”.
- dBm, μV are conventional radio coverage parameters used in industry. Use the boxes to the right to set the range of values displayed by the coverage plot.
Note that receivers for spread spectrum and microwave radios are usually specified in dBm, while mobile and handheld radios are usually specified in μV . Select a coverage sensitivity parameter that relates to the coverage plot required.

- dB μ V/m are typically used to specify broadcast contours from either a Broadcast Radio or a television station. Sometimes linear values of μ V/m are used.

Step 11e select the length of radials used for coverage calculation. The program will calculate coverage along the length of each of these radial lines. They may be selected to be the same length as can be displayed on the map, or they may be shorter, allowing display of several repeaters on the same map.

Step 11f select the azimuth for radials. 360° will give a complete circle. Use either 0.1 ° or 0.5° spacing for radial angular calculation. The more radials and smaller the angle between them, the longer the plot will take.

Step 11g Antenna height at the central station can be changed, or the antenna programmed in the System associated with each radio unit may be used. Note that changing it here will change the antennas for all sites. Changing and selecting antennas as part of a System for each radio unit allows different antennas to be used at each site. Useful only when all antennas at all sites are the same.

Step 11h Check “Draw” and the antenna pattern will be drawn in its own window. This is simply to check what is being used for antenna pattern. Close the antenna pattern window before proceeding.

Combined Cartesian

Coverage using “Combined Cartesian” uses an X-Y method of calculating coverage. Advantage of this is that resolution of coverage plots does not change. Disadvantage is that it takes longer to produce the coverage plot.

Similar input parameters must be used as with Single Polar Coverage.

Step 12 Select the Fixed radio units that will be used to provide the combined radio coverage. Coverage will be sequentially calculated for each of the unit sites specified as “Command” and checked off as “active” units.

Antenna patterns for each base station site are set to their default values from the system parameters; they can be changed here if desired for each individual base station.

The antenna pattern can be drawn in a separate window, to see what pattern is being used.

Step 12a Select mobile unit. This could be a previously defined mobile radio unit or handheld radio unit.

Step 12b Select the network. This can be a previously defined VHF or UHF network.

Step 12c uncheck the “use network antenna” if antenna settings are to be modified, otherwise the program uses antenna pattern from previously programmed system parameters.

Step 12d select link direction, either from base to mobile (mobile receive) or from mobile to base (mobile transmit).

Step 12e Select signal levels to plot. As before, signal levels can be set to 4 options.

- S-Unit – may use the IARU Region 1 standard values. Note that S-Units can be changed under the Options menu to Radio Mobile default values, or specific criteria set can be programmed to calibrate your own “S-meter”.
- dBm, μV are conventional radio coverage parameters used in industry. Use the boxes to the right to set the range of values displayed by the coverage plot.
- dB $\mu\text{V}/\text{m}$ are typically used to specify broadcast contours from either a radio or television station. Sometimes linear values of $\mu\text{V}/\text{m}$ are used.

Step 12f specify the range of signal levels in the units selected. Either a minimum level can be specified, or a range of values can be specified in the units chosen. If a range is wanted, check the box that allows a high range level to be specified. Enter this higher level in the units specified.

Step 12g specify the type of display required, either a pass/fail criteria (default) or rainbow that presents signal levels as a rainbow of colours. Pass/Fail criteria uses the minimum level specified in the “From” box.

Step 12h specify the resolution for the plot. The default is 5 pixels that gives a somewhat poor quality image, particularly in rainbow mode. Reduce this number to 1, 2 or 3 pixels to give a better quality image. Note that computer processing of the plot will take correspondingly longer to obtain a more detailed image.

How long? Depending on computer processing power, it can be up to an hour to obtain the plot output.

Other notes about Coverage Plots

1. **If using rainbow display** to present a range of signal levels, at the top left of any map is a legend showing the signal level and associated colour.
2. **A distance legend** can be placed on the map to assist with determining relative distance and map scale. Click 'Edit', 'Distance Scale' and select the position to place this scale. It can be placed on any of the 4 corners of the map.
3. **Map Corner Lat and Long** can be displayed on the picture. Select "Edit" and "Corner Coordinates". Each corner of the map will have the Lat and Long displayed, both in Degrees/Minutes/Seconds and Decimal Degrees.
4. **Link direction** – in several calculations, it is possible to specify "link direction". Coverage can be plotted from a repeater to a mobile or handheld or the reverse can be plotted, from mobile or handheld back to the repeater.

This direction calculation is used to balance "talk out" and "talk in" of a repeater station.

This is important and a useful comparison. If a radio system is designed so that mobiles and handhelds can receive a base or repeater, it is also important to ensure that the same mobiles and handhelds can "talk back" to the base receiver. Proper radio design includes analysis of the "talk back" path to more or less match signal received at a mobile or handheld from a repeater with signal received at the repeater from the same mobile or handheld radio.

There is little point to designing a system with good repeater coverage, if distant radio units cannot "talk back" to the repeater for communication with others within the repeater coverage area.

5. To show set coverage parameters, such as a contour at 5 μ V and 1 μ V, run the coverage calculation twice, each with a different threshold criteria. Specify a different colour for each plot and the coverage parameters will be overlaid on top of each other.

This may also be used to show handheld versus mobile coverage from the same transmitter site. Simply run the coverage plot using different radio units and systems for the same map. Select a different colour to show the different signal contour levels.

Combining with Geographic and/or Roadmap

Once the coverage map is developed, a geographic map can be combined with it to better show the coverage area and location.

Internet connected to the computer is required for this step. The program obtains map data from the Internet and must have the network available to obtain geographic data.

The various units and base stations can be added to the map at any time. Click on "View", "Show Networks" and select units or lines/links to be displayed.

If what is displayed is not what is wanted, 3 steps can be taken to start over and re calculate coverage.

1. File – Map Properties, extract a new elevation data map.
2. Tools – Radio coverage and replot the radio coverage.
3. Edit – Merge Pictures to add the geography to the coverage map.

Step 13 Select "Edit", "Merge Pictures".

The intent of this is to merge the coverage plot with a number of different map options from the Internet. Several commonly available maps are available and can be selected.

Step 13a choose the method of combining the coverage map with the geographic map. There are 4 options. The options refer to how the computer combines the maps mathematically.

- Copy
- Add
- Multiply
- Bitwise

This will take some experimentation. There are differences in display, however, they are dependent on location and maps selected. Experiment with several to obtain the desired output.

Hot Keys

A number of "Hot keys" are defined within Radio Mobile. Menus may continue to be used; however, the Hot Keys will access various locations in the program more quickly. A list of these hot keys follows.

F2 opens Radio Link.

F3 opens Polar coverage.
F4 opens Cartesian coverage.
F5 opens Find Best site.
F6 opens Route coverage.
F7 opens Merge pictures.
F9 opens Adjust map to picture/selection.
F11 opens Visual coverage.
F12 opens Visual horizon.

Point to Point Radio links

Another aspect of radio path propagation is a point to point link. These are used when linking repeaters together, for example. Usually different antennas and frequency band are used. Radio Mobile provides the ability to predict receive signal level of these point to point links.

Many of the sites will be common and can be used, however, frequency band and systems (gains and losses) will probably be different. If another network is specified and used, frequencies can be changed and additional systems can be defined for the point to point links, using the same Radio Unit locations.

Step 14 Input is virtually identical. A few changes should be made to separate these links from radio coverage.

Step 14a Identify a different 'Net' within the same Network. Set the correct frequency band for the point to point links.

Step 14b Radio Units may be the same.

Step 14c Define additional systems as antennas will probably be directional (different gain parameters and patterns) and therefore different for the point to point link.

Step 14d Select "File", "Network Properties". Click "Membership" and select the specific units at each end of the point to point link. Close Network Properties.

Step 14e Select "Tools", "Radio link". A point to point radio link screen is displayed.

The point to point link file can be reversed by clicking on "swap". It is recommended to look at any point to point link from both directions to determine if there are any obstructions that become significant in one direction and not the other.

Reading information across the top of the point to point link are several important parameters. They are identified and explained further here.

Azimuth	Calculated antenna azimuth from transmitter to receiver. Calculation is based on Latitude and Longitude of the 2 sites, specified under Unit Properties. Angle is calculated relative to True North.
Pathloss	Total pathloss between sites, in dB.
Elevation Angle	Angle that the signal leaves the transmit antenna. This number is useful for interference calculations later.
E-field	Calculated signal level in dB μ V/m. These E-field numbers are usually used for broadcast radio calculations and coverage plots.
Obstruction	Identifies the first obstruction the signal encounters. The first obstruction usually has the highest effect, reducing signal level on a point to point radio link.
Receive Level (dBm)	Receive signal calculated in dBm
Worst Fresnel	Lowest Fresnel Zone clearance calculated along with the Fresnel Zone number.
Receive Level (μ V)	Receive signal calculated in μ V.
Distance	Distance between transmitter and receiver site in kilometres.
Rx (relative)	Calculated signal level above receiver threshold. This number is essentially the fade margin of the path.

Exiting the Program

Each picture created showing a coverage plot can be saved in a number of formats. Select “File” and “Save Picture as”. Several formats are available for saving the picture file, including bitmap, JPG and TIFF. Others are also available.

When the initial network is created, Radio Mobile creates a directory on the computer for storage of coverage information relating to that network. It is best to continue saving files related to that user or geographic area in the same directory. They can be reused later or backed up to a storage device if required.

When exiting the program, there are 3 files that should be saved for next time. The program should request they be saved; however the 3 files are identified here.

Step 15 The program automatically saves 3 files, if they have not been saved previously. Manually saving allows creation of a new or separate directory for the particular coverage plot.

Step 15a Network file – ‘Save Networks’ or ‘Save Networks as’. File is *.net’

Step 15b Map file – ‘Save Map as’ – saves map data. File is *.map’

Step 15c Picture file – ‘Save Picture as’ – the combined output of coverage and geographic maps that were created using Radio Mobile. This picture may or may not have been calculated, depending on whether coverage calculations were completed. File can now be selected as several formats, including *.bmp or *.jpg.

Different coverage plots can be saved as different pictures in the same coverage directory. It is possible to plot VHF coverage, followed by a UHF coverage plot, provided the picture names are different.

Note that coverage plots are saved as pictures. They can be opened or viewed by any program that can read the image format of the coverage plot picture.

Summary

The Radio Mobile program is an extensive program for predicting radio coverage. This paper is meant to provide background information on radio coverage and describe how to “get started” with the program. There are many options within the program not covered by this article.

Once getting started with the program, the user is encouraged to experiment, use and learn more of these options and parameters.

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