Planning Wireless Broadband an Introduction SANOG 18

Table of Contents

Units We Use 4

- dB vs dBm 4
- More Resources 4

Link Budgeting 5

- Why budget 5
- What is a link budget 5
- Where is our energy 5
- Fade Margins 6
- Free Space Loss 6
- Our Formula 6
- Example - Point to Point Link 7
- How Can We Improve a Link 8
- Availability and Reliability 8
- Example Availability 10
- Line of Sight Analysis 10
    - Fresnel Zones 11
    - Fresnal Zone Example 11
- Planning Software 12
- More Resources 13

Designing a Power System 14

- Power Requirements 14
- How to find your power requirements 14

Storing Electricity 14

Example - Working Out Our Power Usage 15

Example - Working Out Storage Requirements 15

Units We Use

Understanding our units gives us a much better understanding of what we are dealing with. Many of the units we use in radio concern energy.

Unit	Short Form	What it Is
Joule	J	Energy
Watt	W	Power. The rate energy is consumed. 1 W = 1 J per second
Decibel	dB	A logarithmic representation of a unit. Often in radio we represent Watts or milliWatts in decibels (dBW or dBm)

dB vs dBm

The difference between dB and dBm can be confusing and they are often used interchangeably.

dBm is an absolute measure, it is directly related to a milliWatt. For example:

1 dBm = 1 milliwatt

12 dBm = 15.85 mW

dB is a ratio measure, so it applies to any absolute power. It's like multiplying the number. It can be like saying we lose 5% of the power, or we halve the power. 3dB in loss roughly equal to halving the power.

More Resources

http://en.wikipedia.org/wiki/DBm

http://en.wikipedia.org/wiki/Logarithmic_unit

http://www.wolframalpha.com/

Link Budgeting

Why budget

We do a link budget for the following reasons:

1. To ensure our link will operate at all
2. To estimate our link uptimes say on an annual basis
3. To understand if we need to change any components (e.g radio, antenna, cables)
4. To understand our full radio systems

What is a link budget

A link budget is effectively an energy budget. We are seeing ho much energy we lose through our radio system. If we lose too much energy the link will not operate or be unreliable. Many things contribute to the loss of energy across the system.

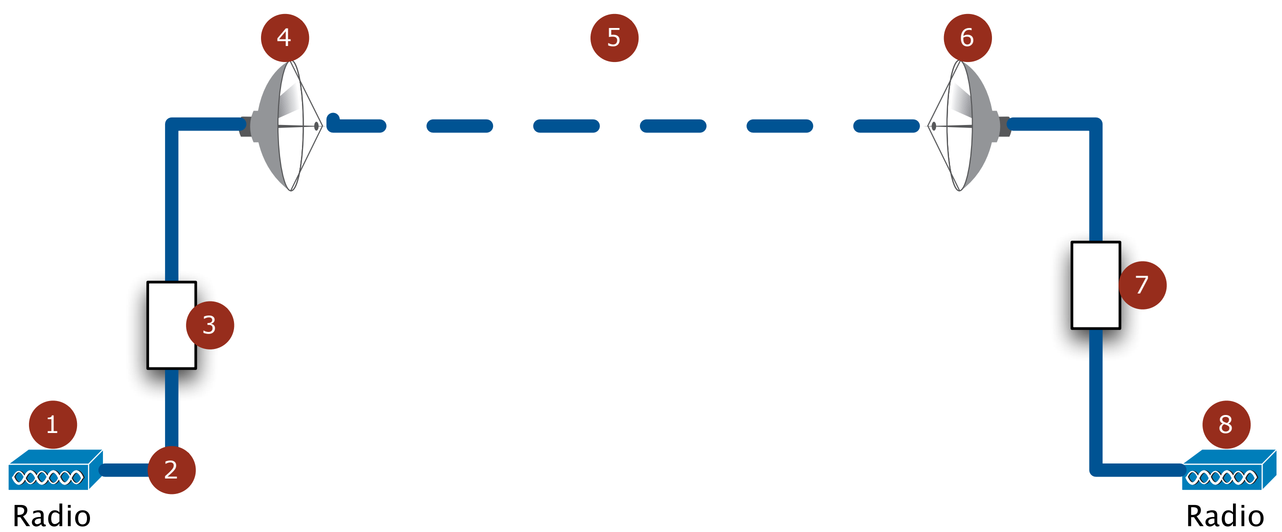
- Losses at connectors or lightning arrestors
- Losses through cables or waveguides
- Losses through the air due to distance
- Losses through the air due to atmospheric conditions
- Losses due to water in the system (e.g. moisture in cables)

We measure our energy in the system in Watts (W). To make life easier we represent watts logarithmically as decibels (dB), so decibels relative to a Watt becomes dBW and relative to a milliWatt becomes dBm.

Representing values using decibels makes it easier to work with numbers. We can use addition and subtraction rather than multiplication and division.

Where is our energy

Taking a very basic outline of a radio system. Energy losses are when the energy goes outside of the system. Energy itself cannot be created or destroyed.



1. The radio takes our energy and modulates it to carry information, we know the output from the radio in Watts, milliWatts, dBw or dBm.
2. The cables transfer the signal to the antenna, cables cause a loss of energy in the system as electrical energy is converted to heat or other forms of energy.
3. Connectors and lightning arrestors cause energy losses in the system.
4. Antennas focus our energy, they don't cause losses as such (their connectors might)
5. The air, energy is lost here as it is absorbed by the atmosphere. This is called the Free Space Loss.
6. Antennas focus our energy, they don't cause losses as such (their connectors might)
7. Connectors and lightning arrestors cause energy losses in the system.
8. The cables transfer the signal to the antenna, cables cause a loss of energy in the system as electrical energy is converted to heat or other forms of energy.
9. The radio receives the energy and demodulates it. The radio will have a threshold of energy it can make sense of.

Fade Margins

Fade margin is the left over energy in our system. It is our surplus energy. A level is required for a link to perform at a certain level of reliability. e.g. 99.99% or 99.9%.

Free Space Loss

Free-space path loss is proportional to the square of the distance between the transmitter and receiver, and also proportional to the square of the frequency of the radio signal.

$$\begin{aligned}
\mathrm{FSPL(dB)} &= 10\log_{10}\left(\left(\frac{4\pi}{c}df\right)^2\right) \\
&= 20\log_{10}\left(\frac{4\pi}{c}df\right) \\
&= 20\log_{10}(d) + 20\log_{10}(f) + 20\log_{10}\left(\frac{4\pi}{c}\right) \\
&= 20\log_{10}(d) + 20\log_{10}(f) - 147.55
\end{aligned}$$

LFS (dB) = 32.45 dB + 20*log[frequency(MHz)] + 20*log[distance(km)]

Our Formula

This is an example that applies to a low power system, we are using dBm (decibels relative to a milliWatt). For a higher power system we may use dBW.

Number	Component	Positive or Negative	Units	Where we get this number
1	Transmit Radio (Transmit power)	Positive	No units it is a ratio - dBm	From the radio specifications, can depend on settings. Could potentially be an amplifier
2	Cable	Negative	No units it is a ratio - dBm	From the cable specifications, generally represented as dBm/m. The longer the cable the more the loss.
3	Connector	Negative	No units it is a ratio - dBm	From the connector specifications. Some connectors are better than others. The more connectors the more loss. e.g 3 dBm per connector
4	Antenna	Positive	No units and called dBi	From the antenna specification. e.g 24 dBi
5	Free Space Loss	Negative	No units it is a ratio - dBm	From free space loss formula
6	Antenna	Positive	No units and called dBi	From the antenna specification. e.g 24 dBi
7	Connector	Negative	No units it is a ratio - dBm	From the connector specifications. Some connectors are better than others. The more connectors the more loss. e.g 3 dBm per connector
8	Receive Radio (receive sensitivity)	Positive	No units it is a ratio - dBm	From the radio specifications, can depend on settings. This is a receive sensitivity, not transmit now.

System Gain = 1+2+3+4+5+6+7

Fade Margin = System Gain - Receive Radio Sensitivity

Generally you would want your fade margin to be at least 20. Preferably 30+.

Example - Point to Point Link

- 34 km link with line of sight
- Using a motorola device with integrated antenna (no cable or connector loss)
- 23 dDm transmit power
- 25 dBm antenna gain
- 5.8 GHz (remember to convert MHz for our formula)
- -80 dBm Receive sensitivity

Free Space Loss

LFS (dB) = 32.45 dB + 20*log[frequency(MHz)] + 20*log[distance(km)]

=32.45 + 20*log(5800)+20*log(34)

=32.45 + 75.27 + 30.63

LFS(dB)=138.38

So

System Gain =

23 dBm + 25 dBi + 25 dBi - 138.8 dB = -65.8 dBm

Fade Margin = -80 - 65.8

= 14 dBm

This is less than 20, we would expect this link to be unreliable.

How Can We Improve a Link

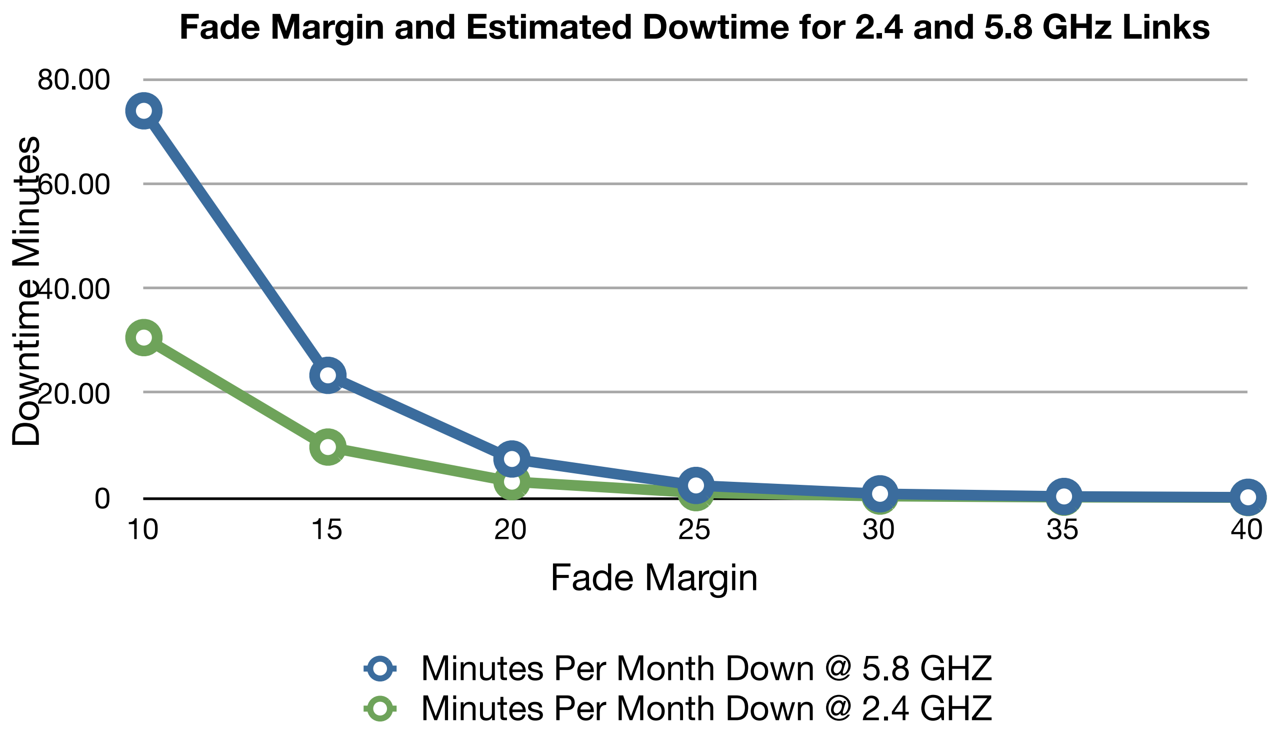
To improve a link we need to change one or some of the factors in the equation. We could do the following:

- Increase the transmit power (some radios may have this setting, some allow wireless cards to be changed, and inline amplifier could also be used)
- Increase the antenna gain
- Decrease cable losses (better cables will have lower loss but can be harder to source and are more expensive)
- Decrease connector losses (better connectors will have lower loss, but are more expensive)
- Shorten the link (decreases free space loss, an example of this might be using an intermediate linking point)
- Decrease the frequency (decreases free space loss)

Availability and Reliability

Availability and reliability is affected my many things, not just RF. Mechanical, power, security, electronics and many other factors affect reliability. Presented below is a formula for estimating the availability of a wireless link. The wireless can be affected by many different things, so this is not a comprehensive measure but useful for planning.

The diagram below shows how fade margin influences availability. This example is for a humid, mountainous region.



Uptime	Minutes Per Year Down	Minutes Per Month Down
99.00%	5,256	438.0
99.90%	526	43.8
99.99%	52.6	4.4
99.999%	5.3	0.4

Av = (1 – a x b x 10-5 x f/4 x d^3 x 10-FM/10) x 100%

Av = availability (uptime) expressed in percent

a = terrain roughness factor

b = climate factor

f = frequency in GHz

d = distance between sites in miles

FM = fade margin

Terrain Factors

4.0 For very smooth terrain, including over water

1.0 For average terrain, with some roughness

0.25 For mountainous, very rough, or very dry

Climate Factors

0.125 Dry

0.5 Humid

Example Availability

- Fade margin = 14 dBm (from above)
- Terrain = Mountainous so terrain factor = 0.25
- Climate = Humid so climate factor = 0.5
- 34 Km = 21.13 miles
- Frequency = 5.8GHz

Av = (1 – a x b x 10^-5 x f/4 x d^3 x 10^-FM/10) x 100%

=(1-0.25 x 0.5 x 10^-5 x 5.8/4 x 21.13^3 x 10^-14/10) x 100%

=(1- .25 x .5 x .00001 x 1.45 x 9434 x 10 ^-1.4) x 100%

= 99.93 % uptime

Looking at an estimate of downtime per month:

Assuming a 30 day month. 30 days x 24 hours x 60 minutes = 43,200 minutes a month

Downtime = 100% - 99.93% = 0.07%

Downtime = 0.07% x 43,200 = 30.24 minutes ==> say half an hour.

Please note - this works out downtime due to RF conditions, there are many other factors affecting the reliability of a radio site.

Line of Sight Analysis

Generally a link requires line of sight this is especially true for microwave (>1Ghz), there are some conditions where a link may work without line of sight, these are unusual and probably won't be encountered in most real world situations, they include:

- Lower frequencies which we would not typically use for broadband, although 900 MHz is sometimes used and can perform well without line of sight.
- Where you can use much higher powers
- Where you can use reflection to create a path

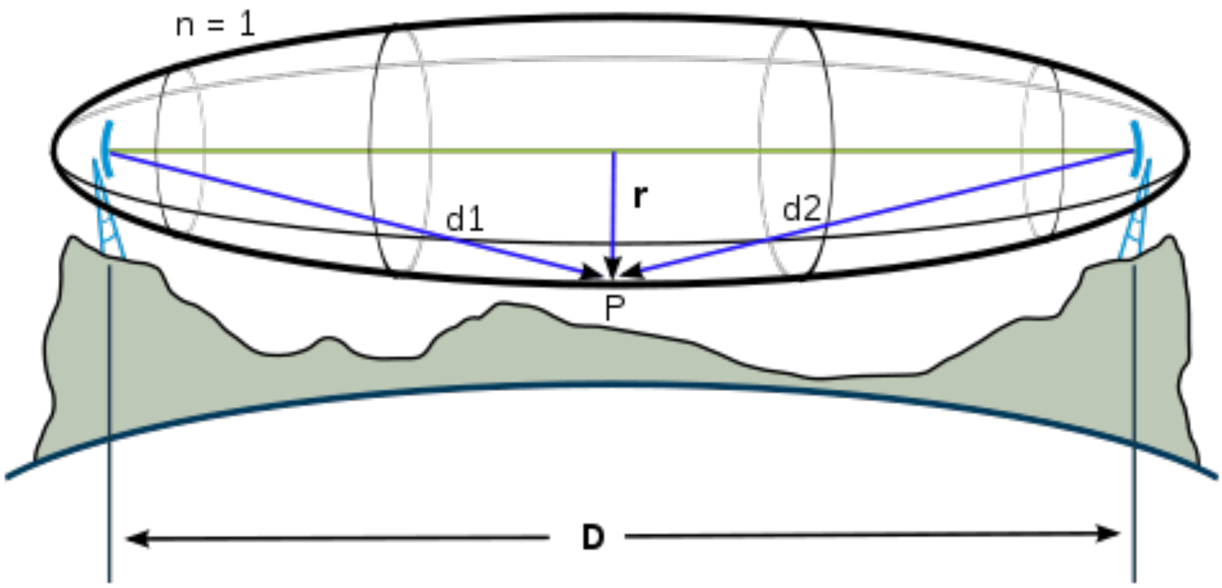
You can determine line of sight in a number of ways, there is no substitute for site visits to establish line of site, maps can lack the precision required. Some ways of establishing line of sight include:

- Taking elevations off a map and plotting the link in a spreadsheet
- Eyeballing with Google Earth in 3D mode
- Using specialist link planning software
- Using a telescope from a site
- Using a very high powered light from a site

Fresnel Zones

The fresnel zone is the area around the line of sight where the radio waves have dissipated. It means we cannot plan a link based exactly on a straight line but need to take account of fresnel zone clearance.

This is how we can visualise a fresnel zone:



http://de.wikipedia.org/wiki/Benutzer:Averse

In the above example the radius of the 1st fresnal zone is represented as r. A guideline is we don't want more that 20% of the fresnal zone obstructed, although up to 40% may be acceptable.

We can work the fresnal zone out in a number of ways. Below is a simplified way.

$$r = 8.657\sqrt{\frac{D}{f}}$$

Where

r = radius in metres

D = total distance in kilometres

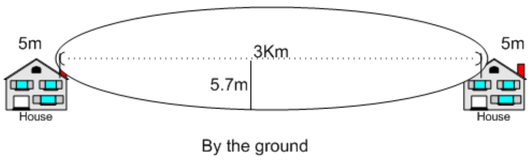
f = frequency transmitted in gigahertz.

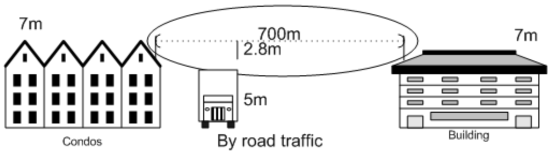
Fresnal Zone Example

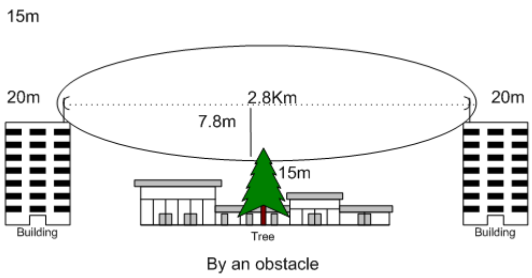
Looking at the first example in the following digram we will work out the following for a 5.8GHz link.

1) Is there fresnal zone obstruction and;

2) If there is, will the link still be likely to work







http://commons.wikimedia.org/wiki/User:Kgrr

Using our formula, we know the frequency is 5.8 Ghz and the distance is 3 km. First we need to work out where we want to measure along the path. Which is half way so we use 1.5 km.

r= sqrt(D/f)

r= sqrt(1.5/5.8)

r = 4.4 metres

In this case we would expect the link to happily work

Trying this at a different frequency, say 1.4 Ghz (L band).

r= sqrt(D/f)

r= sqrt(1.5/1.4)

r = 9 metres

We have 5 metres of clearance and this is well outside of the 20% threshold so we would expect to have some path interference.

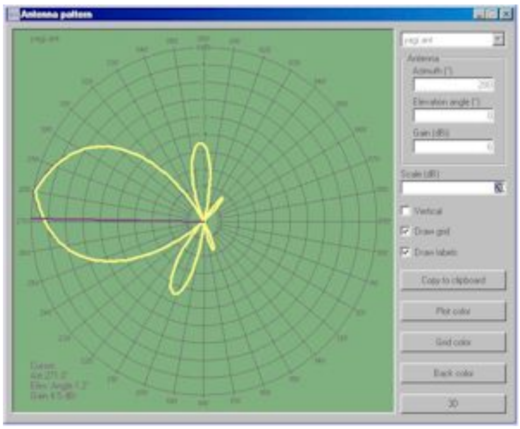
Planning Software

A lot of planning software is available, and tools as simple as Google Earth and Google Maps can be very useful. There is a lot of software available some free, some open source, some proprietary.

A useful tool can be RadioMobile and some discussion is given to it here.

http://www.cplus.org/rmw/english1.html

This is freeware and available for non-commercial and humanitarian use. It integrates with Google Earth and can be very useful. It allows for link planning an propagation modeling.



Base terrain data can be obtained from NASA.

http://asterweb.jpl.nasa.gov/gdem.asp

Instructions on how to integrate the data with RadioMobile can be found here:

http://www.ictworks.org/book/export/html/240

More Resources

http://www.softwright.com/faq/engineering/MICROWAVE%20SYSTEM%20EQUATIONS.html

http://setup-wireless.blogspot.com/2008/11/radio-frequency-mathematics.html

http://en.wikipedia.org/wiki/Path_loss

http://www.narte.org/n/212/Summer03Page10_13.pdf

http://en.wikipedia.org/wiki/Fresnel_zone

Designing a Power System

Power is often one of the major points of failure in a radio based Broadband network. When designing a radio system regardless of how it is powered you need to know:

1. The power requirements including any peak power requirements
2. How much energy you need to store
3. How you are acquiring your energy (e.g. mains power, solar, wind, hydro)

The requirements will differ from site to site.

Power Requirements

Things that can consume electricity on a radio site include:

- The radio equipment
- Monitoring equipment
- Environment control (fans etc..)

Don't forget to count everything.

How to find your power requirements

Power requirements can often be acquired from technical specifications of equipment suppliers, however sometimes these may represent an upper limit. A preferable way to understand the power a device consumes is to bench test it under load.

Bench testing under load means simulating a real world throughput and measuring the consumed power. This can be done simply by measuring the draw by putting a multi-meter inline.

Example

12 Volt (V) radio drawing 0.8 Amps (I)

$P = VI$

Power = 12 X 0.8

Power = 9.6 W

Equipment manufacturers do not necessarily assume their equipment will be deployed in a place where power may be a major limiting factor. It is often worthwhile bench testing your equipment.

Storing Electricity

The amount of electricity you store is dependent on how long of a period you need to get through where you cannot capture electricity. The units we quantify this with is Ampere hours (AH). Batteries storage capacity is measure in Ampere hours.

We need to store enough energy in the batteries it get through the period where we don't have electricity. Some things that affect this include.

- Cloud cover if using solar
- Load shedding and power cuts
- Lack of wind energy

To work out how much energy we need to store we need to know the following:

1. The length of time we may not have power (expressed in hours, minutes or days)
2. The energy usage of our site (expressed in Watts)
3. The system voltage (expressed in Volts)

Example - Working Out Our Power Usage

We will look at an example site using one point to point link in and an access radio with two point to multipoint links.

- 1 X 8 W point to point radio
- 1 access unit with two radios, 8W
- We have to get through 16 hours of load shedding, so we assume 24 to be safe.

Total power = 16W

We need to get through 24 hours @ 16 Watts.

We need to express the power and time as Watt hours or Kilowatt hours.

16 W x 24h = 384 Watt hours (Wh) or;

0.384 kilowatt hours (kWh)

- Watts are the rate at which we consume energy
- Watt hours are an absolute measure of how much energy we have consumed

Example - Working Out Storage Requirements

The information we need to work out storage requirements is:

- The system voltage. The system voltage refers to the voltage of the storage system.
- The system efficiency. 80% is a useful benchmark. Remember losses in conversion and inversion will happen.
- The Watt hours we require (Wh)

The formula for working out required storage is:

Storage Required (Ah) = Total Watt hours /(system voltage x efficiency)

Extending the above example we can work out the storage we require, that is the minimum size of the battery required.

- 0.384 kWh (note this is from above and what we need to store for one day)
- 12 V system
- 80% efficient

The formula for working out required storage is:

Storage Required (Ah) = Total Watt hours /(system voltage x efficiency)

Storage Required (Ah) = 384/(12x0.8)

Storage Required (Ah) = 40Ah @ 12 volts