Radio Link Calculation

Sebastian Büttrich, wire.less.dk

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Goals

- To introduce all the elements and tools that are needed to calculate a radio link
- To discuss each of these elements
- To enable us to evaluate results in close touch with reality

Table of Contents

- What is a link budget?
- Elements of a radio link
  - Transmitting side
  - Propagating side
  - Receiving side
- How to calculate a link budget

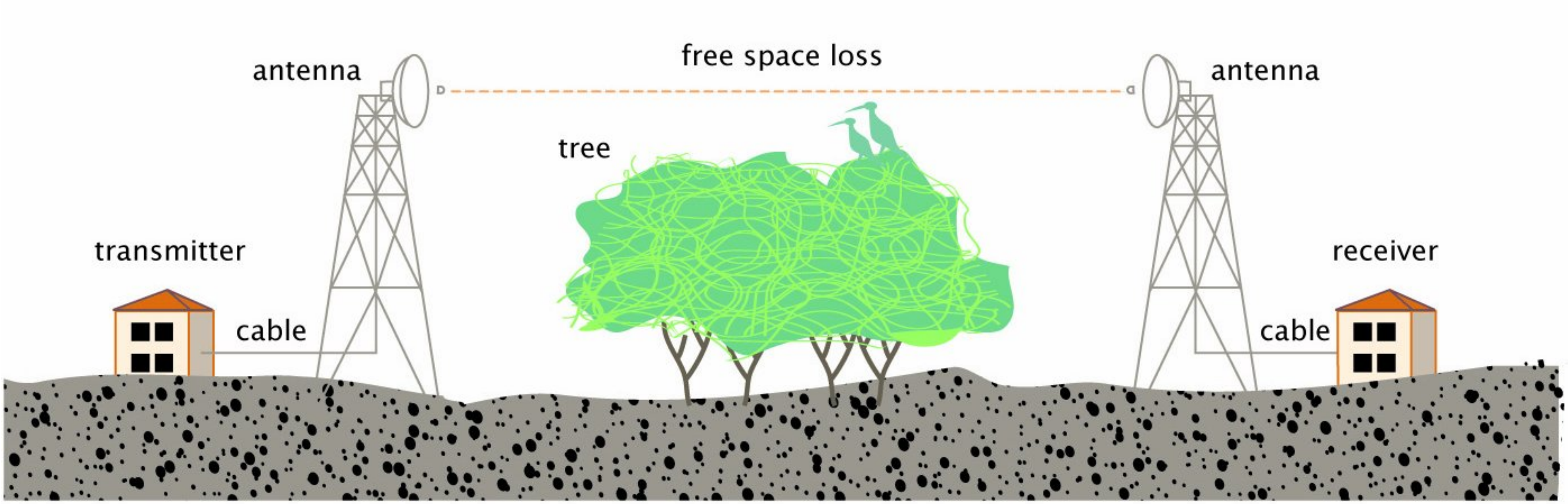
What is a Link Budget?

- The accounting of all of the gains and losses from transmitter to receiver.
- A good link budget is essential for a functioning link.
- Estimation of losses/gains in a radio link
  - Suitable design
  - Adequate choice of equipment

Elements of a Radio Link

- Transmitting side
  - Transmitting power, cable loss, antenna gain
- Propagating side
  - FS(P)L, Fresnel zone
- Receiving side
  - Antenna gain, cable loss, receiver sensibility

Elements of a Radio Link



Transmitting side   Free Space   Receiving side

Radio Link Equation

- + Transmitter power [dBm]
- - Cable TX loss [dB]
- + Antenna TX gain [dBi]
- - Free Space Path Loss [dB]
- + Antenna RX gain [dBi]
- - Cable RX loss [dB]
- = Margin - Receiver Sensitivity [dBm]

Transmit Power (Tx)

- The power output of the radio card.
  - The upper limit depends on regulatory limits.
- Typical value for 802.11b/2.4 GHz is

  20 dBm = 100 mW

Cable Loss

- Losses due to attenuation
- Antenna cable should be as short as possible
- Frequency dependent
- Check data sheets and verify
- Typical loss values range from 1 dB/m to < 0.1 dB/m
- The lower the loss, the more expensive the cable

Cable Loss

Cable type	*Loss [db/100m]*
RG 58	ca 80-100
RG 213	ca 50
LMR-200	50
LMR-400	22
Aircom plus	22
LMR-600	14
1/2” Flexline	12
7/8” Flexline	6,6
C2FCP	21
Heliax ½ “	12
Heliax 7/8”	7

Losses in Connectors

- Losses in connectors (≈0.25 dB per connector)
- Dependent on frequency and type of connector
- Losses in lightning arrestors (≈1 dB)

Amplifiers

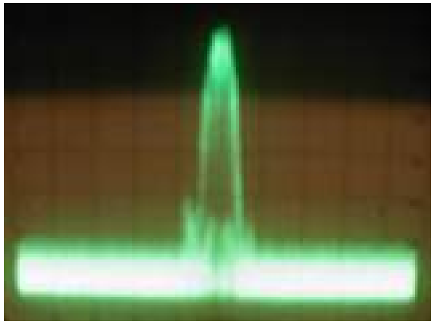
- May compensate for cable loss
- May change frequency characteristics and add noise
- Consider legal limits
- Intelligently optimized antennas and high receive sensitivity are better than brute force amplification

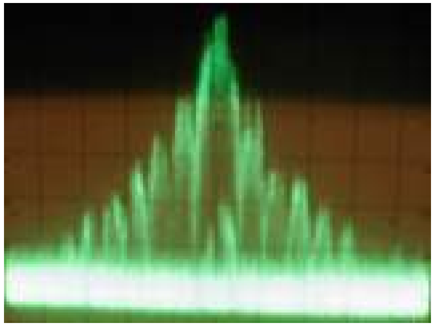
Amplifiers

What a (cheap) amplifier might do:

before

after





Antenna Transmitter Side

- Antenna gains range from
  - 2 dBi (simple integrated antenna)
  - 5 dBi (standard omni directional)
  - 8-20 dBi (panel/patch antennas)
  - 18-27 dBi (parabolic)
- Verify that you really get the nominal gain
  - Tilt losses, Polarization losses, etc.

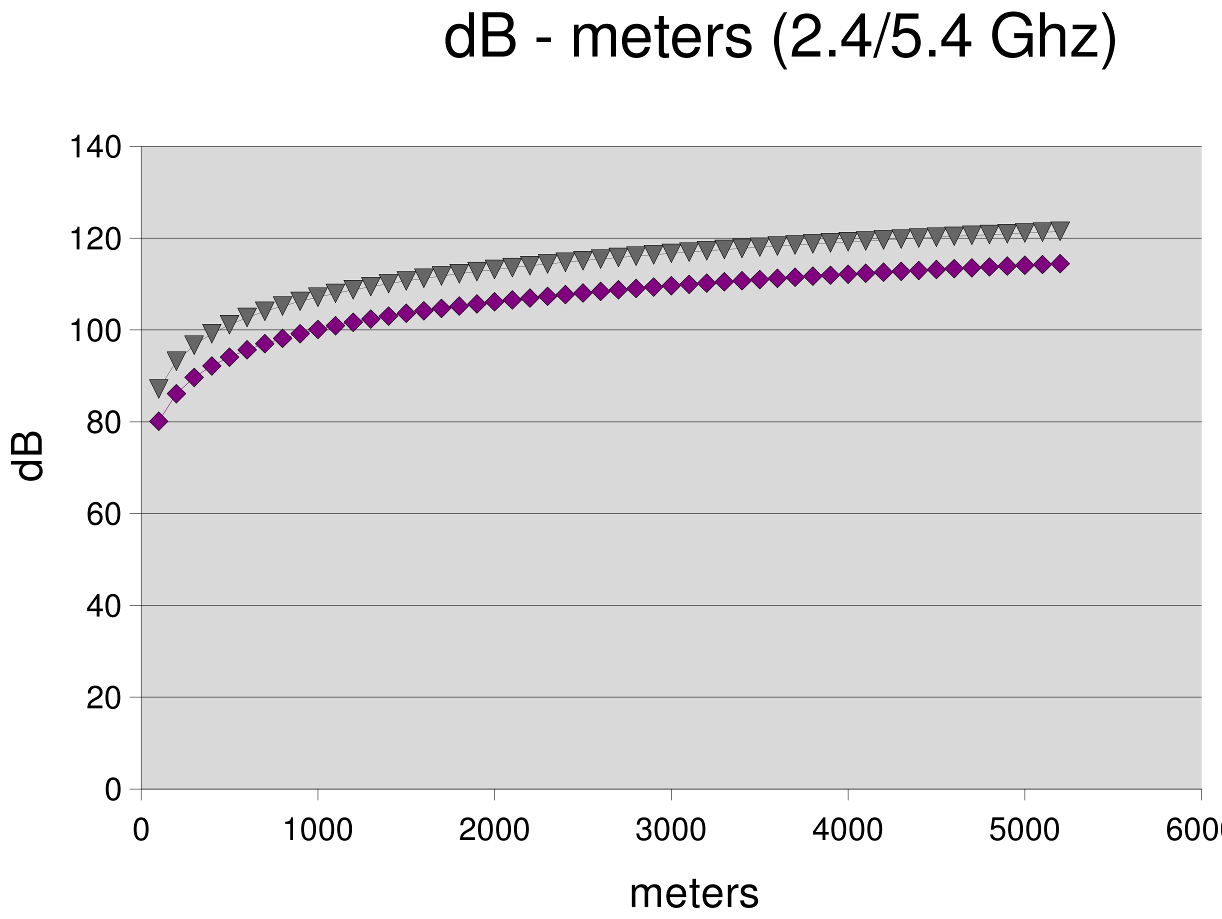
Free Space Loss

- Proportional to the square of the distance
- Proportional to the square of the radio frequency
- **FSL(dB) = 20log10(d) + 20log10(f) – 147.5**
- *d = distance [m]*
- *f = frequency [Hz]*
- *assuming isotropic antenna*

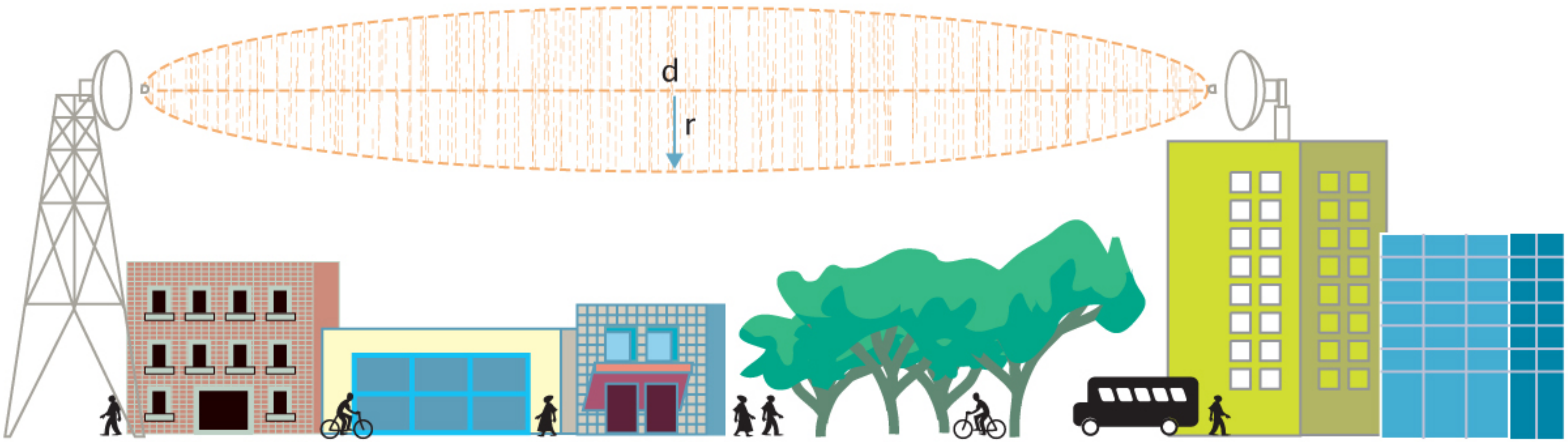
Free Space Loss

Distance [km]	***915 Mhz***	***2,4 Ghz***	***5,8GHz***
1	92 dB	100 dB	108 dB
10	112 dB	120 dB	128 dB
100	132 dB	140 dB	148 dB

Linear Approximation of FSL



Free Space Propagation: Fresnel zones



Free Space Propagation: Fresnel zones

- $$r = 17{,}32 * \sqrt{((d1 * d2)/(d * f))}$$
- d1= distance to obstacle from transmitter
- d2 = distance to obstacle from receiver
- d = distance [km]
- f= frequency [Ghz]
- r= radius [m]

Free Space Propagation: Fresnel zones

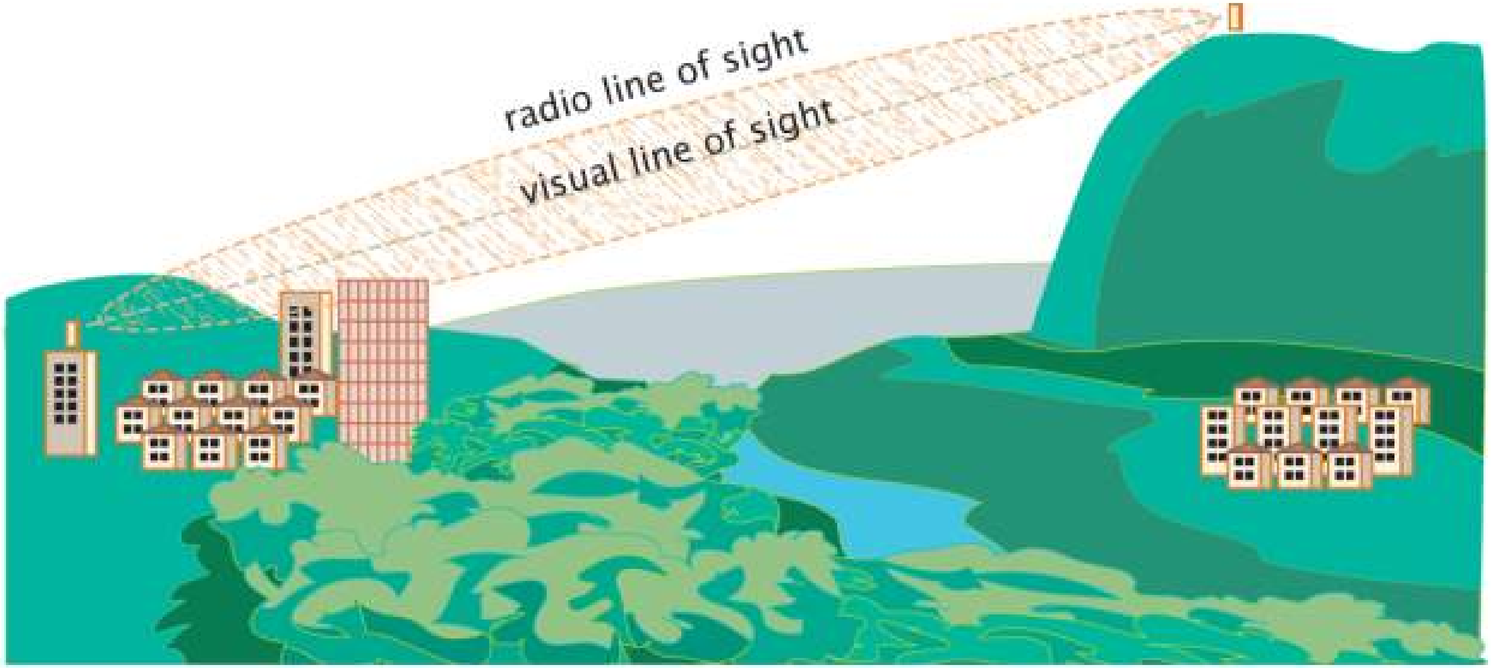
- Obstacle situated in the middle (d1=d2):

$$r = 17{,}32 * \sqrt{(d/4f)}$$

- The radius containing 60% of the total power:

$$r(60\ percent) = 10{,}4 * (d/4f)$$

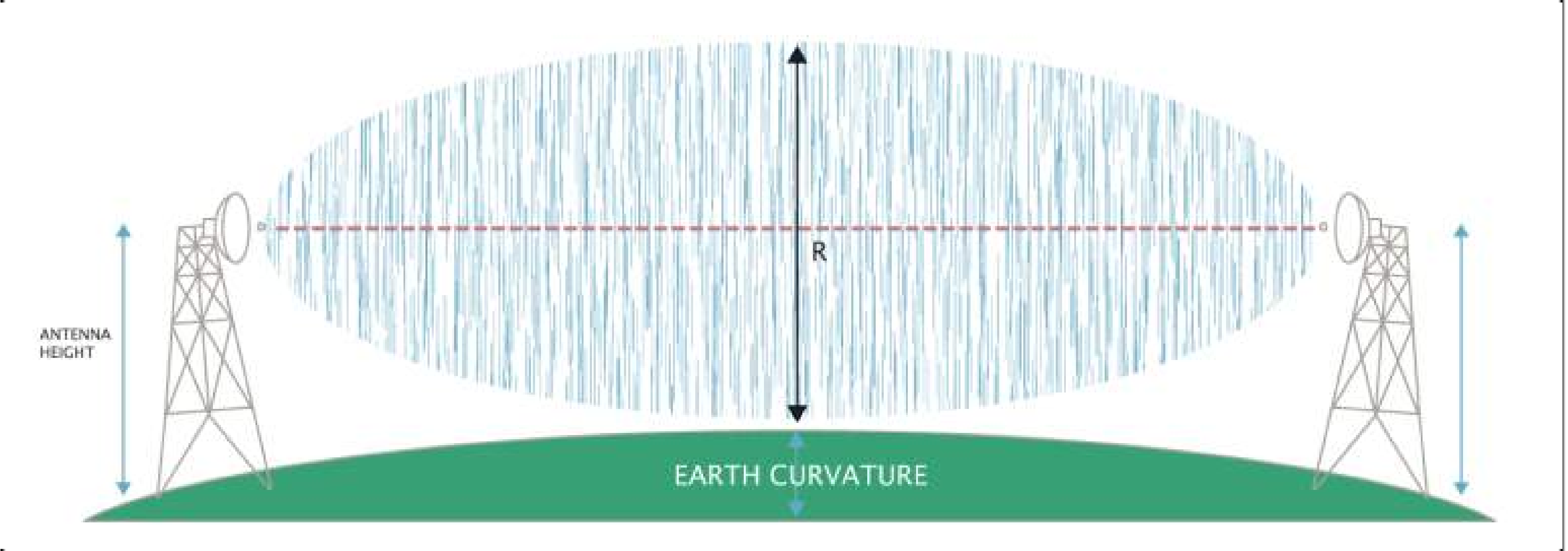
Free Space Propagation: Fresnel zones



Free Space Propagation: Fresnel zones

Distance[km]	*915 Mhz*	*2,4 Ghz*	*5,8 GHz*	*Height [m] (rel. earth*)*
1	9	6	4	0,02
10	29	18	11	2
100	90	56	36	200

Free Space Propagation: Fresnel zones



Receiver Side
Antennas, Cable Loss and Amplifiers

- Calculations are the same as for transmitter side

Receiving Sensitivity

- Tells you the *minimum value of power* that is needed to successfully decode/ extract “logical bits” and achieve a certain bit rate
- The lower the sensitivity, the better the radio receiver.
- A 10 dB difference here is just as important as 10 dB gain in an antenna

Receiving Sensitivity

Card	*11 Mbps*	*5,5 Mbps*	*2 Mbps*	*1 Mbp*
Orinoco cards PCMCIA Silver/Gold	-82 dBm	-87 dBm	-91 dBm	-94 dBm
Senao 802.11b card	-89	-91	-93	-95

Margin and SNR

- Margin = Signal received in the receiver – sensitivity
- It is not enough that S > N
- Margin between Signal and Noise (SNR) is also needed: typically at least 8 to 10 dB Margin for a working link

Terms and Concepts

- Link Budget / Power Budget / System Gain
  - A calculation of signal/power throughout the system
- System operating margin
  - Signal received – sensitivity

Terms and Concepts

- EIRP (Effective Isotropic Radiated Power)
  - Maximum Radiated Power
  - 100 mW in Europe
  - 1-4 W in other countries
- EIRP = Transmitter Power – Losses in cables and connectors) + Antenna Gain (dBi).

Calculating with dB

- Decibel is dimensionless (like percent)
- dB= 10*log(P(W)/(1W))
- dBm= 10*log(P/0.001)= 10*log(P(W)/1(mW))
- dBi = dB relative to an ideal isotropic antenna (the one-point source)
- Decibel units can be added and subtracted and the results will remain dimensionless

Calculating with dB

- The Golden Rule:
  - Duplicating the power is equal to adding 3 dB
  - Reducing the power by half is equal to subtracting 3 dB

The Complete Link Budget

- Two realistic examples to discuss
- The key question is

  How much margin do you need for a working link?

The Complete Link Budget

- + Transmitter power [dBm]
- - Cable TX loss [dB]
- + Antenna TX gain [dBi]
- - Free Space Path Loss [dB]
- + Antenna RX gain [dBi]
- - Cable RX loss [dB]
- = Margin - Receiver Sensitivity [dBm]

Complete Link Budget: Example 1

- Distance: 50 kms
- Frequency: 2,4 GHz

Element	***Value***
Transmit output	+ 15 dBm
Cable and connectors	- 3 dB
Antenna TX	+ 24 dBi
FSL	-134 dB
Antenna RX	+ 24 dBi
Cable and connectors	- 3 dB
Receive Sensibility	- 85 dBm
Total: (margin)	+ 8 dB

Complete Link Budget: Example 2

- Distance: 1 km
- Frequency: 2,4 GHz
- Low quality cabling
- Low antenna gain

Element	***Value***
Transmit output	+ 18 dBm
Cable and connectors	- 5 dB
Antenna TX	+ 5 dBi
FSL	-100 dB
Antenna RX	+ 8 dBi
Cable and connectors	- 5 dB
Receive Sensibility	- 92 dBm
Total: (margin)	+ 13 dB

Factors From Higher OSI Layers

- Not only the physical layer determines the performance of links
- Drivers, implementations and settings affects the performance
- Timing settings of wireless cards becomes relevant for long links (SIFS and DIFS!)

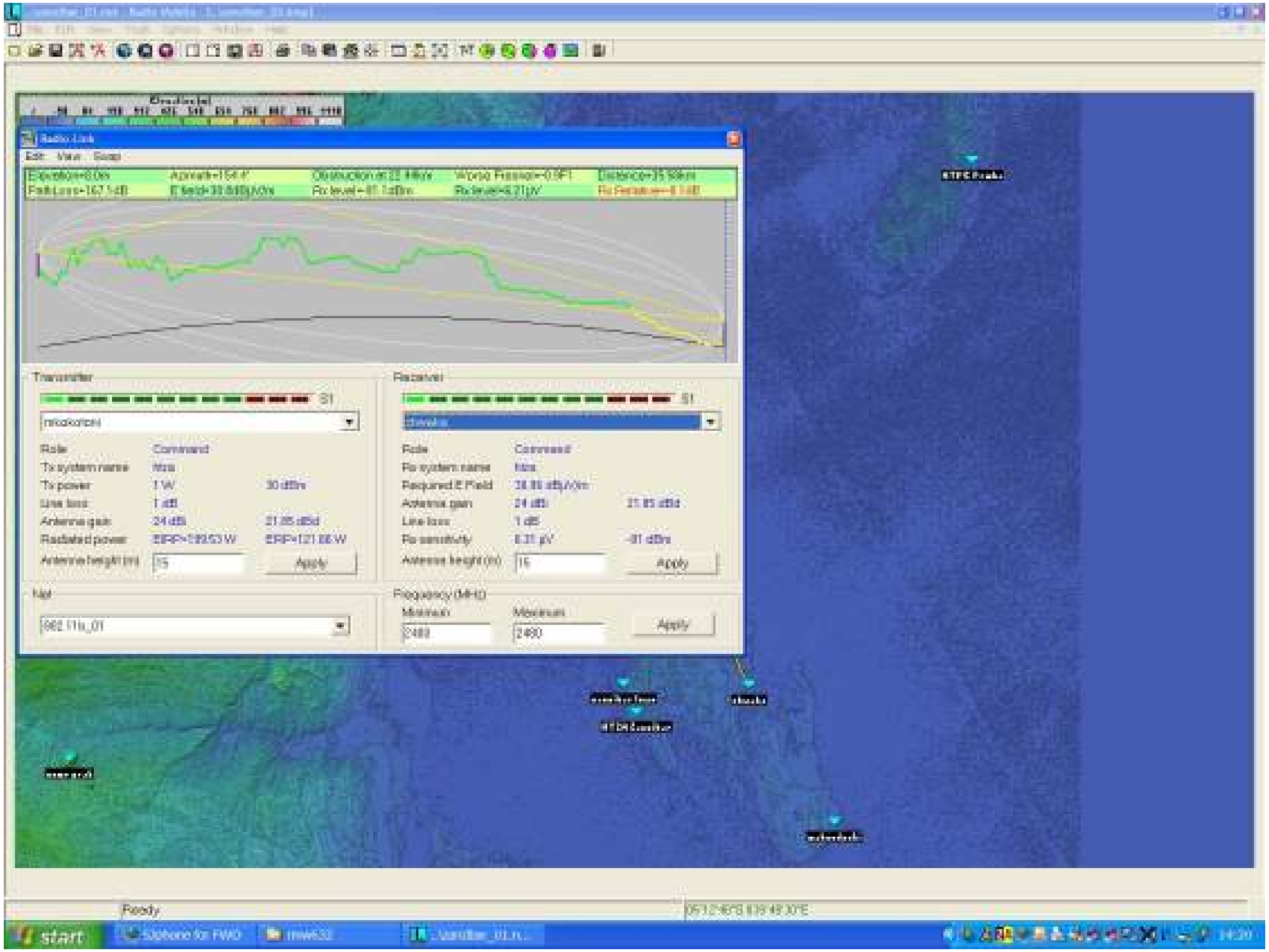
Sources of Lat/Long, elevation and distance data

- Local knowledge
- Measure!
- GPS data
- Shuttle Radar Topography Mission (SRTM) project
- Aviation sites, airport locators
- Ham radio sites, Islamic sites
- City lists

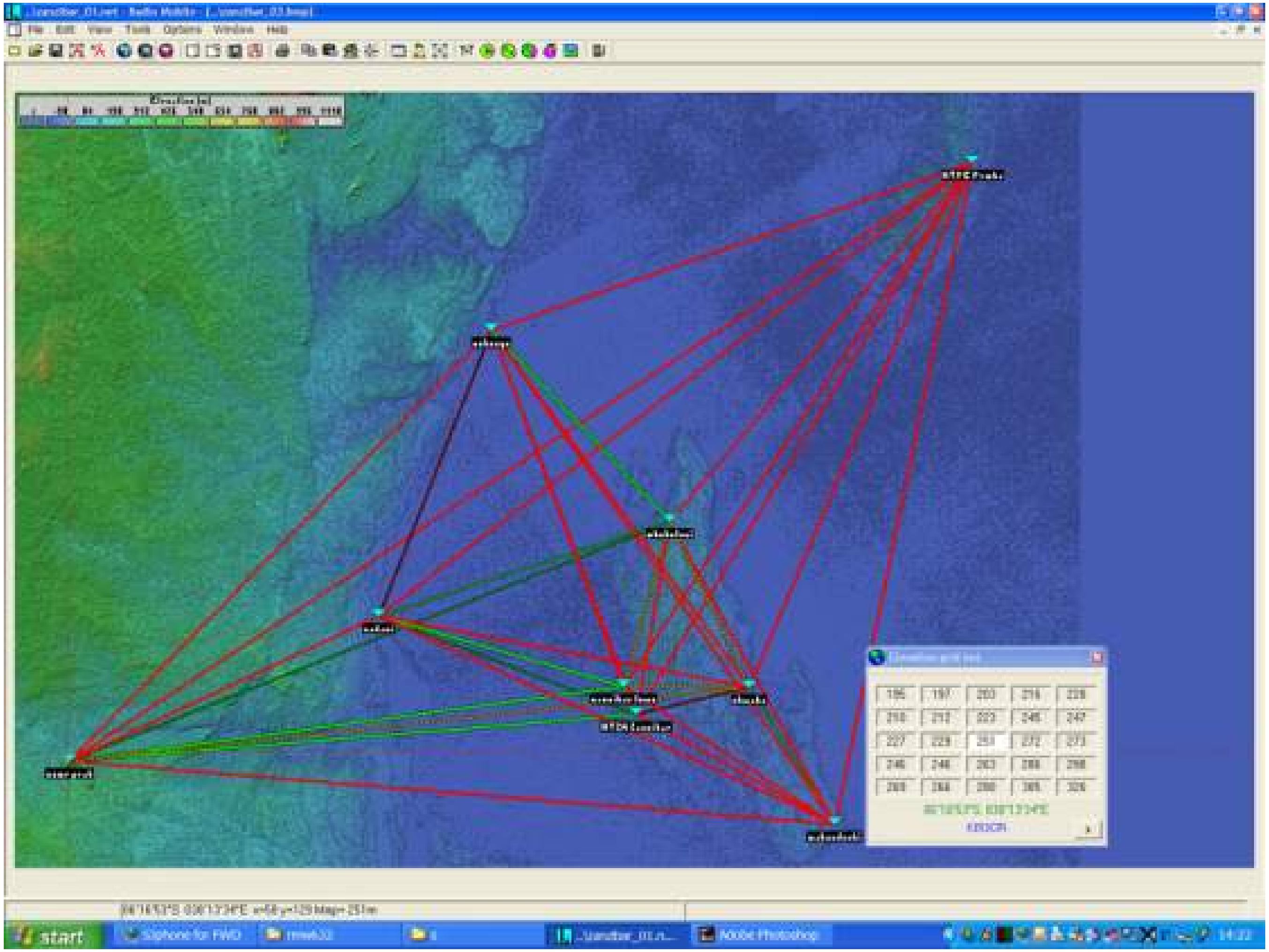
RadioMobile Software

- Integrated network planning, LOS and coverage calculations based on terrain data
- Free software from the ham (amateur) radio scene
- For Windows
- Can use elevation data from various sources: HGT, DTED, GLOBE, SRTM30, GTOPO, ... formats
- Can integrate maps and backgrounds, GIS data
- http://www.cplus.org/rmw/english1.html

RadioMobile Software



RadioMobile Software



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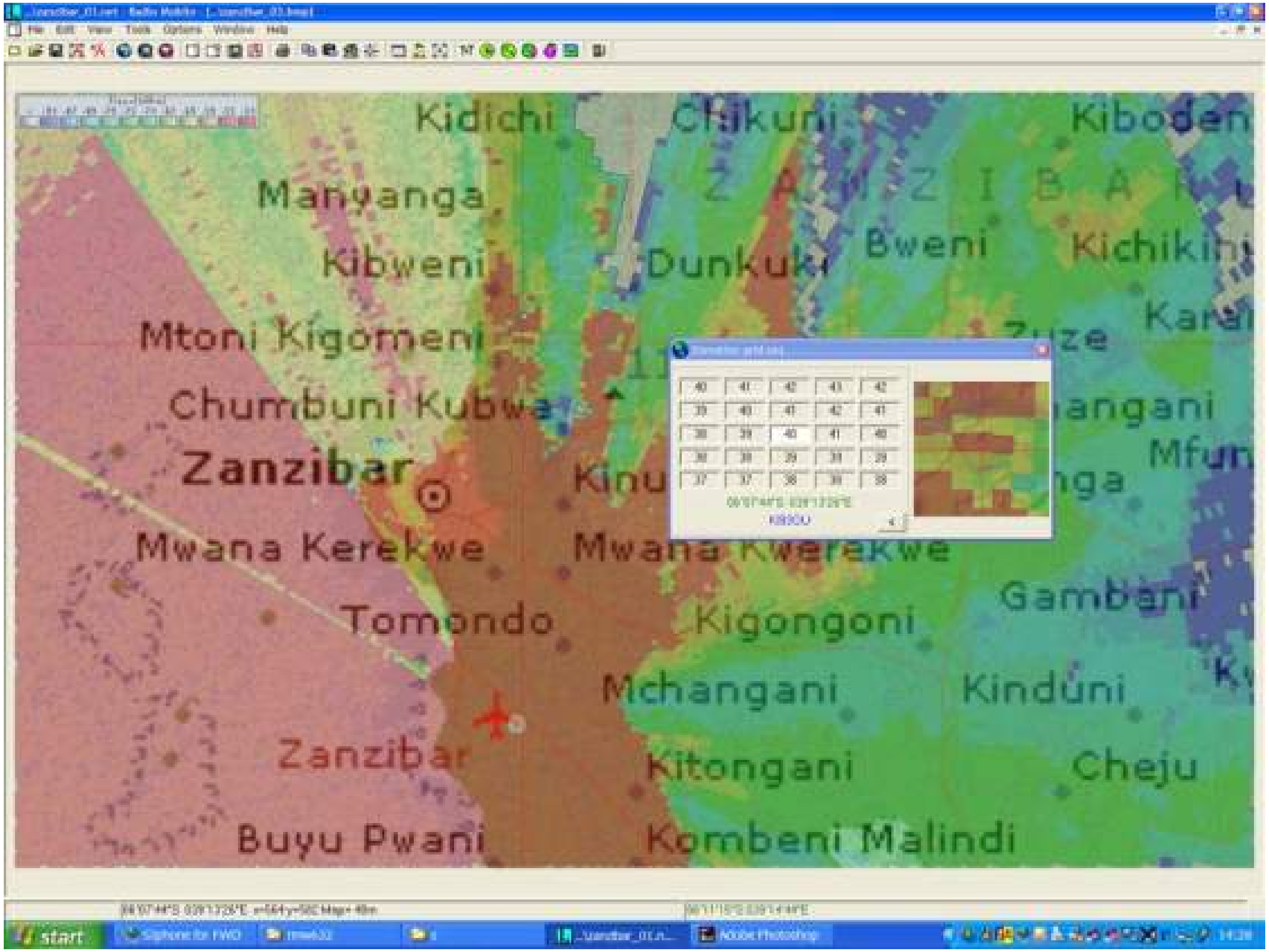

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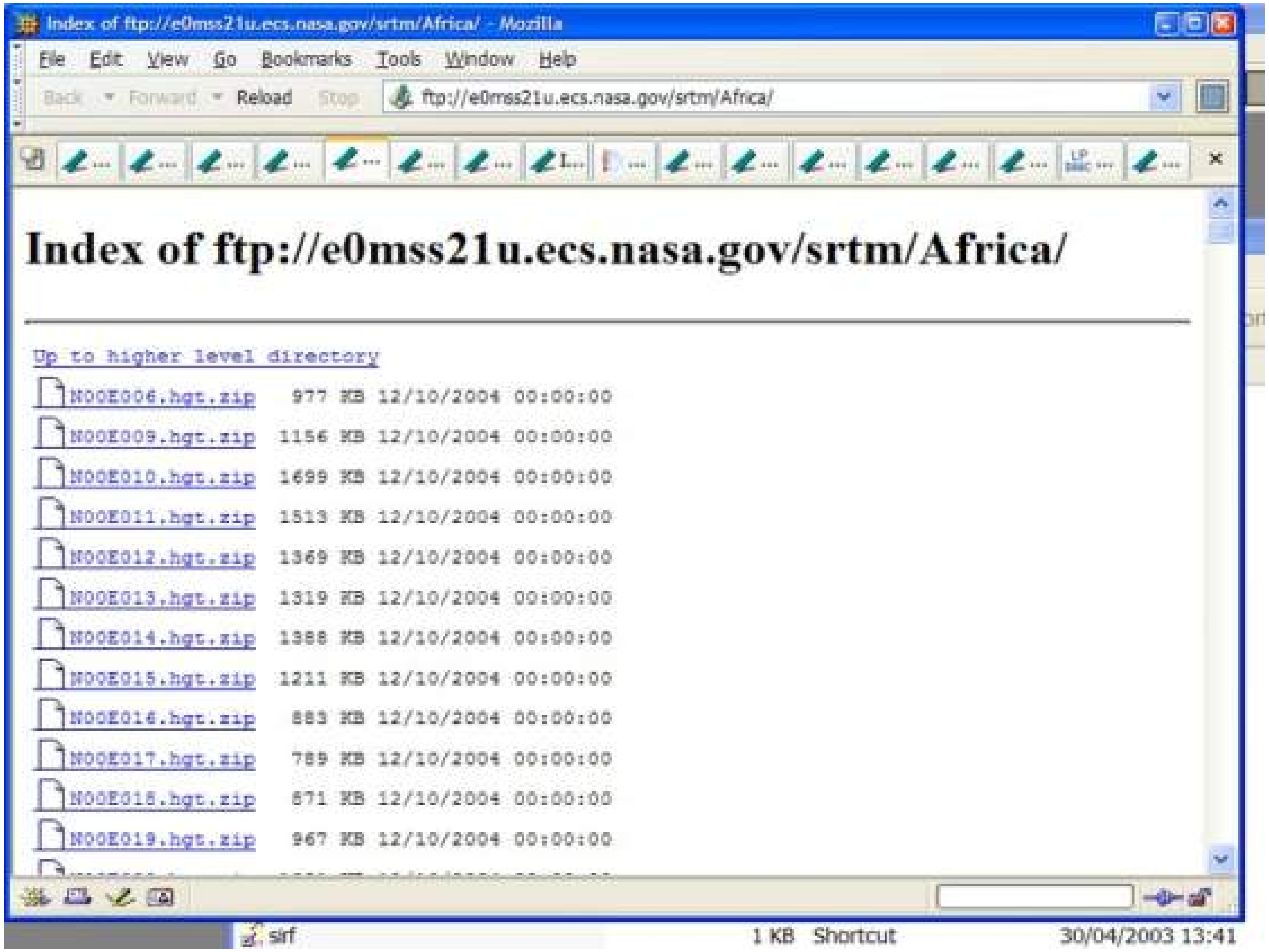

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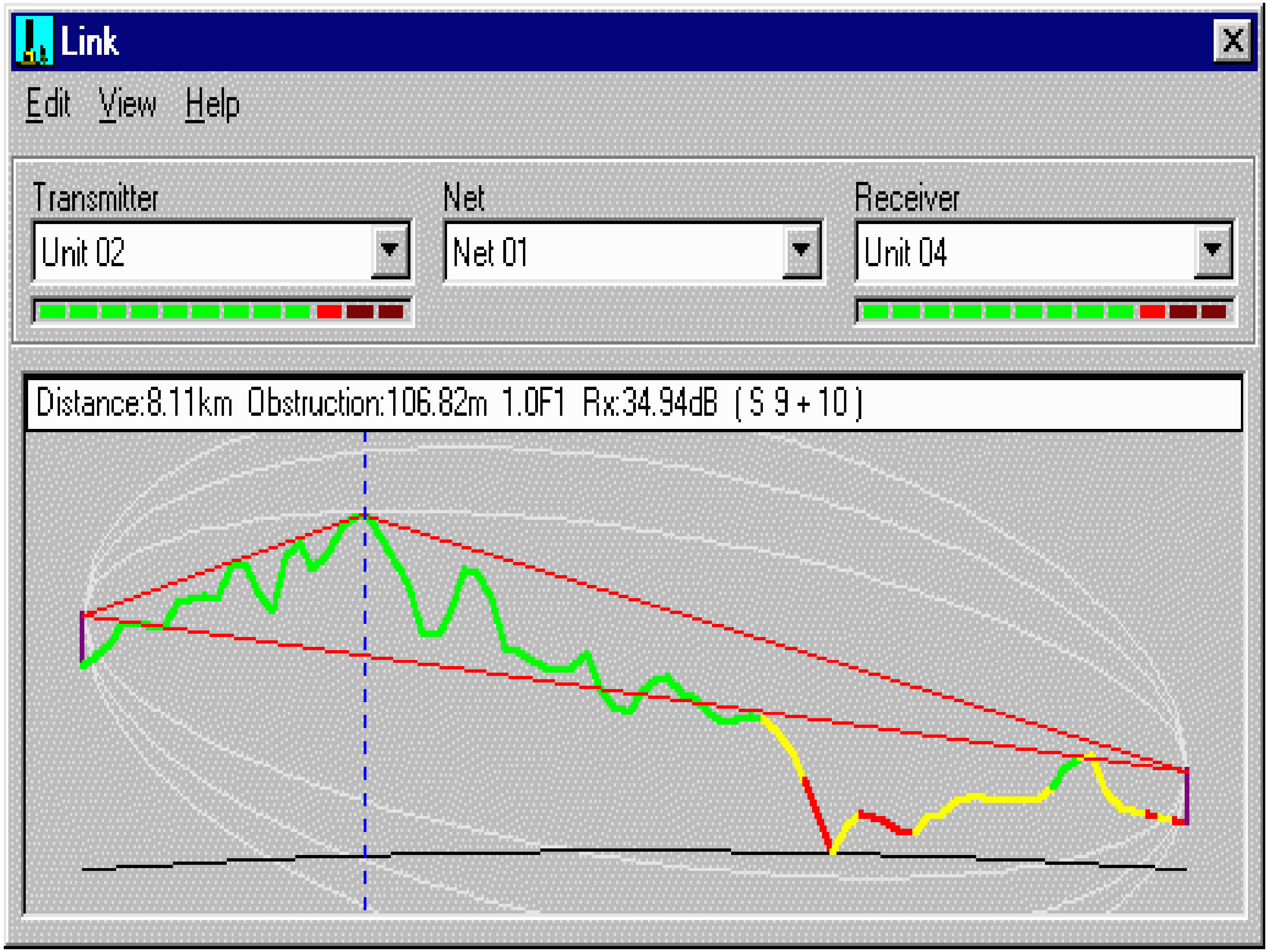

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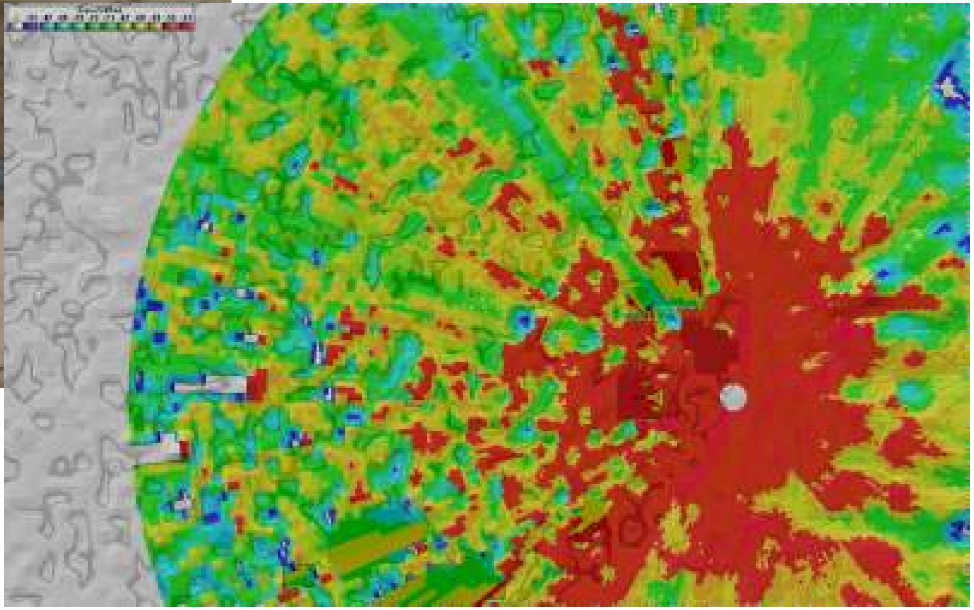

Conclusions

- A good link budget is the basic requirement of a well functioning link
- Losses takes place in every element along the transmission path
- Limiting the losses is the key issue
- Many online free tools available