Radio Link Calculation

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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

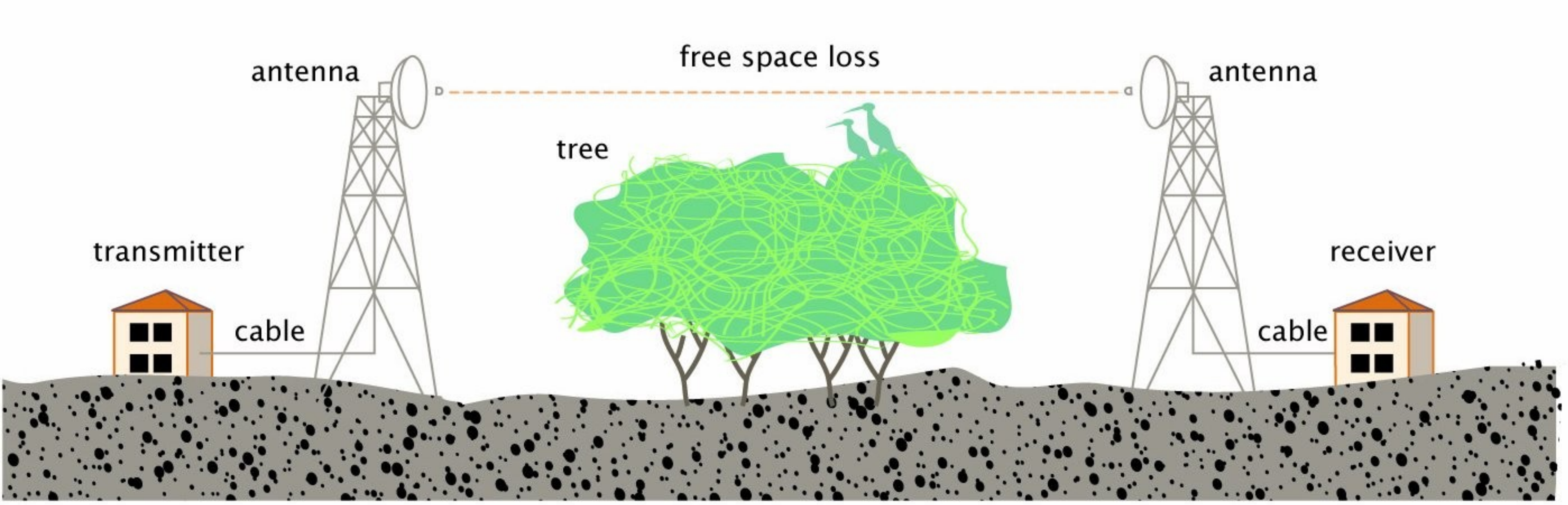
What is a Link Budget?

- 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 and therefore on country/region and point in time

Protocol	***Peak power [dBm]***	***Peak power [mW]***
IEEE 802.11b	18	65
IEEE 802.11a	20	100

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 loss the more expensive 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)

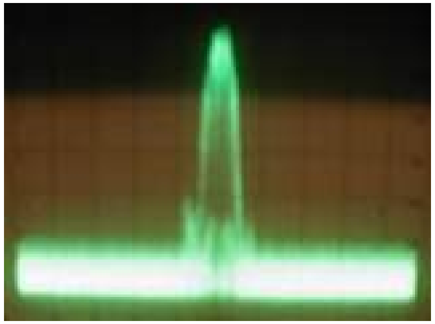
Amplifiers

- Optionally to use, makes up 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

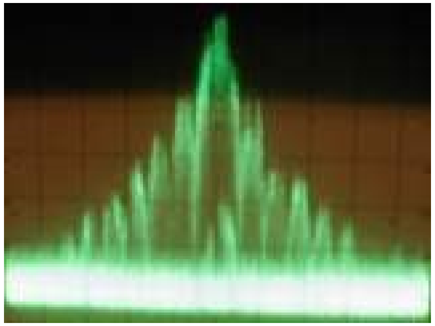
Amplifiers

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)
  - 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

$$\mathbf{FSL(dB) = 20\log_{10}(d) + 20\log_{10}(f) - 147.5}$$

d = distance [m]

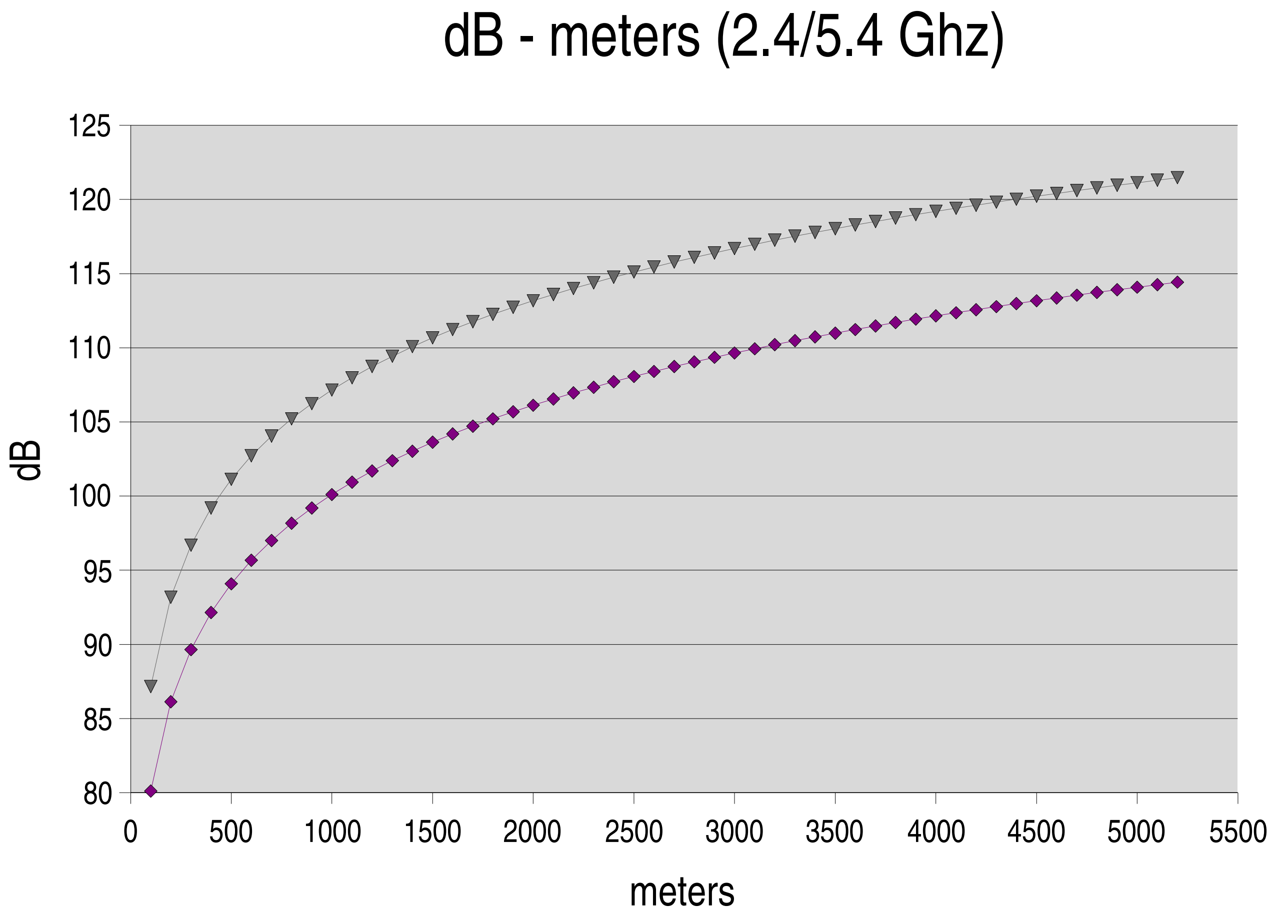
f = frequency [Hz]

assuming isotropic antenna

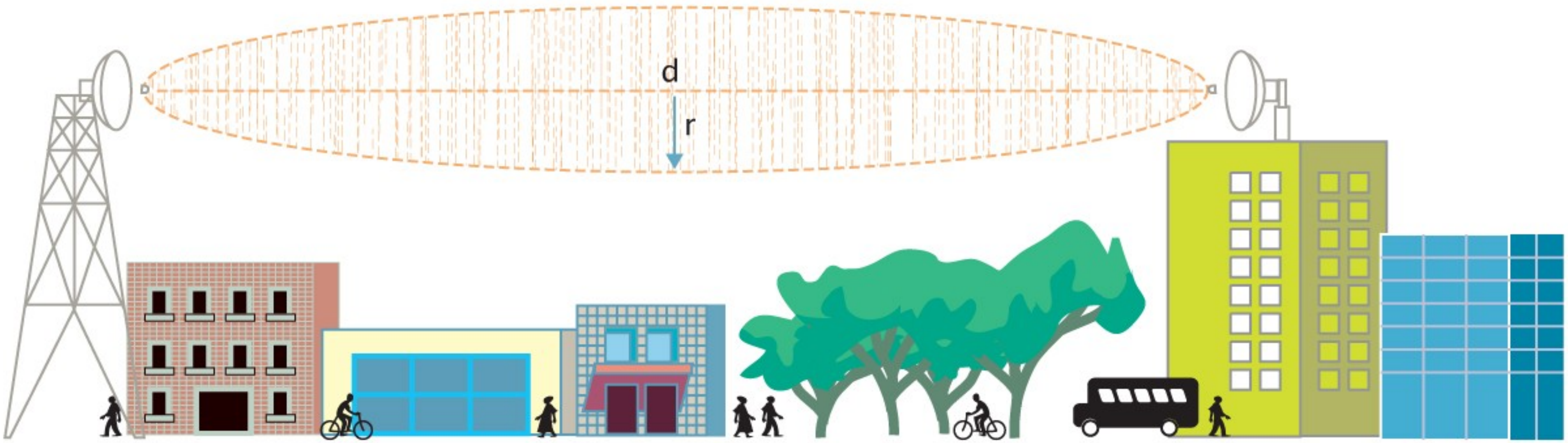
Free Space Loss

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

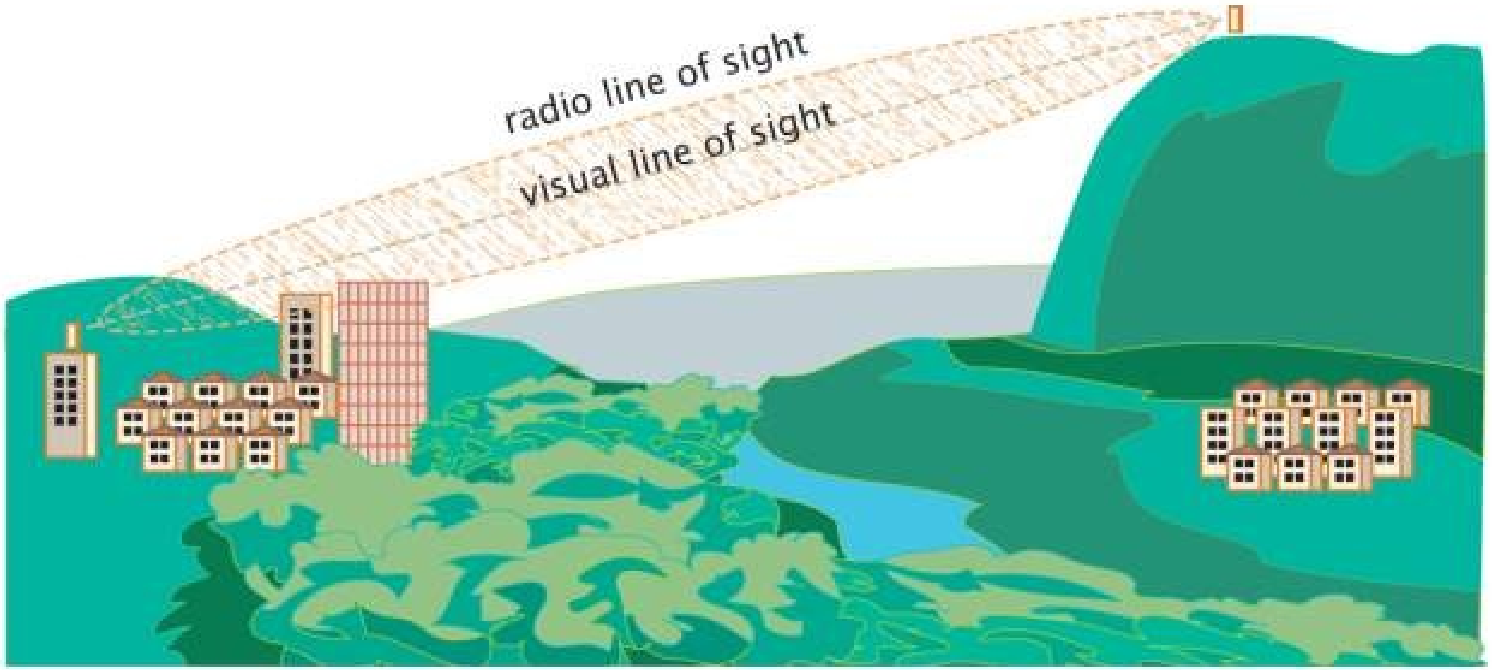
Obstacle situated in the middle (d1=d2):

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

The radio containing 60% of the total power:

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

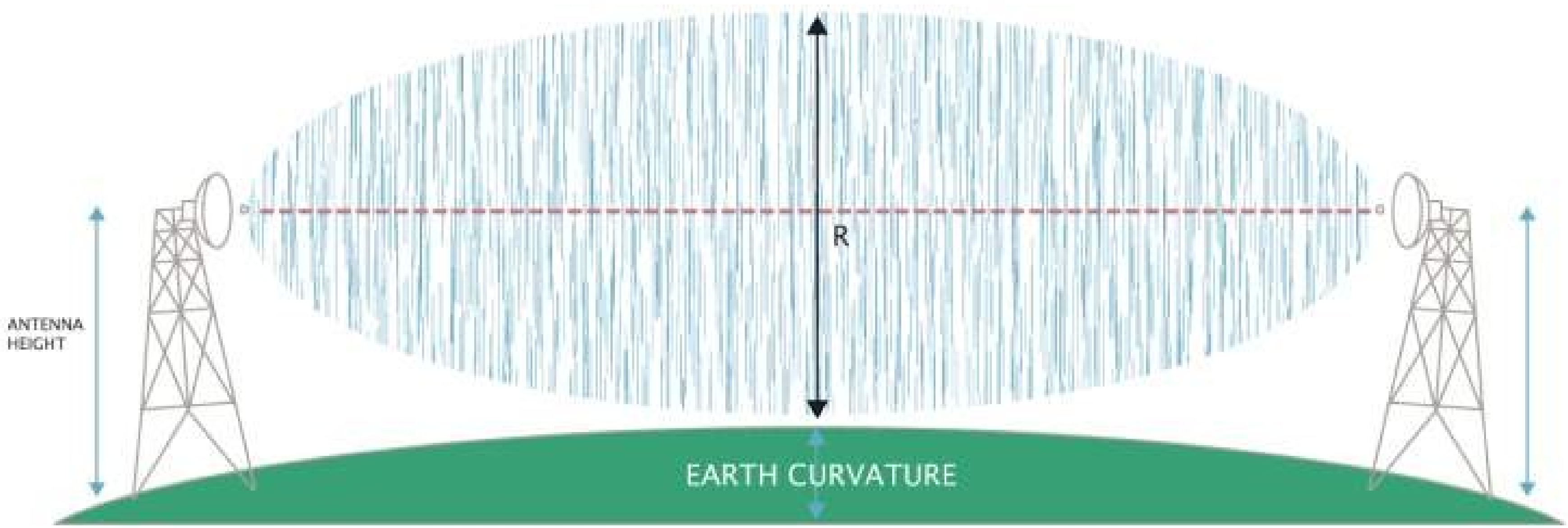
Free Space Propagation: Fresnel zones



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 is, the better 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
- Typical requirement of SNR is
  - 16 dB for 11 Mbps
  - 4 dB for 1 Mbps.

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 big 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 (31,1 miles)
- 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 (0,622 miles)
- 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

Other Relevant Calculations

- Antenna Tilt
  - Compensate for earth curvature
  - Compensate for tower height differences

$$\textbf{angle} = \mathbf{Tan^{-1} * ((h_1 - h_2) / (d * 5280))}$$

where d is the distance

Other Relevant Calculations

- Bearing (angle towards north) and distance from latitude/longitude
  distance = r * arccos[sin(lat1/57.2958) * sin(lat2/57.2958) + cos(lat1/57.2958) * cos(lat2/57.2958) * cos(lon2/57.2958 -lon1/57.2958)]

  lat, lon in metric degrees
  r=6378.7 (kilometers)
  r=3963.0 (normal miles)

Other Relevant Calculations

- Correction factors due to
  - Terrain and building structures
  - Humidity, rain, snow and water surfaces
- Difficult to estimate and they change with time
- Can have great impact on the total link budget
- Theoretical calculations is one thing, reality is another

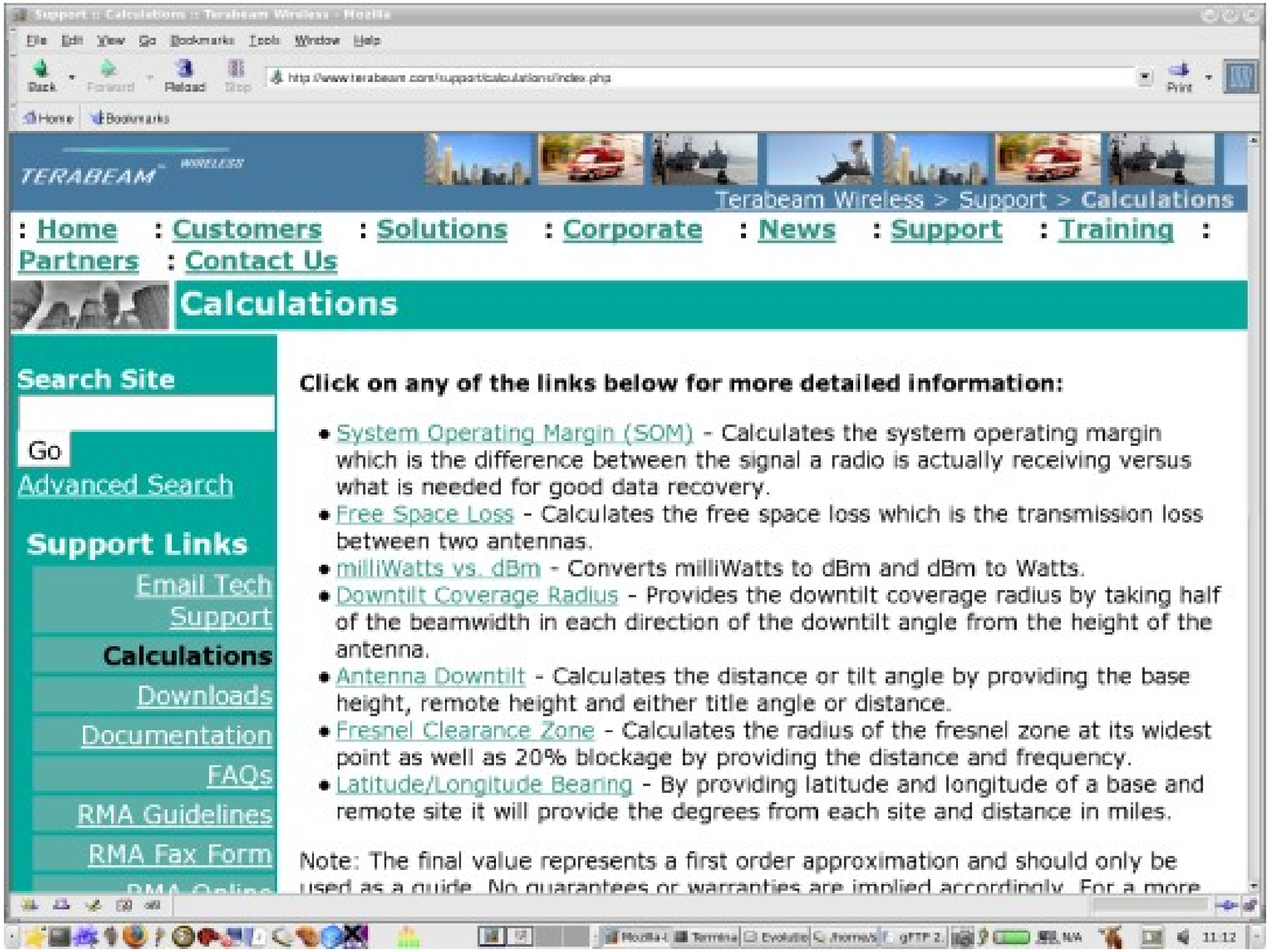
Factors From Higher OSI Layers

- 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!)

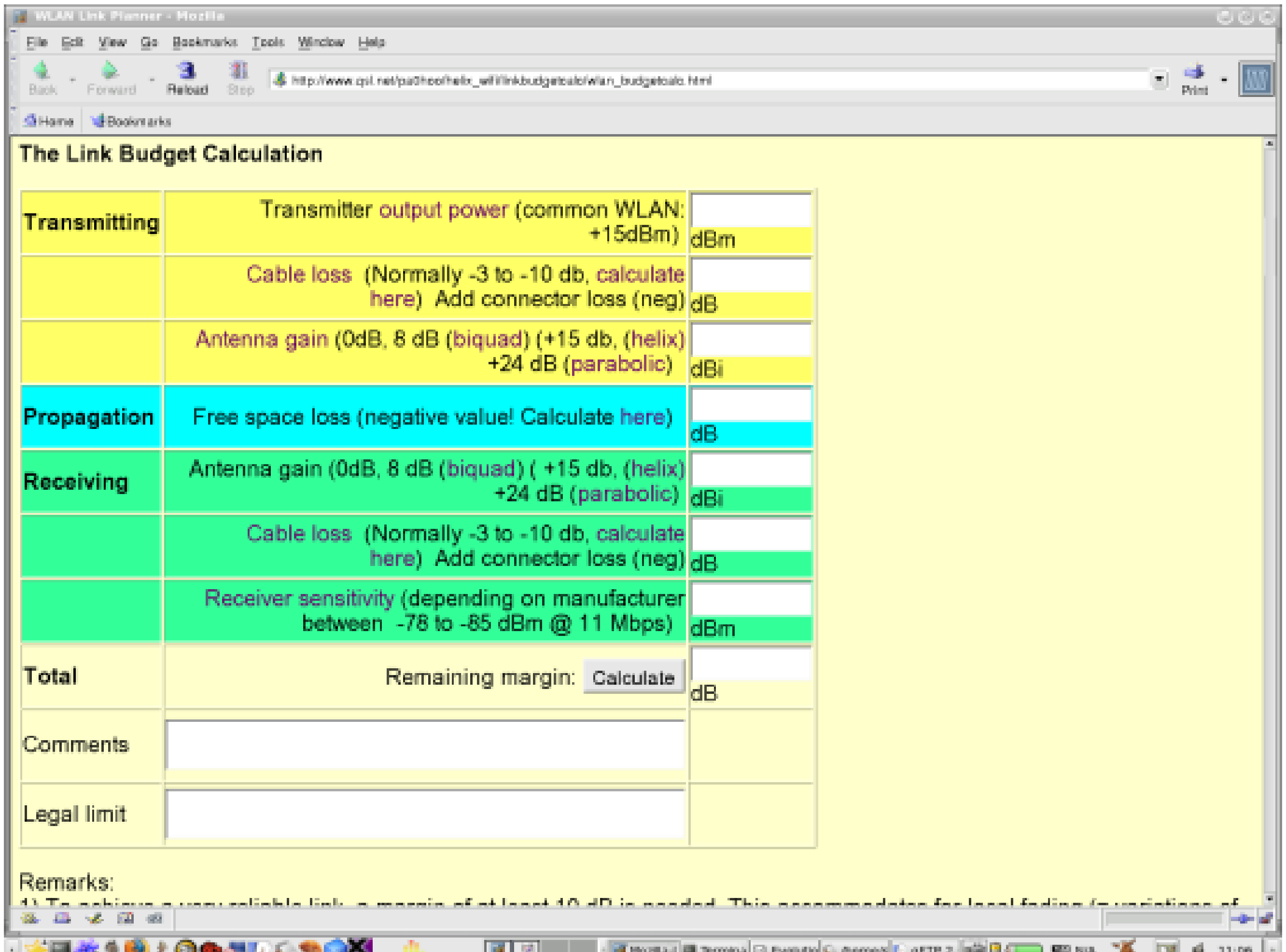
Online Calculators

- Great resource to verify your calculations
- Do not rely completely on online resources
  - They can change or simply “disappear”
- One example of a spreadsheet tool is made available in this unit

Online Calculators



Online Calculators



Some URLs for calculators

www.google.com/search?hl=en&lr=&q=wireless+link+calculator&btnG=Search

www.terabeam.com/support/calculations/index.php (ex-YDI.com)

www.qsl.net/n9zia/

www.qsl.net/pa0hoo/helix_wifi/linkbudgetcalc/wlan_budgetcalc.html

www.zytrax.com/tech/wireless/calc.htm

www.connect802.com/antenna_c_main.php

www.connect802.com/literature.htm

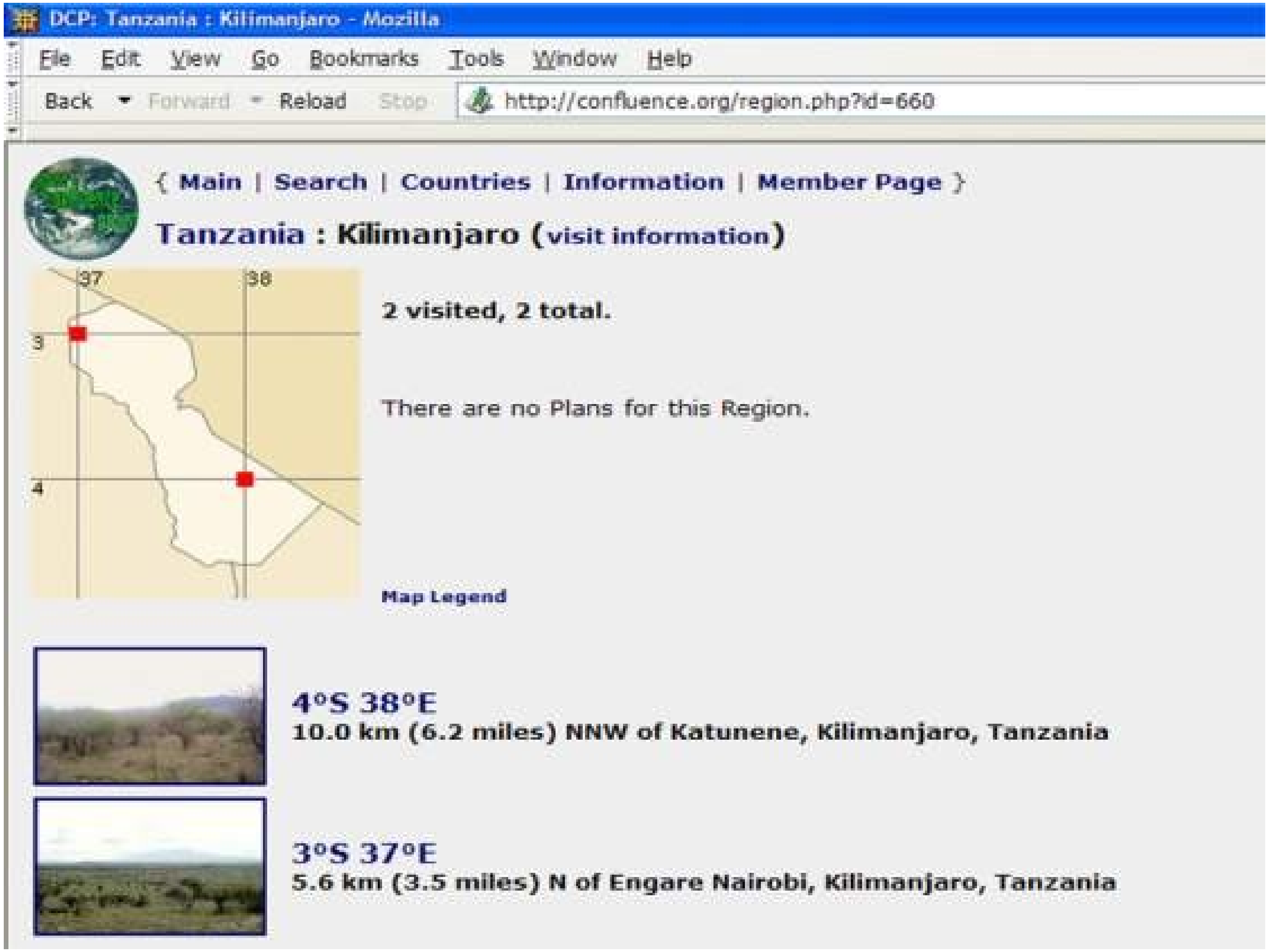
my.athenet.net/~multiplx/cgi-bin/tilt.main.cgi

www.it46.se/courses2/wireless/calculator/en/

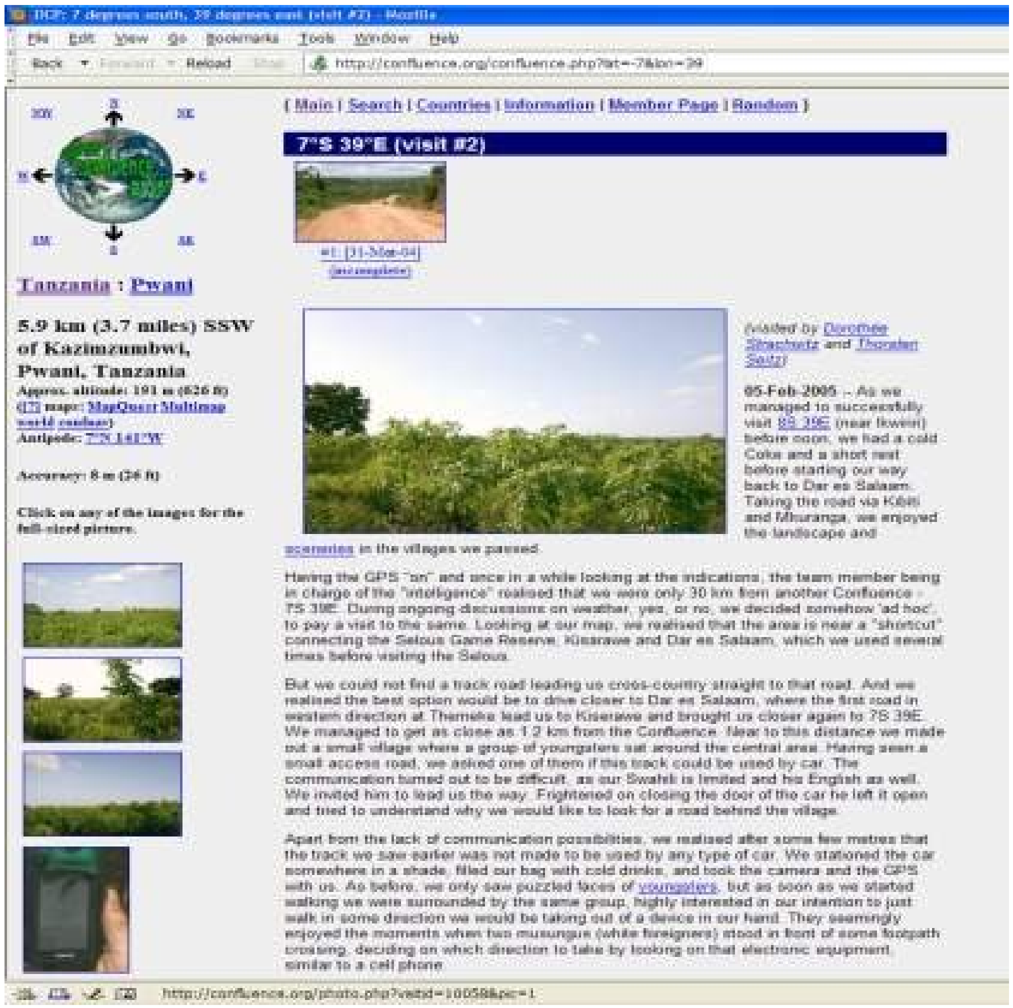
Sources of Lat/Long, elevation and distance data

- Local knowledge
- GPS data
- Shuttle Radar Topography Mission (SRTM) project
- Aviation sites, airport locators
- Ham radio sites, Islamic sites
- City lists
- The *confluence.org* project as a rough first view

Confluences



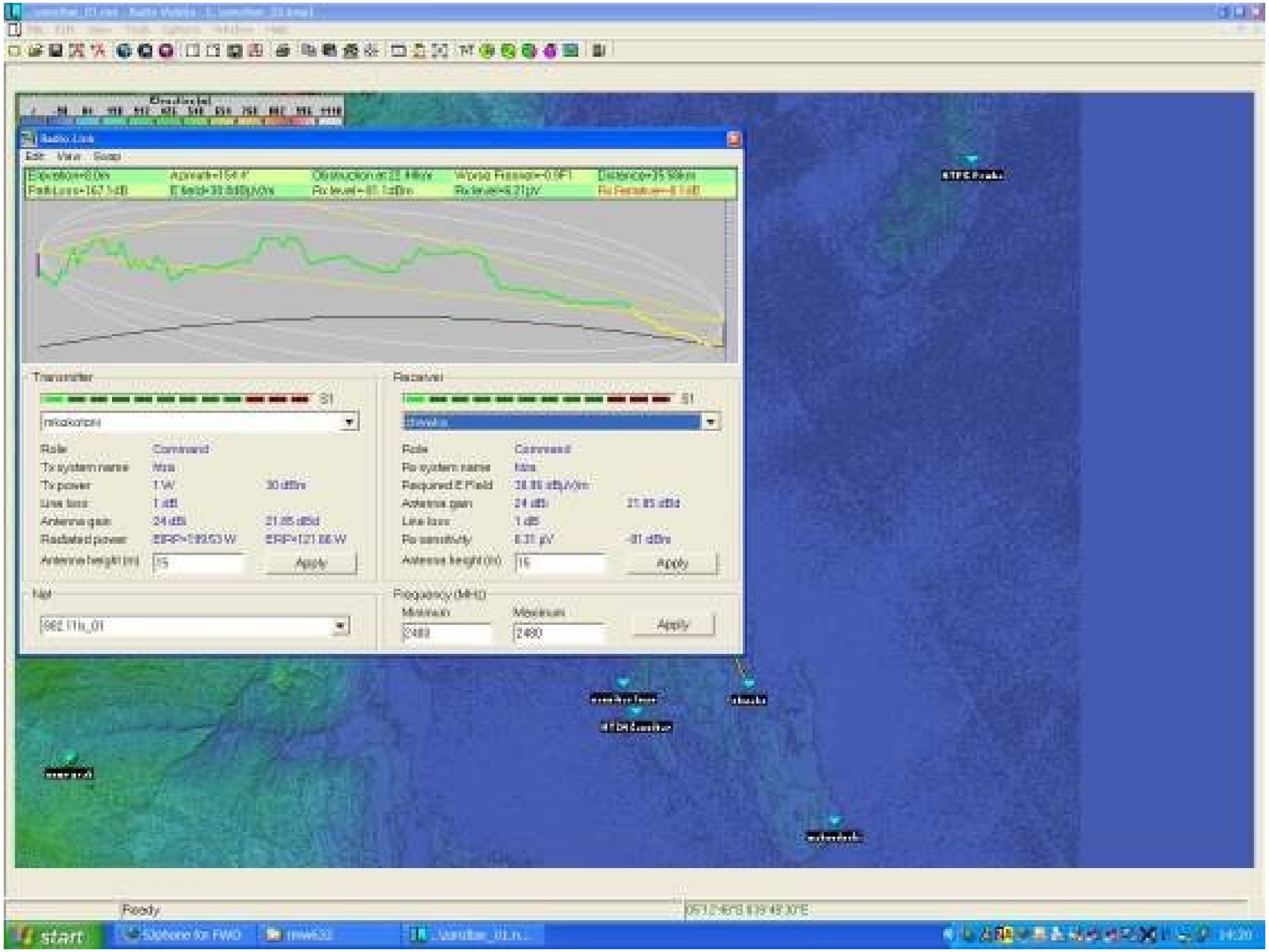
Confluences



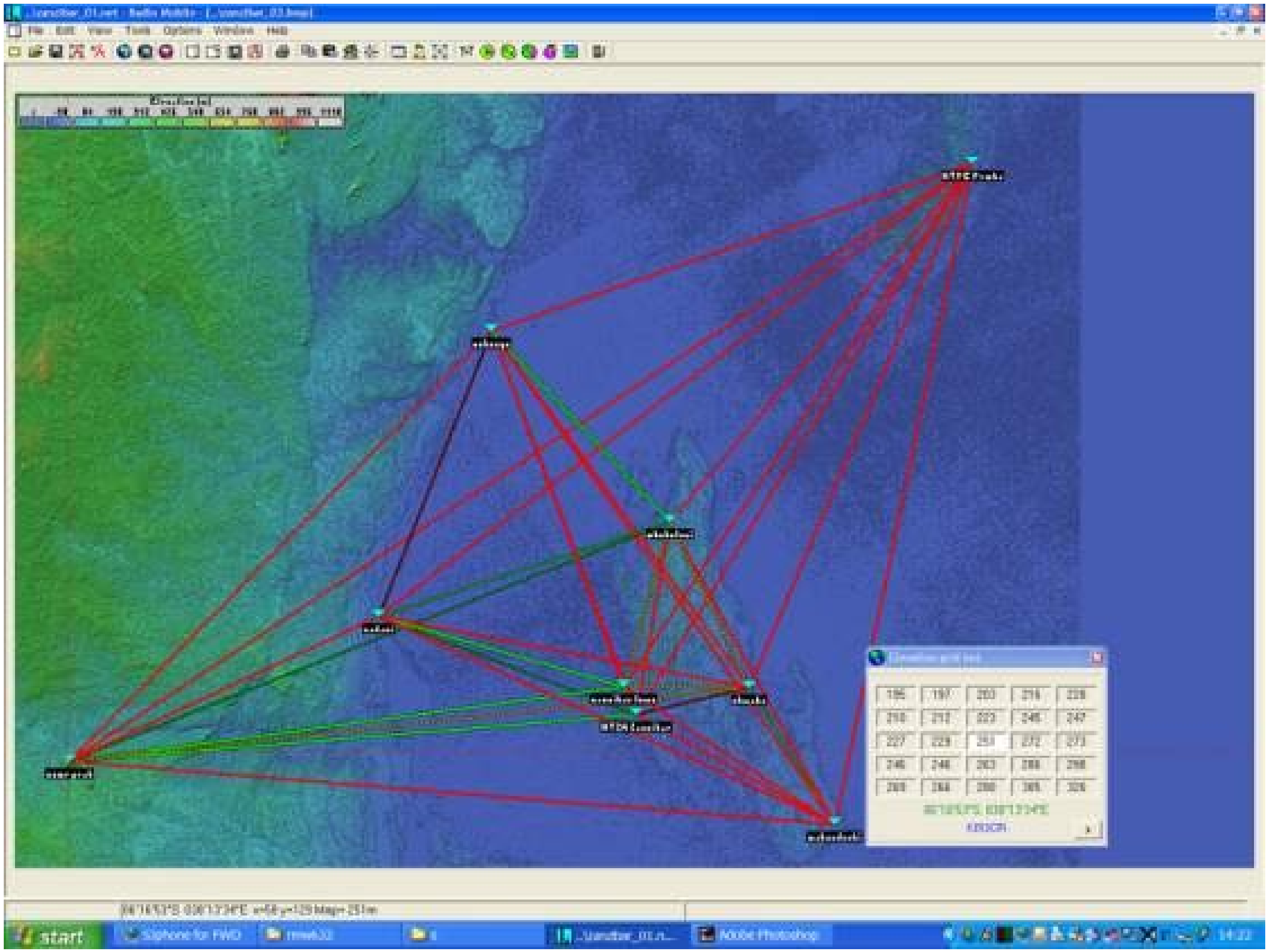
RadioMobile Software

- 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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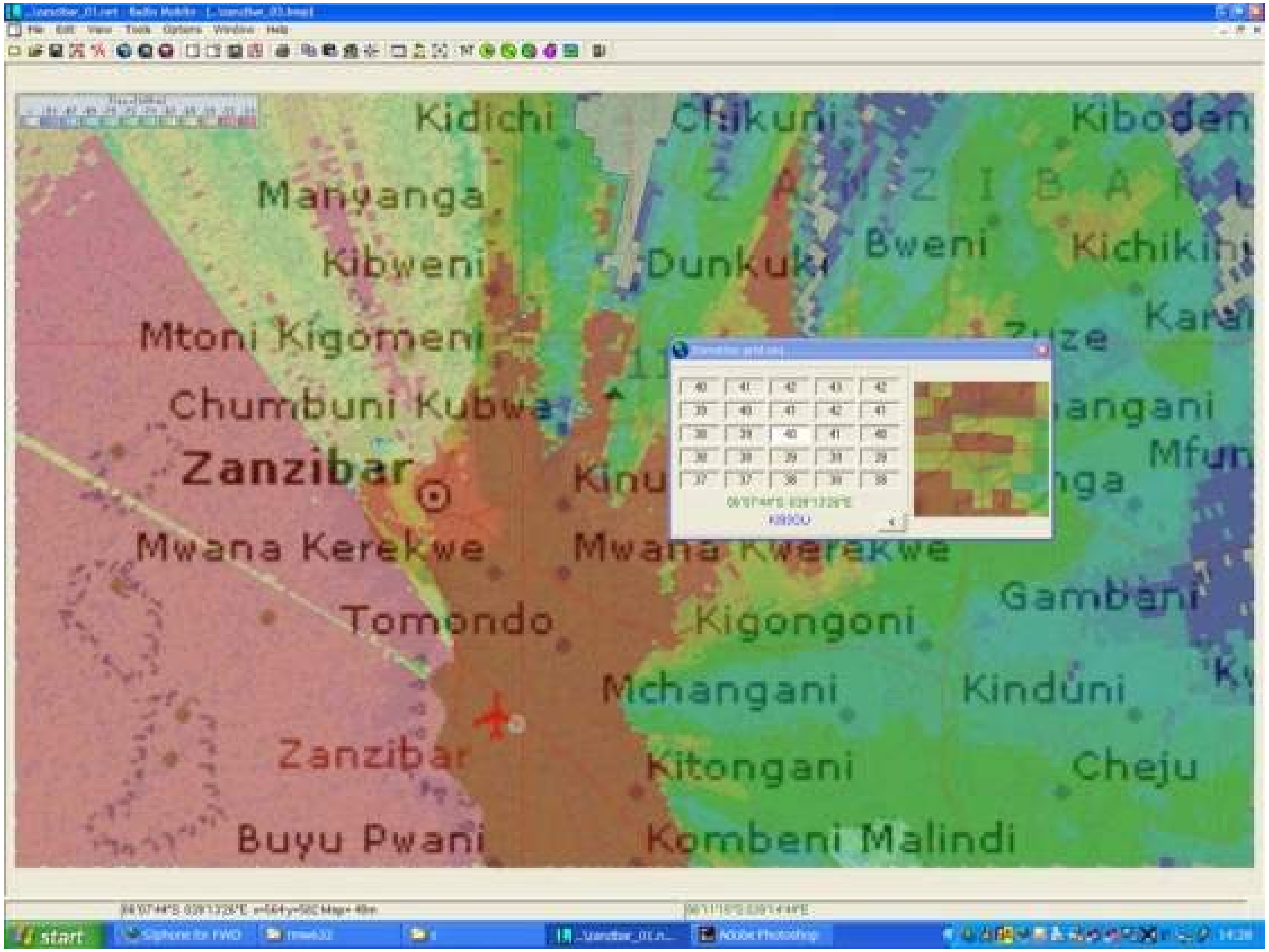

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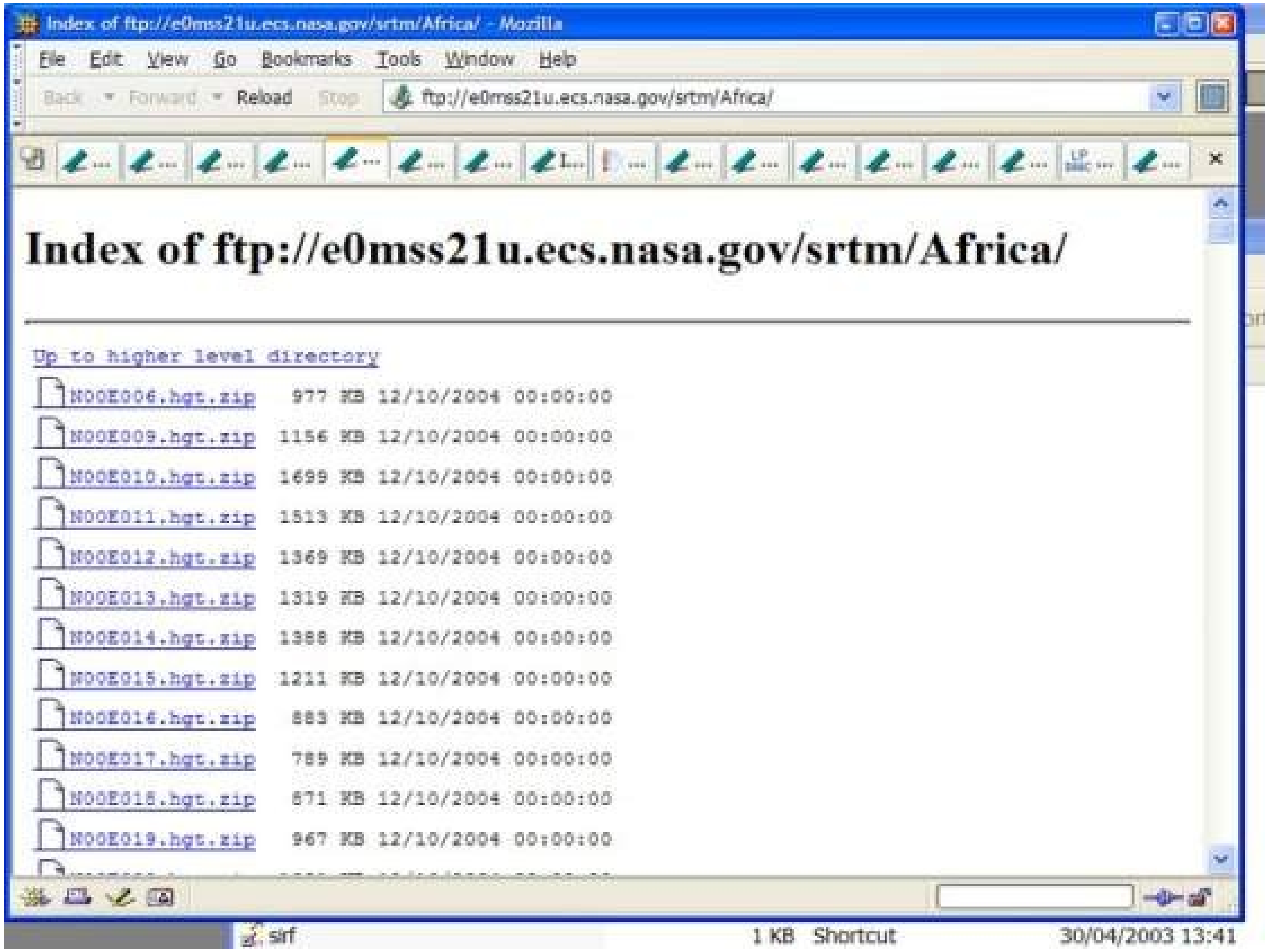

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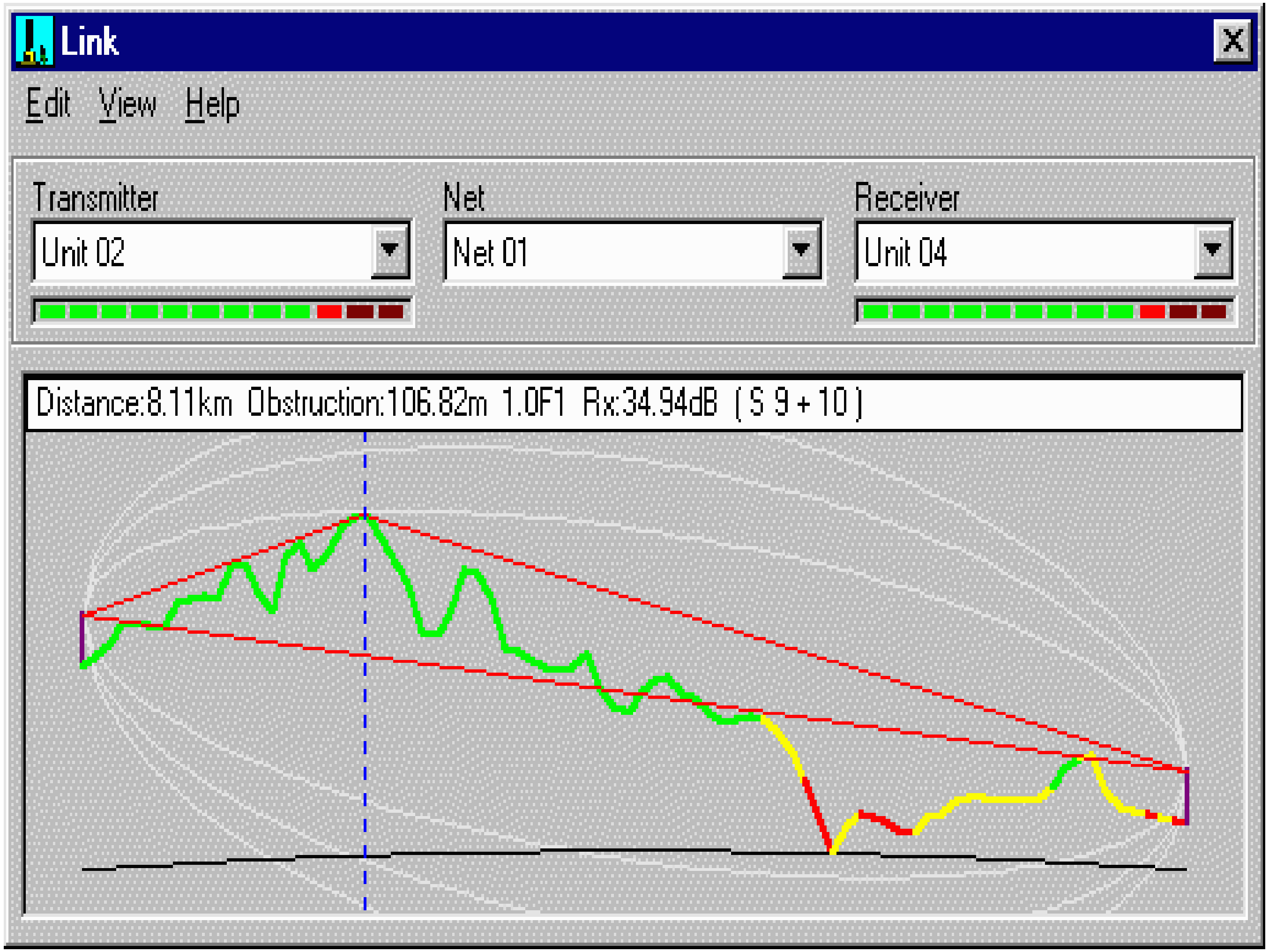

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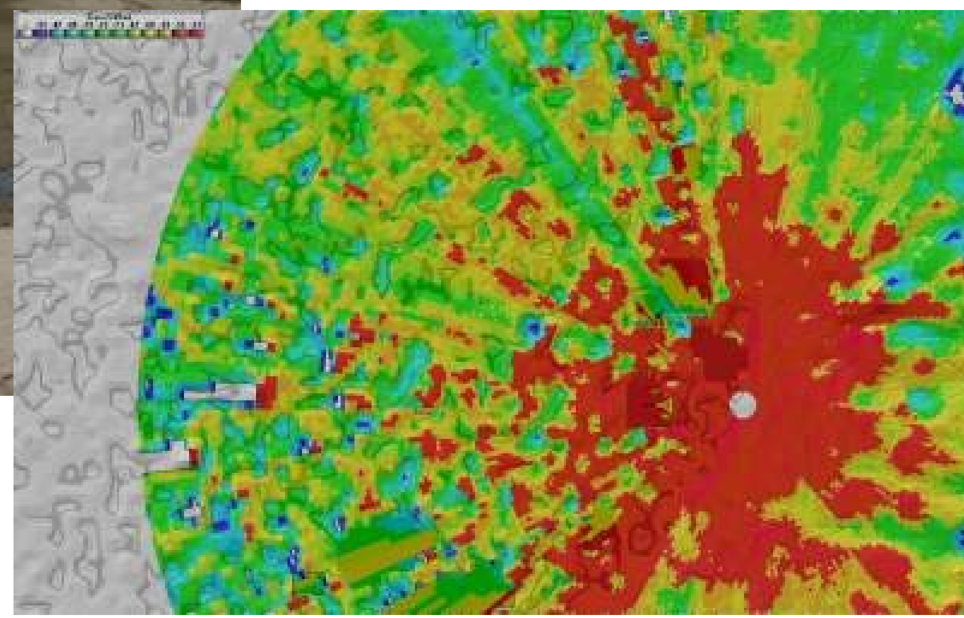

Conclusions

- 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