

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

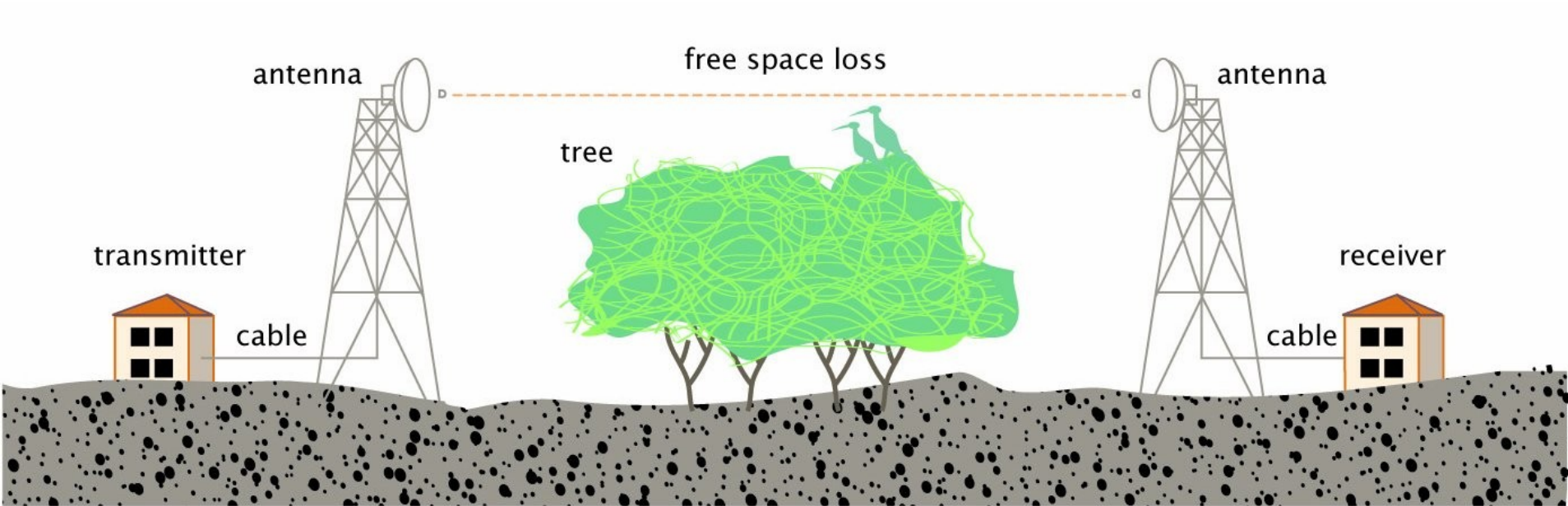
What is a Link Budget?

- 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

$$\begin{aligned} &+ \text{Transmitter power [dBm]} \\ &- \text{Cable TX loss [dB]} \\ &+ \text{Antenna TX gain [dBi]} \\ &- \text{Free Space Path Loss [dB]} \\ &+ \text{Antenna RX gain [dBi]} \\ &- \text{Cable RX loss [dB]} \\ &= \text{Margin} - \text{Receiver Sensitivity [dBm]} \end{aligned}$$

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

<i>Protocol</i>	<i>Peak power [dBm]</i>	<i>Peak power [mW]</i>
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

<i>Cable type</i>	<i>Loss [db/100m]</i>
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 1/2 "	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

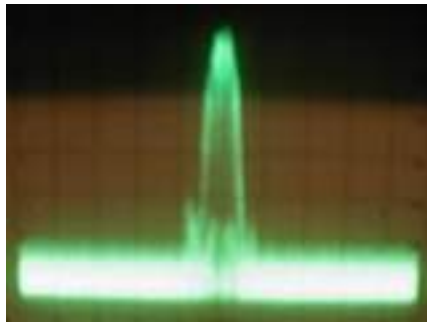
- Optionally to use, makes up for cable loss
- May change frequency characteristics and add noise
- Consider legal limits
- Intelligently optimized antennas and high receive sensitivity are better than brute force amplification

Amplifiers

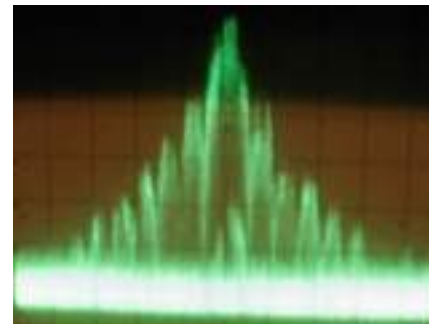


What a (cheap) amplifier might do:

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]

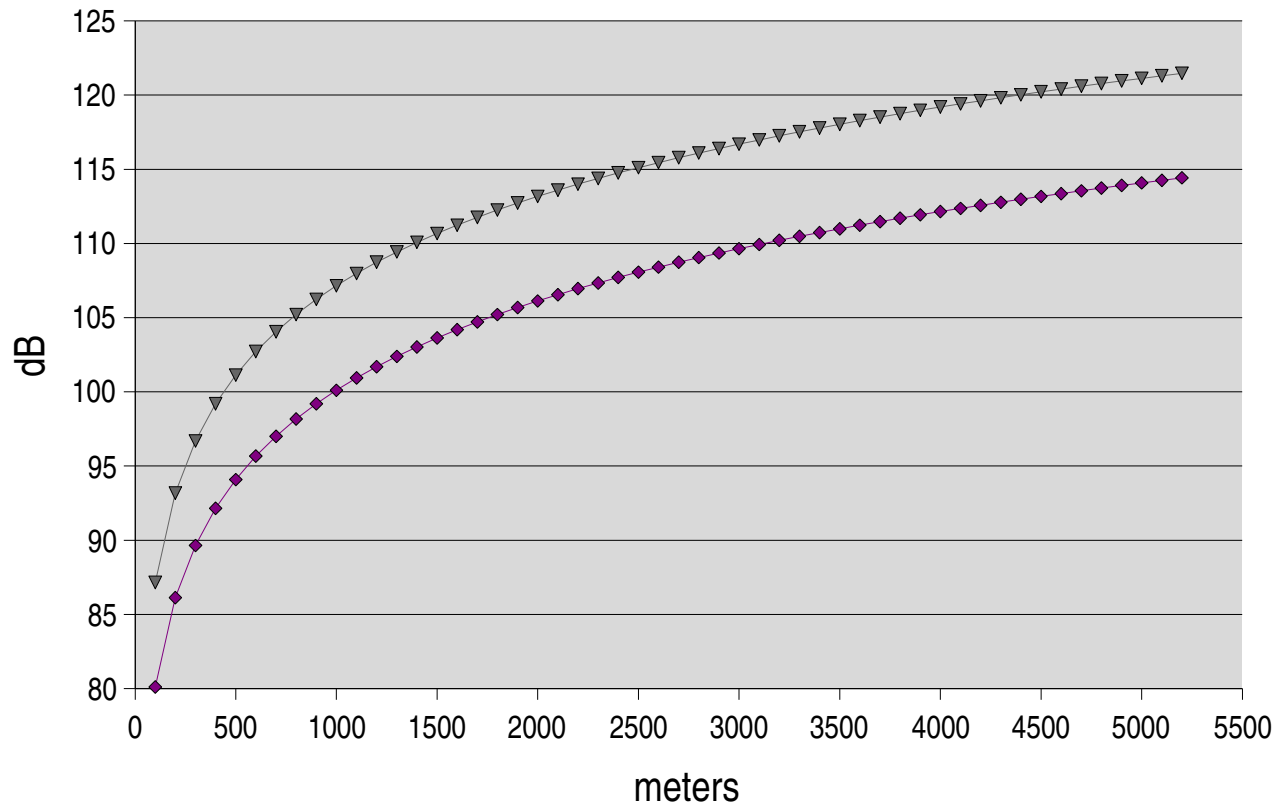
assuming isotropic antenna

Free Space Loss

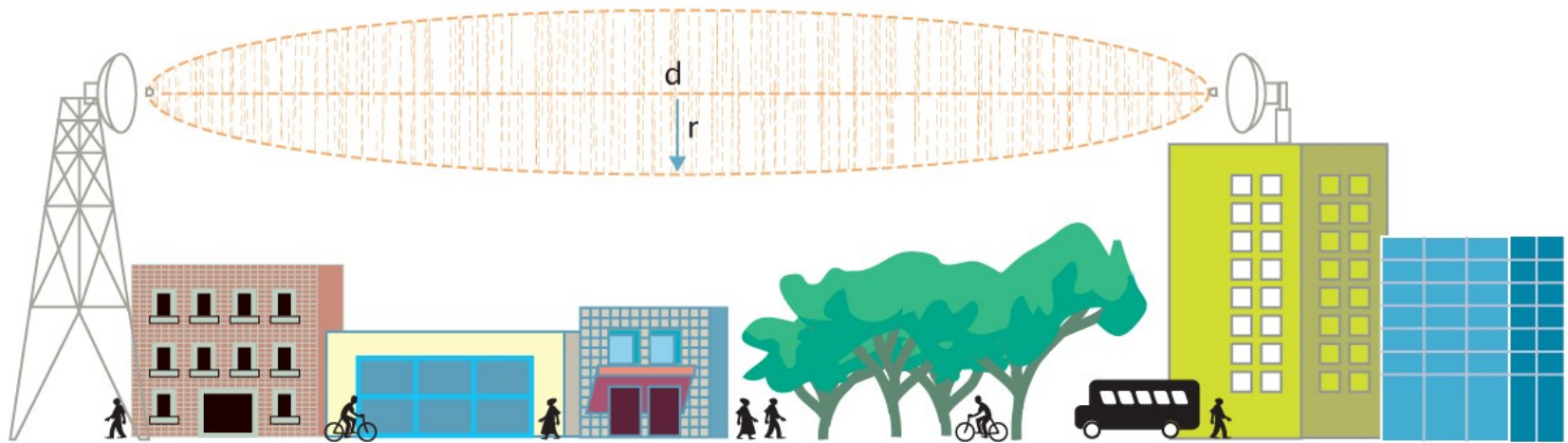
<i>Distance [km]</i>	<i>915 Mhz</i>	<i>2,4 Ghz</i>	<i>5,8GHz</i>
1	92 dB	100 dB	108 dB
10	112 dB	120 dB	128 dB
100	132 dB	140 dB	148 dB

Linear Approximation of FSL

dB - meters (2.4/5.4 Ghz)



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

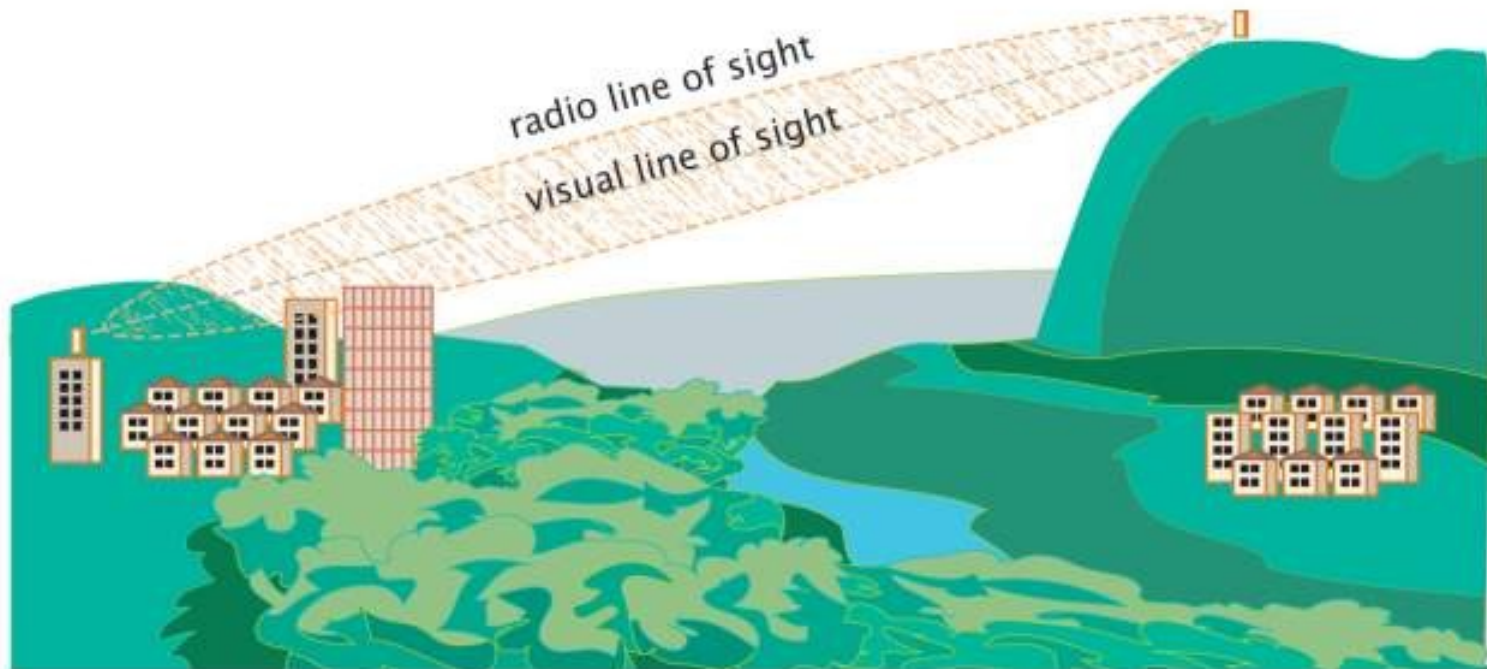
Obstacle situated in the middle ($d_1=d_2$):

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

The radio containing 60% of the total power:

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

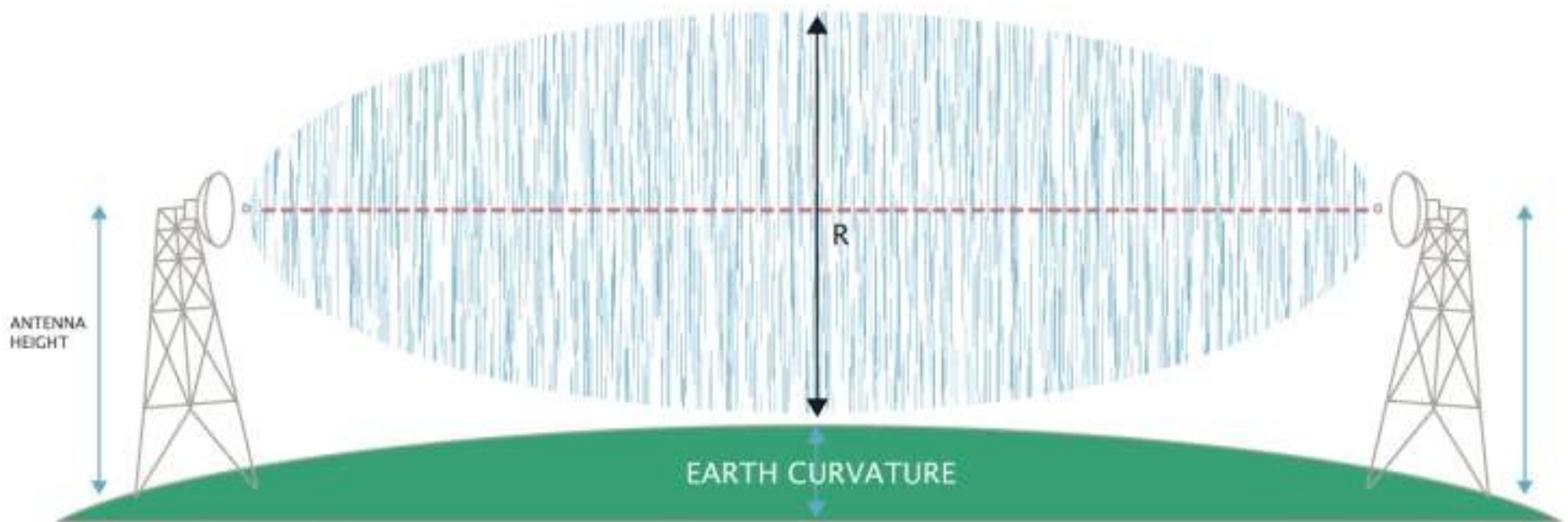
Free Space Propagation: Fresnel zones



Free Space Propagation: Fresnel zones

<i>Distance[km]</i>	<i>915 Mhz</i>	<i>2,4 Ghz</i>	<i>5,8 GHz</i>	<i>Height [m] (rel. earth*)</i>
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

<i>Card</i>	<i>11 Mbps</i>	<i>5,5 Mbps</i>	<i>2 Mbps</i>	<i>1 Mbp</i>
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)
- $\text{dB} = 10 \cdot \log(P(W)/(1W))$
- $\text{dBm} = 10 \cdot \log(P/0.001) = 10 \cdot \log(P(W)/1(\text{mW}))$
- $\text{dBi} = \text{dB}$ 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

$$\begin{aligned} &+ \text{Transmitter power [dBm]} \\ &- \text{Cable TX loss [dB]} \\ &+ \text{Antenna TX gain [dBi]} \\ &- \text{Free Space Path Loss [dB]} \\ &+ \text{Antenna RX gain [dBi]} \\ &- \text{Cable RX loss [dB]} \\ &= \text{Margin} - \text{Receiver Sensitivity [dBm]} \end{aligned}$$

Complete Link Budget: Example 1

- Distance: 50 kms (31,1 miles)
- Frequency: 2,4 GHz

<i>Element</i>	<i>Value</i>
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

<i>Element</i>	<i>Value</i>
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

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

where d is the distance

Other Relevant Calculations

- Bearing (angle towards north) and distance from latitude/longitude

$$\text{distance} = r * \arccos[\sin(\text{lat1}/57.2958) * \sin(\text{lat2}/57.2958) + \cos(\text{lat1}/57.2958) * \cos(\text{lat2}/57.2958) * \cos(\text{lon2}/57.2958 - \text{lon1}/57.2958)]$$

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

Support :: Calculations :: Terabeam Wireless - Mozilla

File Edit View Go Bookmarks Tools Window Help

Back Forward Reload Stop http://www.terabeam.com/support/calculations/index.php

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Click on any of the links below for more detailed information:

- [System Operating Margin \(SOM\)](#) - Calculates the system operating margin which is the difference between the signal a radio is actually receiving versus what is needed for good data recovery.
- [Free Space Loss](#) - Calculates the free space loss which is the transmission loss between two antennas.
- [milliWatts vs. dBm](#) - Converts milliWatts to dBm and dBm to Watts.
- [Downtilt Coverage Radius](#) - Provides the downtilt coverage radius by taking half of the beamwidth in each direction of the downtilt angle from the height of the antenna.
- [Antenna Downtilt](#) - Calculates the distance or tilt angle by providing the base height, remote height and either tilt angle or distance.
- [Fresnel Clearance Zone](#) - Calculates the radius of the fresnel zone at its widest point as well as 20% blockage by providing the distance and frequency.
- [Latitude/Longitude Bearing](#) - By providing latitude and longitude of a base and remote site it will provide the degrees from each site and distance in miles.

Note: The final value represents a first order approximation and should only be used as a guide. No guarantees or warranties are implied accordingly. For a more

Online Calculators

WLAN Link Planner - Mozilla

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Back Forward Reload Stop http://www.qsl.net/pa2hco/helix_wifilinkbudgetcalc/wlan_budgetcalc.html Print

Home Bookmarks

The Link Budget Calculation

Transmitting	Transmitter output power (common WLAN: +15dBm)	<input type="text"/>	dBm
	Cable loss (Normally -3 to -10 db, calculate here) Add connector loss (neg)	<input type="text"/>	dB
	Antenna gain (0dB, 8 dB (biquad) (+15 db, (helix) +24 dB (parabolic)	<input type="text"/>	dBi
Propagation	Free space loss (negative value! Calculate here)	<input type="text"/>	dB
Receiving	Antenna gain (0dB, 8 dB (biquad) (+15 db, (helix) +24 dB (parabolic)	<input type="text"/>	dBi
	Cable loss (Normally -3 to -10 db, calculate here) Add connector loss (neg)	<input type="text"/>	dB
	Receiver sensitivity (depending on manufacturer between -78 to -85 dBm @ 11 Mbps)	<input type="text"/>	dBm
Total	Remaining margin: <input type="button" value="Calculate"/>	<input type="text"/>	dB
Comments	<input type="text"/>		
Legal limit	<input type="text"/>		

Remarks:
1) To achieve a very reliable link a margin of at least 10 dB is needed. This accommodates for local fading (variations of

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


DCP: Tanzania : Kilimanjaro - Mozilla

File Edit View Go Bookmarks Tools Window Help

Back Forward Reload Stop <http://confluence.org/region.php?id=660>

{ Main | Search | Countries | Information | Member Page }


 **Tanzania : Kilimanjaro (visit information)**




2 visited, 2 total.

There are no Plans for this Region.

Map Legend

 **4°S 38°E**
10.0 km (6.2 miles) NNW of Katunene, Kilimanjaro, Tanzania

 **3°S 37°E**
5.6 km (3.5 miles) N of Engare Nairobi, Kilimanjaro, Tanzania


Confluences

DCP: 7 degrees south, 39 degrees east (visit #2) - Mozilla

Back Forward Reload http://confluence.org/confluence.php?lat=-7&lon=39

(Main | Search | Countries | Information | Member Page | Random)

7°S 39°E (visit #2)




Tanzania : Pwani

5.9 km (3.7 miles) SSW of Kazimzumbwi, Pwani, Tanzania


Approx. altitude: 191 m (626 ft)
([MapQuest](#) [Multimap](#) [World eXplorer](#))
Antipode: [2°N 141°W](#)

Accuracy: 8 m (26 ft)

Click on any of the images for the full-sized pictures.



#1: [31-May-04] (complete)



(visited by [Dorothea Stachetz](#) and [Thorsten Seitz](#))

05-Feb-2005 - As we managed to successfully visit [RS 39E](#) (near Kieni) before noon, we had a cold Cola and a short rest before starting our way back to Dar es Salaam. Taking the road via Kibiti and Mburanga, we enjoyed the landscape and

[sceneries](#) in the villages we passed.

Having the GPS "on" and since in a while looking at the indications, the team member being in charge of the "intelligence" realised that we were only 30 km from another Confluence - 7°S 39E. During ongoing discussions on weather, yes, or no, we decided somehow 'ad hoc' to pay a visit to the same. Looking at our map, we realised that the area is near a "shortcut" connecting the Selous Game Reserve, Kusarawe and Dar es Salaam, which we used several times before visiting the Selous.

But we could not find a track road leading us cross-country straight to that road. And we realised the best option would be to drive closer to Dar es Salaam, where the first road in western direction at Thamaka lead us to Kiserawe and brought us closer again to 7°S 39E. We managed to get as close as 1.2 km from the Confluence. Near to this distance we made out a small village where a group of youngsters sat around the central area. Having seen a small access road, we asked one of them if this track could be used by car. The communication turned out to be difficult, as our Swahili is limited and his English as well. We invited him to lead us the way. Frightened on closing the door of the car he left it open and tried to understand why we would like to look for a road behind the village.

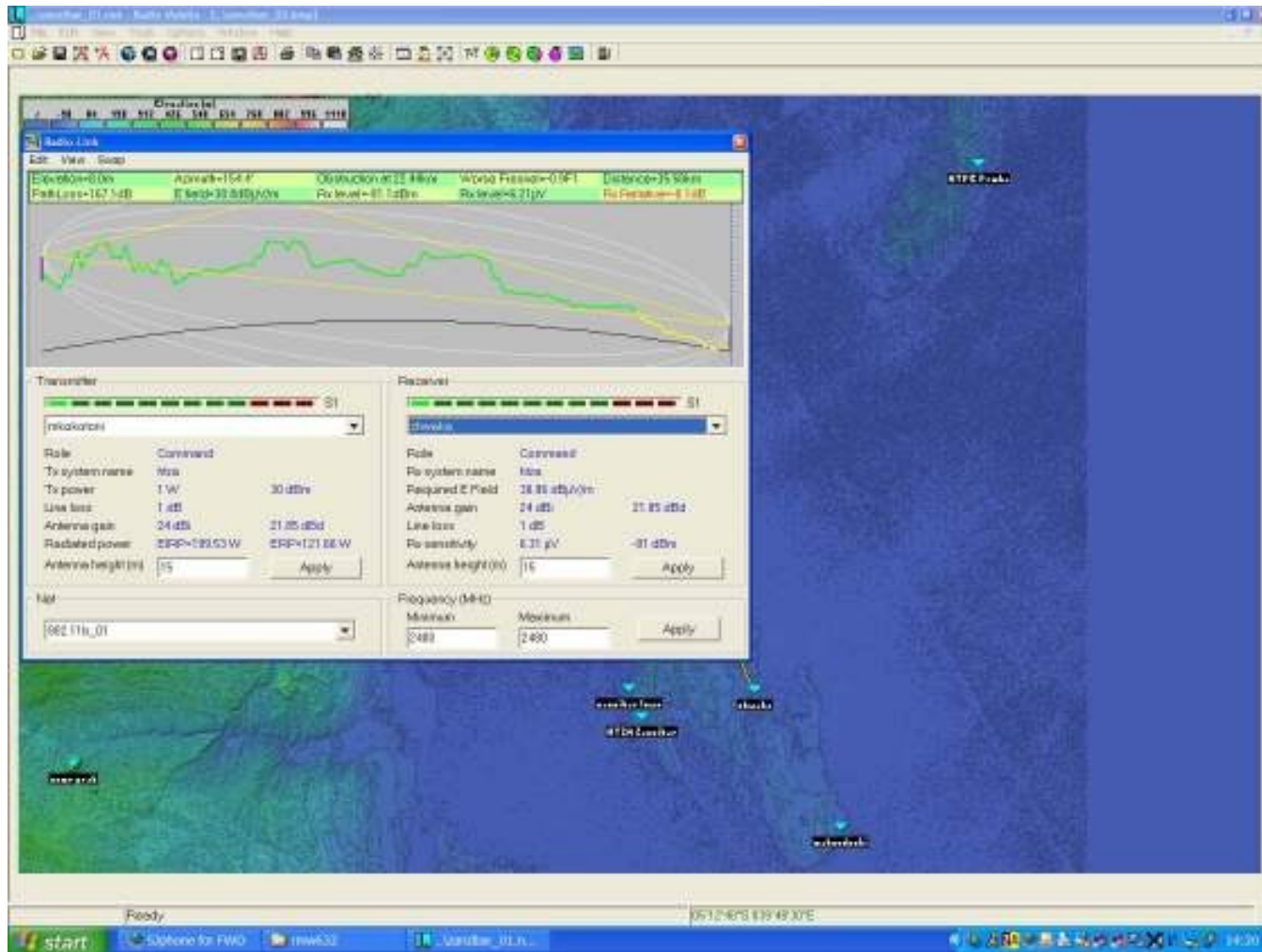
Apart from the lack of communication possibilities, we realised after some few metres that the track we saw earlier was not made to be used by any type of car. We stationed the car somewhere in a shade, filled our bag with cold drinks, and took the camera and the GPS with us. As before, we only saw puzzled faces of [youngsters](#), but as soon as we started walking we were surrounded by the same group, highly interested in our intention to just walk in some direction we would be taking out of a device in our hand. They seemingly enjoyed the moments when two musungus (white foreigners) stood in front of some footpath crossing, deciding on which direction to take by looking on that electronic equipment, similar to a cell phone.

http://confluence.org/photo.php?visitid=10058&pc=1

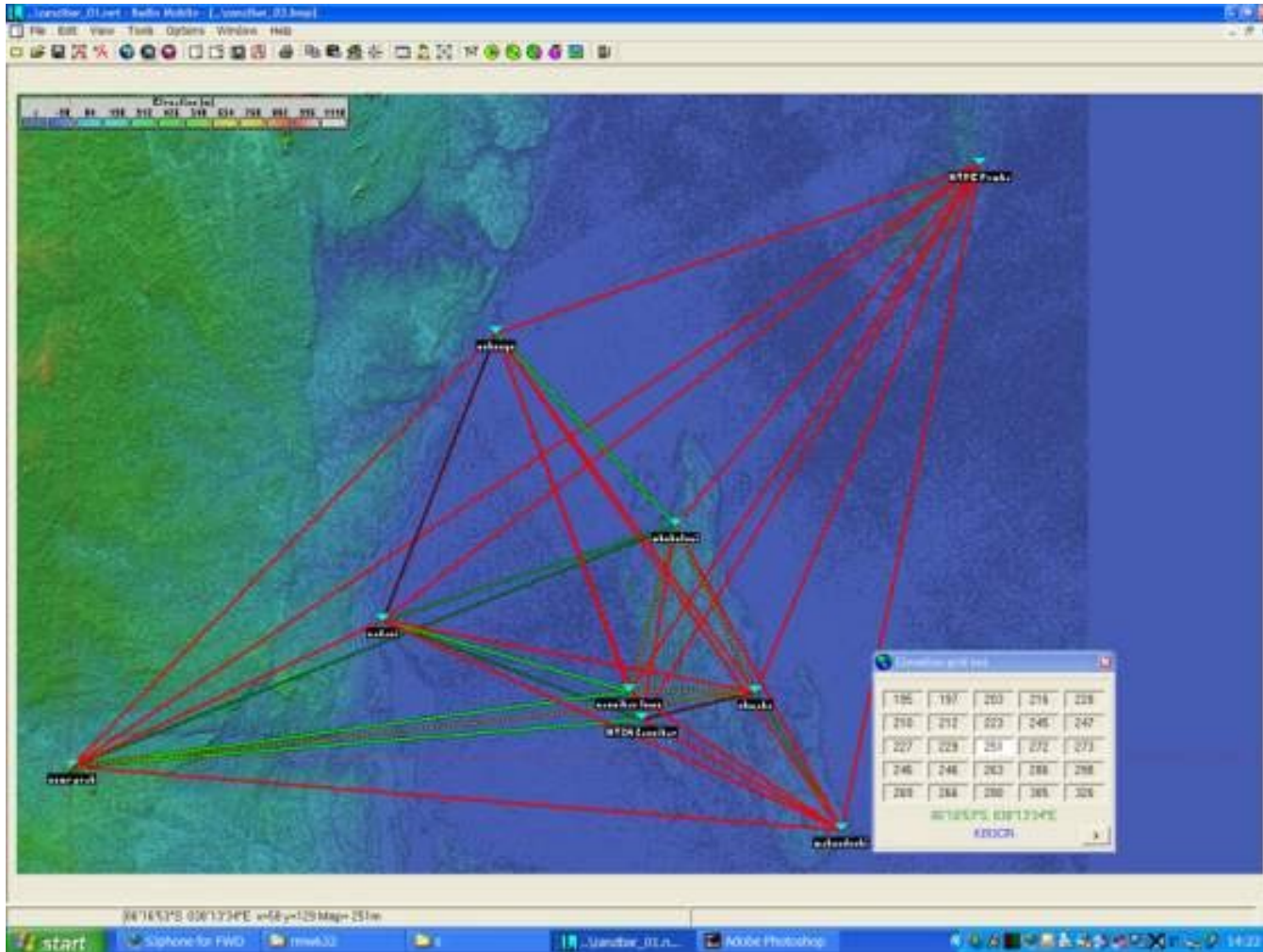
RadioMobile Software

- 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>

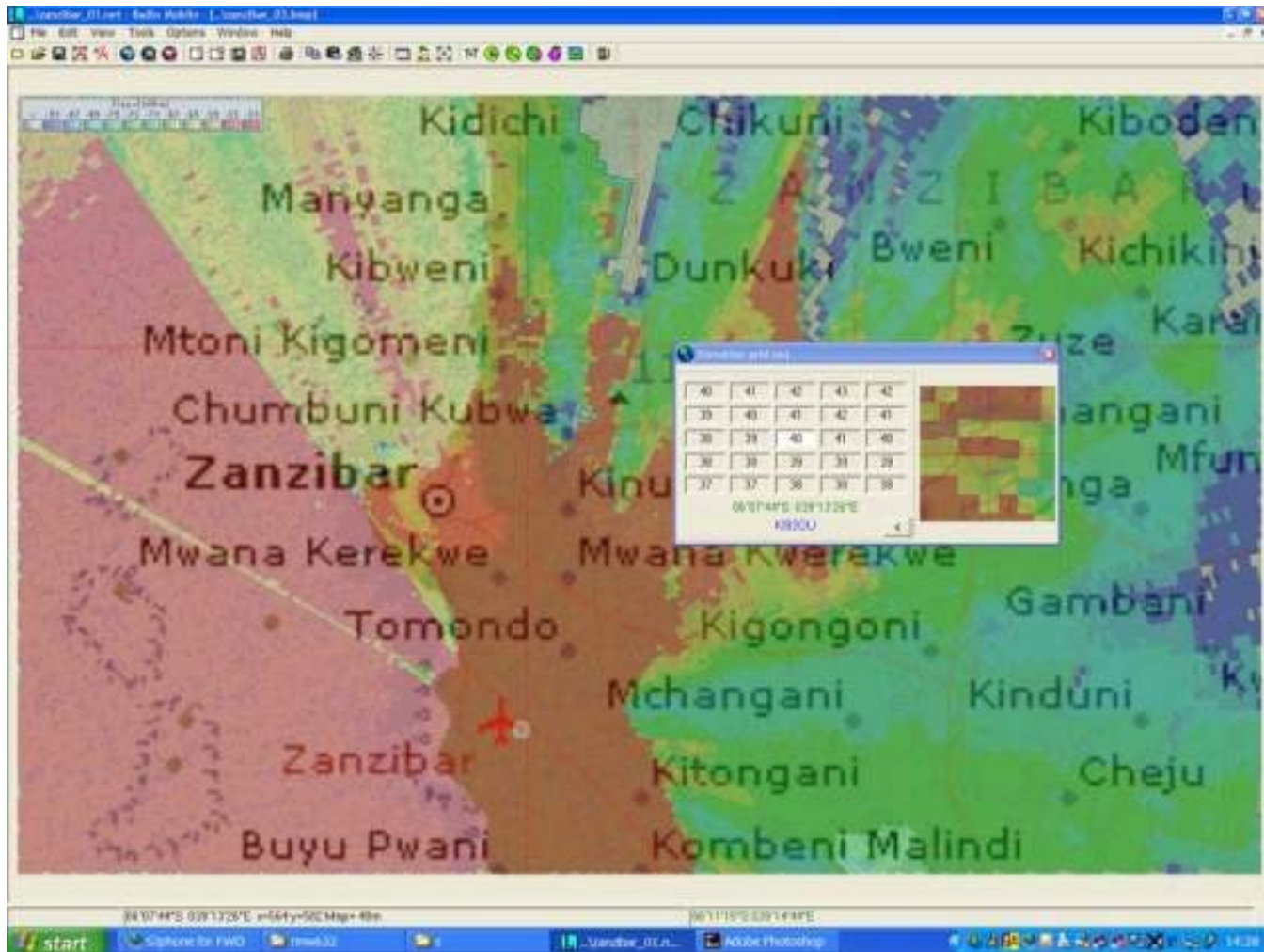
RadioMobile Software



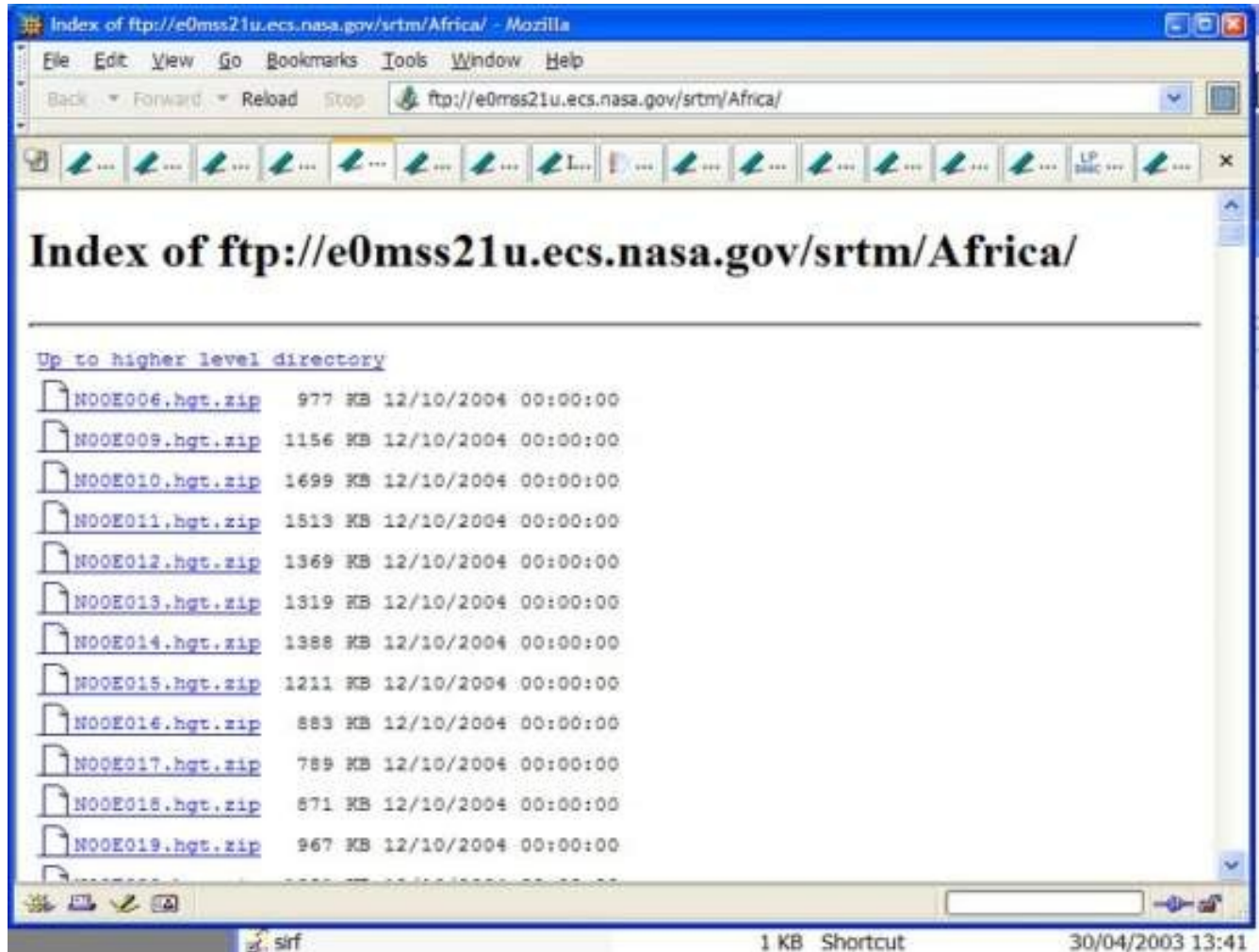
RadioMobile Software



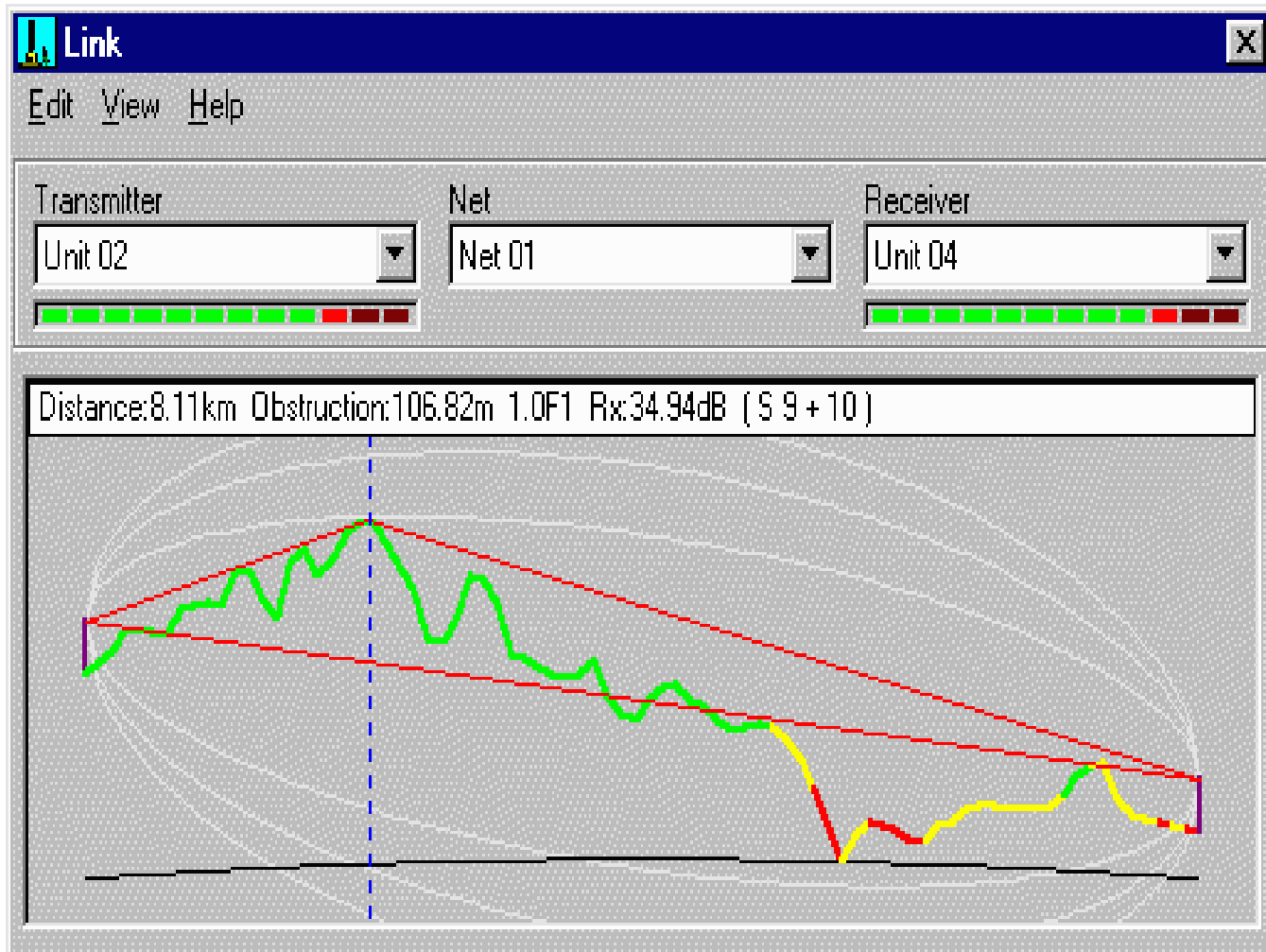
RadioMobile Software



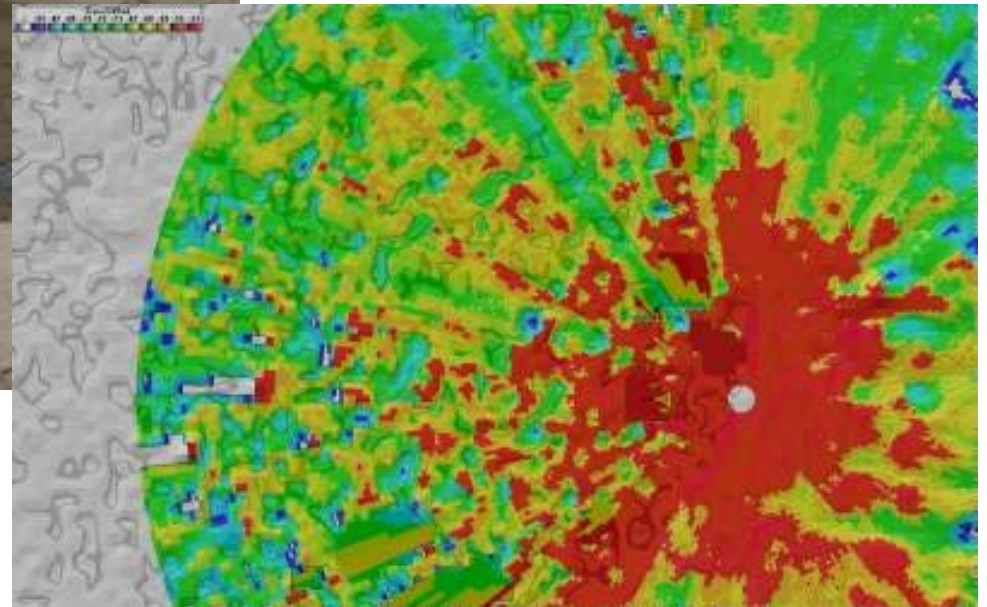
RadioMobile Software



RadioMobile Software



RadioMobile Software



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