Radio Link Calculation

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Developed by: Sebastian Buettrich

Goals

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

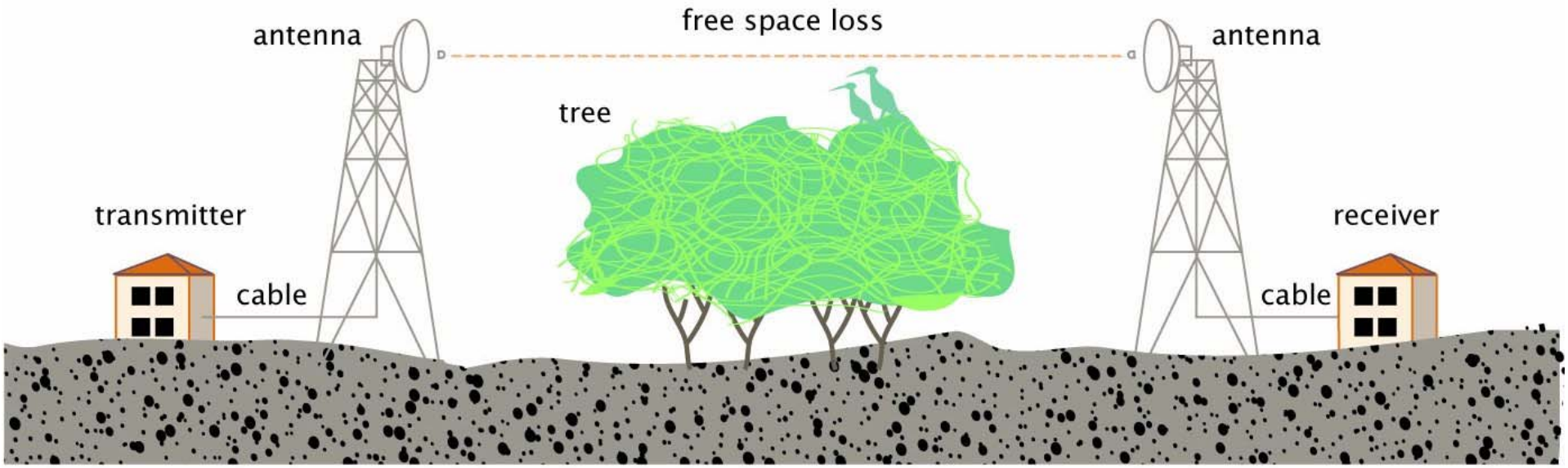
Elements of a radio link

- *Making a **link budget** – what does this mean?*

  Adding up all gains and losses from start to end, much like:
  “I gain 10 here, I lose 5 there, I gain 2 there, ...”
  and so forth.

- *And then, to know how to judge the result.*

Elements of a radio link



Transmitting side Free Space Receiving side

Elements of a radio link

- ***Effective transmit power:***
  transmit power [dBm] - (cable + connector) loss [dB] + amplifier gain [dB] + antenna gain [dBi]
- ***Free Space:*** *Free space loss [dB]*
- ***Effective receiving sensibility:***
  antenna gain[dBi] + amplifier gain [dB] - cable loss [dB] - receiver sensitivity [dBm]

The elements one by one

- *Complete radio link calculation is simply a sum of all contributions, with all values in dBs*
- *All positive values are gain*
- *All negative values are losses*
- *Realistic knowledge of component is key!*

Terms you will encounter

- Link budget / power budget / system gain
- System operating margin = what you have in the end
- *SNR: Signal-to-Noise ratio*
- *EIRP: Effective Isotropic Radiated Power*

Some Conversions

- Meter = Feet x 0.3048
- Km = Miles x 1.609344

- dBm = 30 + Log 10 (Watt)
- Watts = $10^{((dBm - 30)/10)}$
- MilliWatts = $10^{(dBm/10)}$

Transmit (TX) power

- What comes out of the radio unit
- Depends on regulatory limits and therefore on country/region and time
- Check vendor's technical specifications – and verify!
- may vary with temperature, voltage supplied etc
- Typical in 802.11b: 15 ... 20 dBm (30 ...100 mW)

Transmit (TX) Power

- *Example from a 802.11a/b card datasheet:*

  Output Power:

  802.11b: 18 dBm (65 mW) peak power
  802.11a: 20 dBm (100 mW) peak power

Cable loss

- Rule: antenna cable should be as short as possible
- Typical loss values range from
  1 dB/m down to less then 0.1 dB/m
- Frequency dependent
- Check datasheets (and verify)

Cable loss: typical values

Cable Type	loss [dB/100m]	
RG 58	ca. 80-100	“thin black”
RG213	ca. 50	“big black”
LMR-200	50	
LMR-400	22	
Aircom plus	22	
LMR-600	14	
1/2” Flexline	12	
7/8” Flexline	6.6	

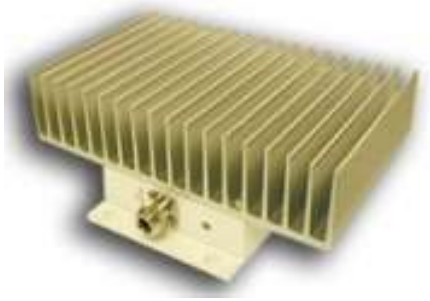
Cable loss – connectors & lightning arrestors

- **Allow at least – 0.25 dB (loss) for each connector in your cabling**
- **Check data sheets for loss at your frequency for your connector type**
- **Lightning arrestors: loss circa 1 dB**

Amplifiers

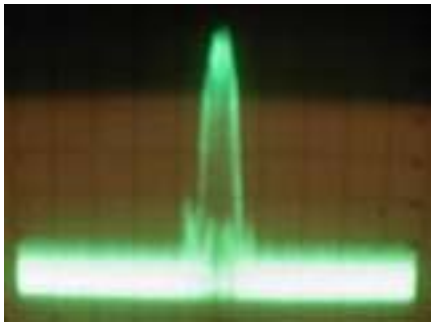
- **optionally, amplifiers might be used – mostly, to make up for cable loss**
- **high quality amplifiers are expensive**
- **amplifiers may change frequency characteristics (broadening) and add noise**
- **intelligently optimized antennas and high receive sensitivity are better than brute force amplification**
- **consider legal limits**

A bit off-topic: Amplifiers

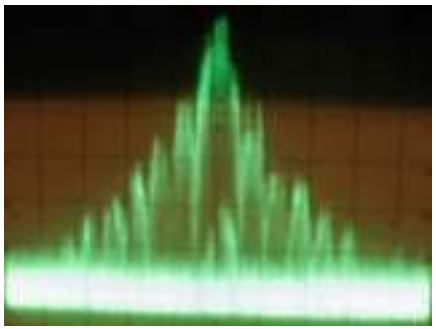


What a (cheap) amplifier might do:

before



after



Antenna – Transmitter side

- Antenna gains range from
  2 dBi (simple integrated antennas)
  5 dBi (standard omnidirectionals)
  up to
  25-30 dBi (parabolas)
- verify that you really get the nominal gain
  (tilt losses, polarization losses, etc)

Free Space Loss

- Proportional to the square of the distance and also proportional to the square of the radio frequency
- ***FSL [dB]****= C + 20 * Log(D) + 20 * Log(F)*

  D distance, and F frequency [MHz].
  The constant C is 36.6 if D is in miles, and 32.5 if D is in kilometers.

Free Space Loss - values

	915 Mhz	**2.4 Ghz**	**5.8 Ghz**
1 km	92	100	108
10 km	112	120	128
100 km	132	140	148

loss in dB

Free Space Propagation: Fresnel zones

- r = 17.33 sqrt(d1*d2/f*d) radius for first zone [m]

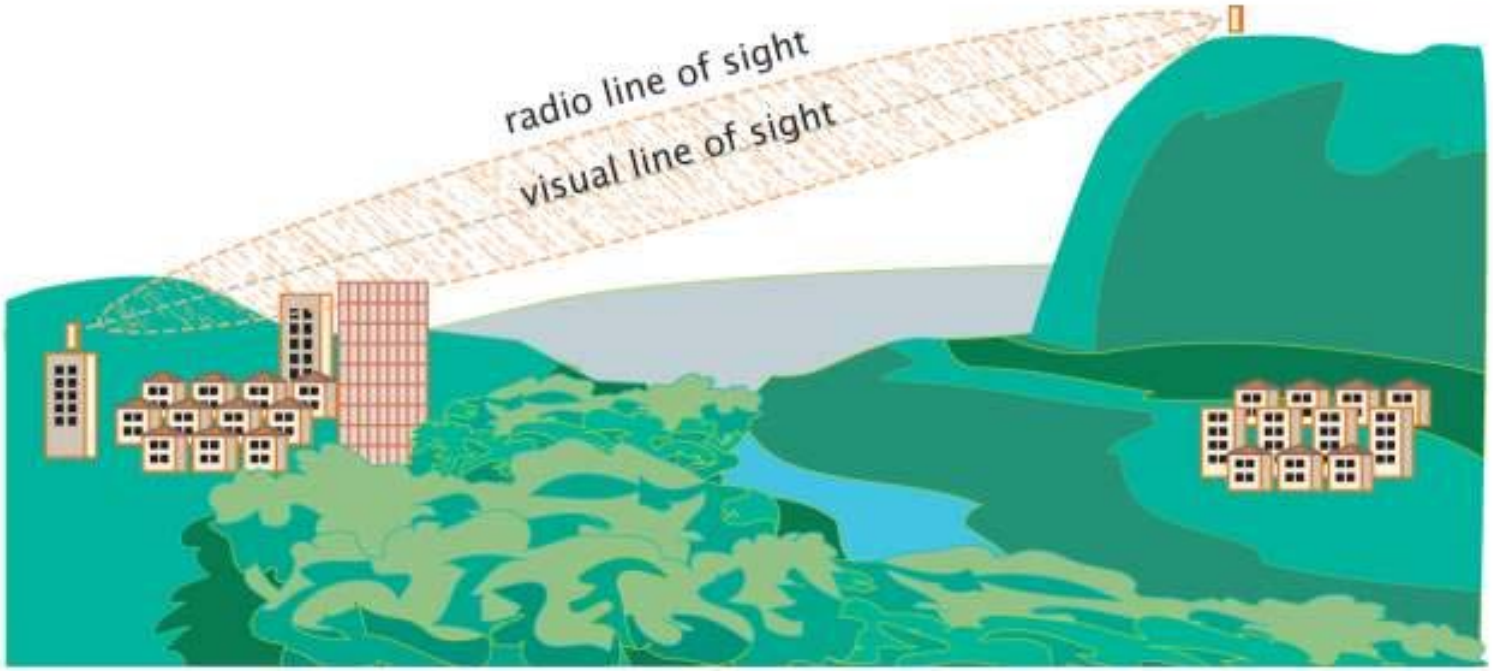
  d1, d2 distances from obstacle to link end points,
  d link distance [km], f [Ghz]

- if d1 = d2 (= obstacle in the middle)

  r = 17.33 sqrt (d / 4*f)

- r (60%) = 10.4. (d / 4*f)

Free Space Propagation: Fresnel zones

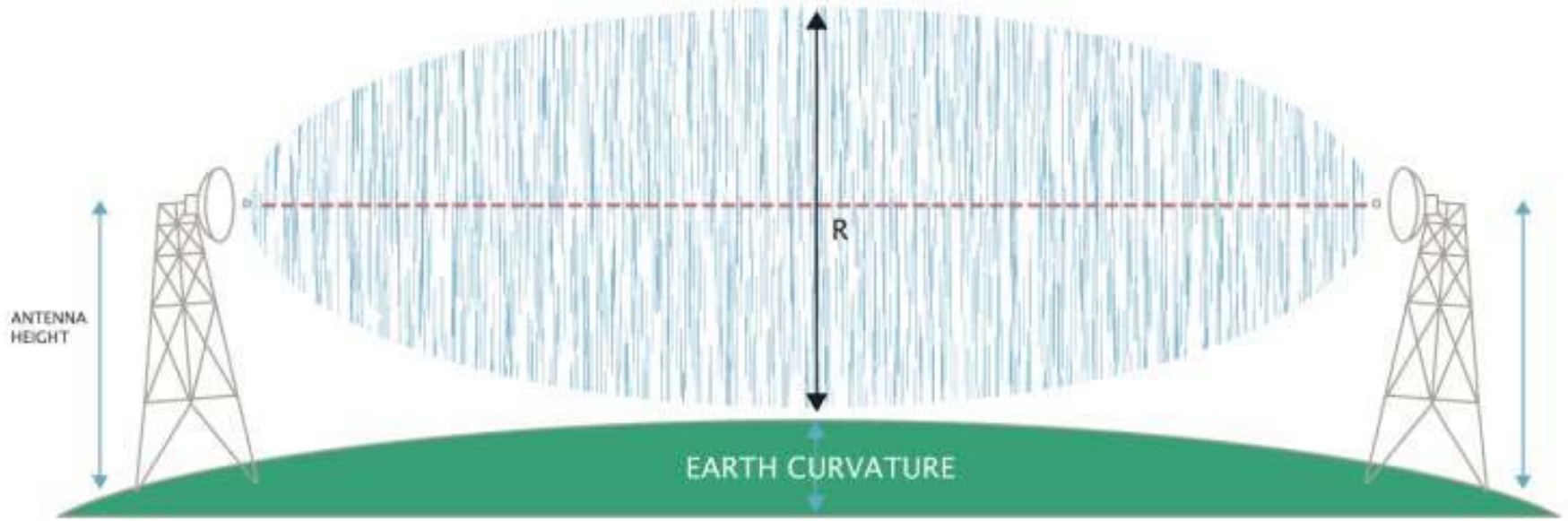


Free Space Propagation: Fresnel zones - values

	915 Mhz	2.4 Ghz	5.8 Ghz	rel. earth height
1 km	9	6	4	0.02
10 km	29	18	11	2
100 km	90	56	36	200

radius first fresnel zone [m]

Free Space Propagation: Fresnel zones



Antenna – Receiver side

- Calculation is the same as for antenna – transmitter side (there is no real difference between transmitting and receiving on the physical level anyway)

Cable on receive side

- Calculation is the same as on transmit side

Amplifiers on receive side

- Same as on transmit side
- Again, not a suggested method

Receiving Sensitivity

- *Reminder: receiving sensitivity tells you how much power the radio card needs to receive to function properly*
- *Typical values are -85 dBm for maximum data rate in 802.11b*
- *Example: Orinoco cards PCMCIA Silver/Gold*
  11Mbps => -82 dBm ; 5.5Mbps => -87 dBm;
  2Mbps=> -91 dBm; 1Mbps=> -94 dBm.
- *Example: Senao 802.11b card*
  11 Mbps => -89dBm; 5.5 Mbps =>-91dBm
  2 Mbps => -93dBm; 1 Mbps => -95dBm

The complete link budget

- *We show 2 realistic examples and discuss them*
- *A key question is:*
  ***How much margin do you need** for a working link?*

  Some people say 12 dB, some say 8 dB ...
  it really depends on expectations towards stability,
  and how optimistic you are :)

Complete link budget – ex. 1

- *Transmit output* *+ 015 dBm*
- *Cable + Connectors* *- 003 dB*
- *Antenna TX* *+ 024 dBi*
- *FSL (50 km / 31.1 miles at 2.4 Ghz)* *- 134 dB*
- *Antenna RX* *+ 024 dBi*
- *Cable + Connectors* *- 003 dB*
- *Receive Sensitivity* *- 085 dBm (subtract!)*

- ***TOTAL*** ***+ 008 dB margin***

Complete link budget – ex. 2

- *Transmit output* *+ 018 dBm*
- *Cable + Connectors* *- 005 dB (low quality cabling)*
- *Antenna TX* *+ 005 dBi (an omni)*
- *FSL (1 km / 0.622 miles at 2.4 Ghz)* *- 100 dB*
- *Antenna RX* *+ 008 dBi (patch antenna)*
- *Cable + Connectors* *- 005 dB (bad again :)*
- *Receive Sensitivity* *- 092 dBm (subtract!)*

- ***TOTAL*** ***+ 13 dB margin***

Other relevant calculations

- Antenna tilt to compensate for earth curvature and 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

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,
  water surfaces,
  ... and many many other things!
- They are difficult to know and they change with time!
- You find terms like *rain fade*, *urban fade*, ...
- **Easily the most important contributions,**
  and at the same time the hardest to control !!!
- **So, link calculation is one thing, reality another!!!**

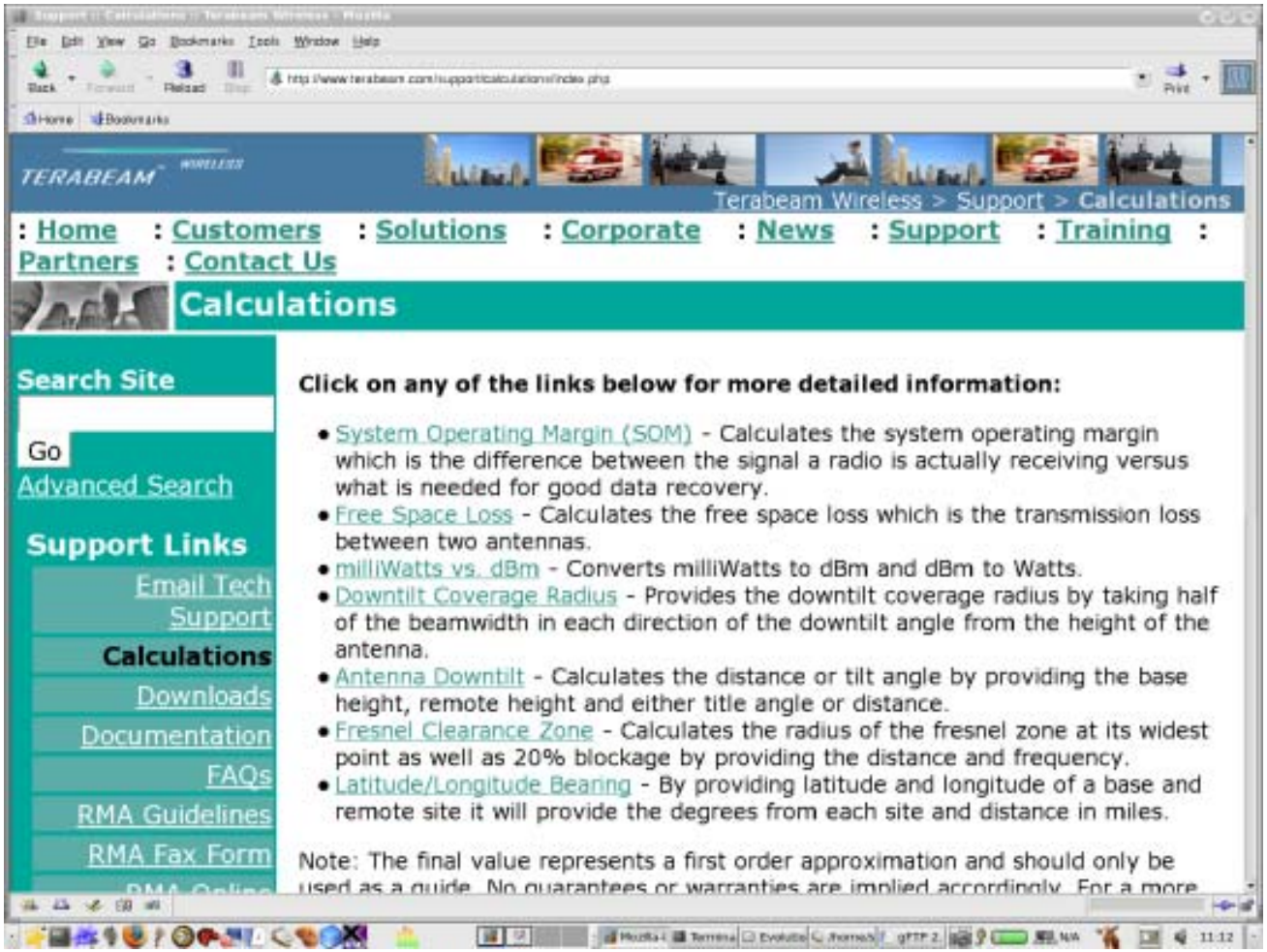
Factors from higher OSI layers

- Not only the physical layer (radio propagation) determines the performance of (long distance) links
- Drivers, implementations and settings etc have an influence
- E.g. the ACK/PCF/timing settings of wireless cards that become relevant for long links

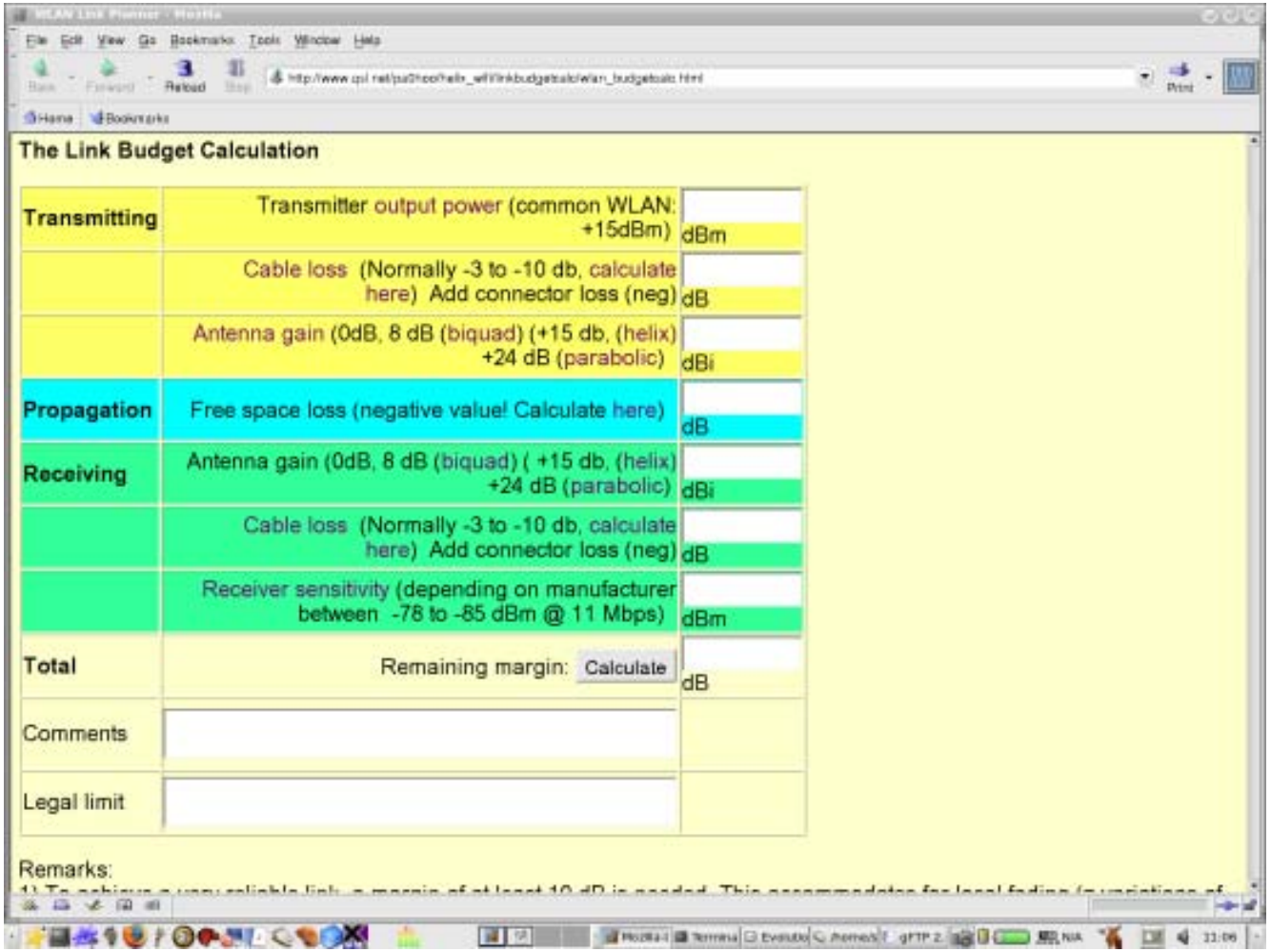
Online calculators

- You do not have to do the Mathematics from scratch and on your own
- Online Calculators are a great help and integrate a lot of experience of others before you
- **BUT, make sure that you can calculate without being online – sites can disappear, and you may be offline when you plan the link!**
  (have a spreadsheet or a JavaScript based calculator ready ... or simply pen and paper!)
- **One example of a spreadsheet tool is made available with this unit**

Online calculators



Online calculators



The Link Budget Calculation

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

Remarks:

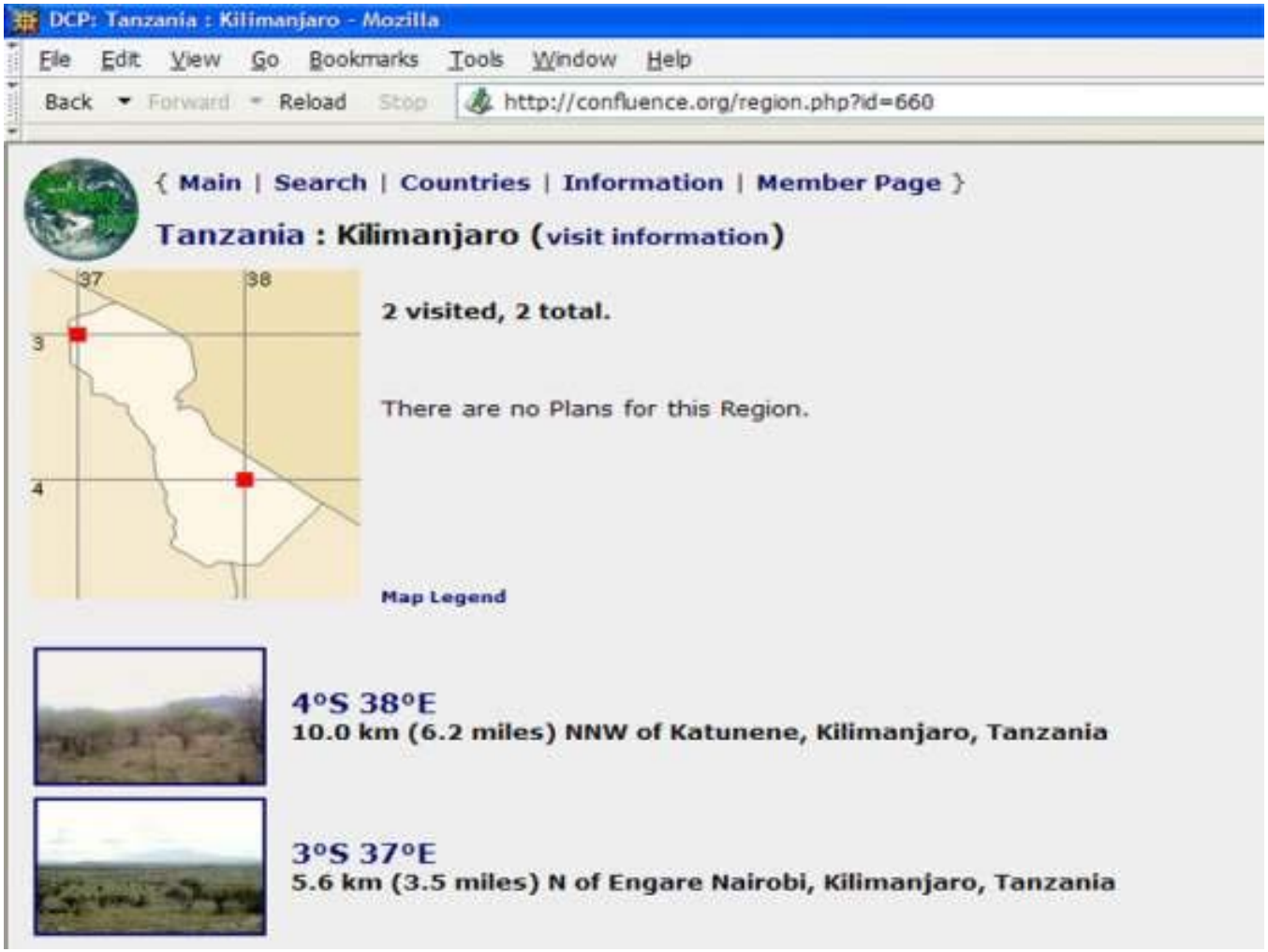
Some URLs for calculators

- http://www.google.com/search?hl=en&lr=&q=wireless+link+calculator&btnG=Search
- http://www.terabeam.com/support/calculations/index.php (ex-YDI.com)
- http://www.qsl.net/n9zia/
- http://www.qsl.net/pa0hoo/helix_wifi/linkbudgetcalc/wlan_budgetcalc.html
- http://www.zytrax.com/tech/wireless/calc.htm
- http://www.connect802.com/antenna_c_main.php
- http://www.connect802.com/literature.htm
- http://my.athenet.net/~multiplx/cgi-bin/tilt.main.cgi

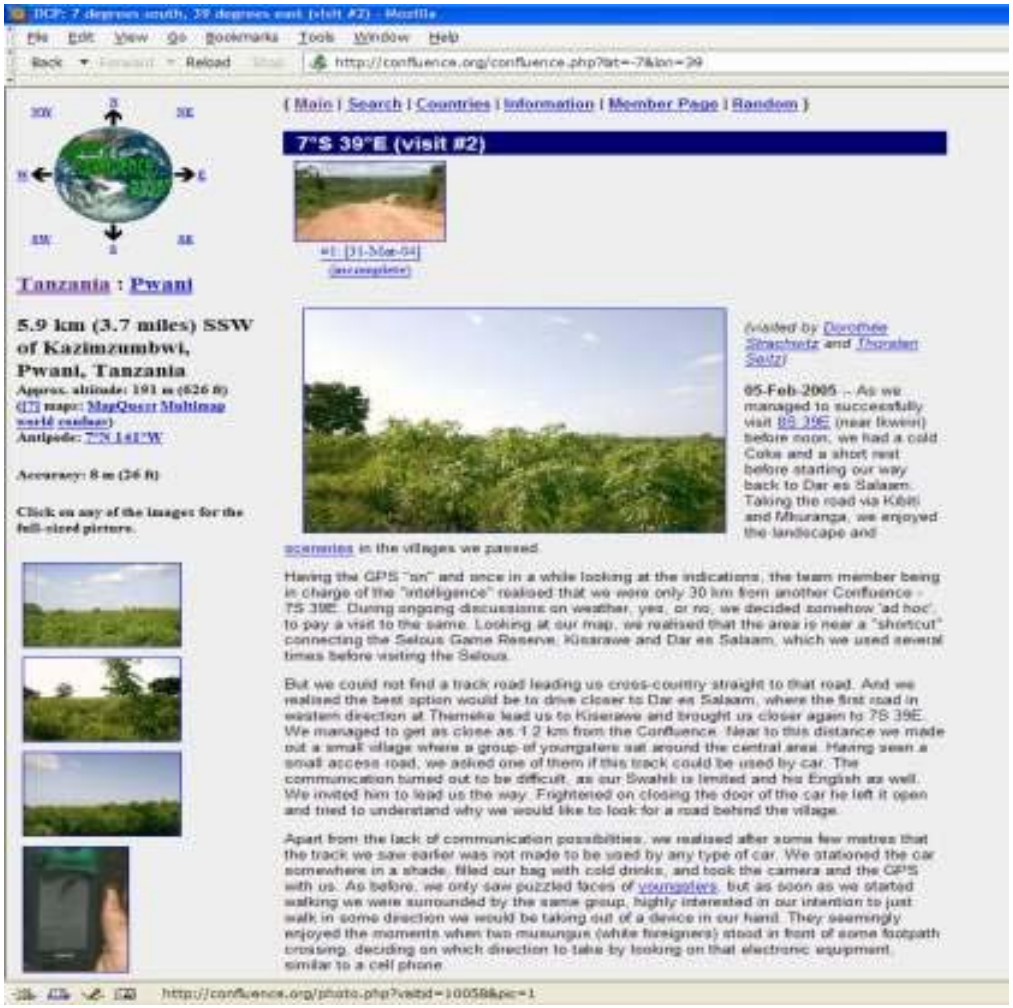
Sources of lat/long, elevation, and distance data

- 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 very rough first view
- ***Don't forget local knowledge and methods ... asking a villager or using fireworks can be a good way to find out about distance :)***

Confluences



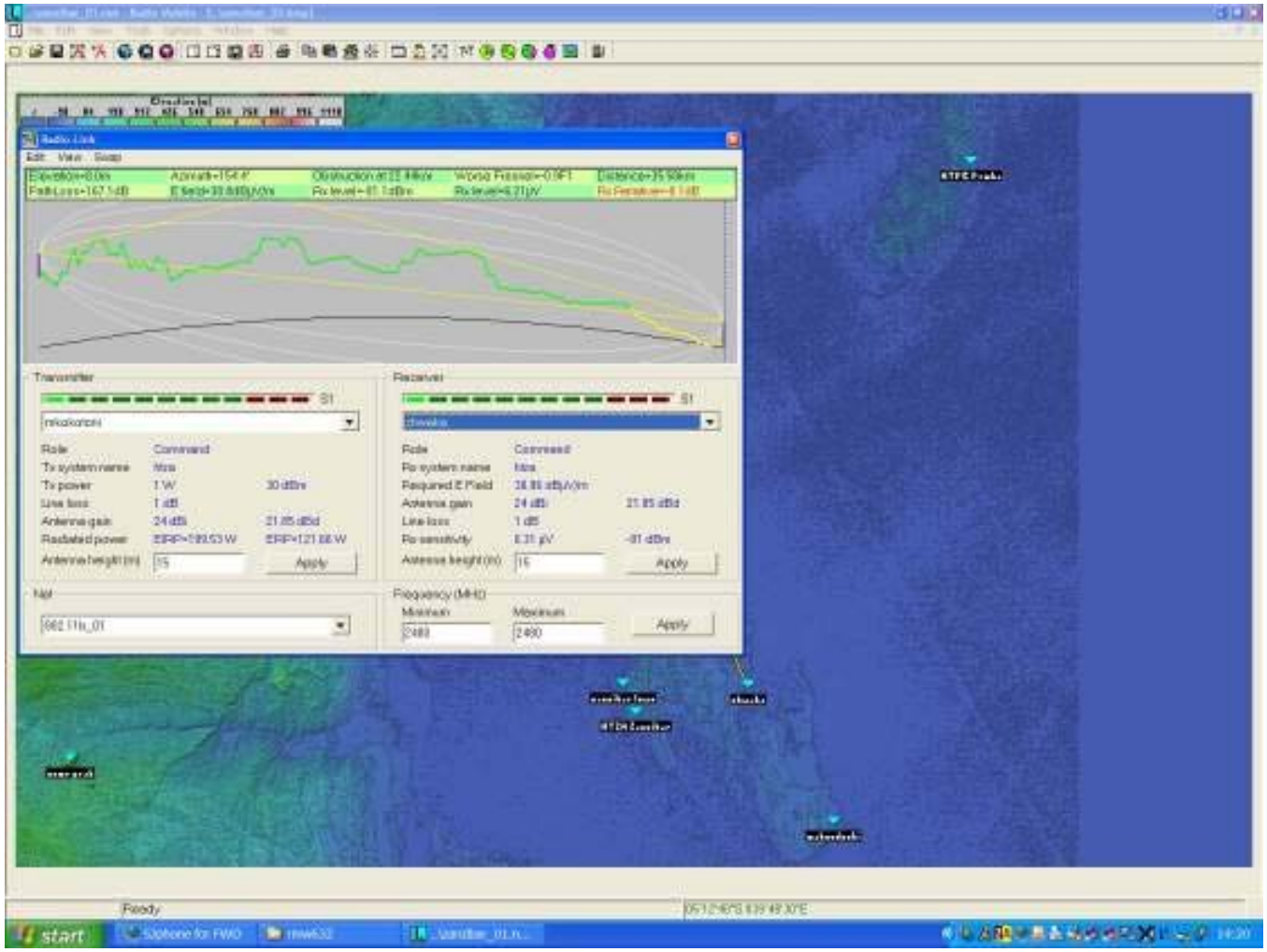
Confluences



RadioMobile Software

- Integrated network planning, LOS and coverage calculations based on terrain data
- Free software from the ham 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



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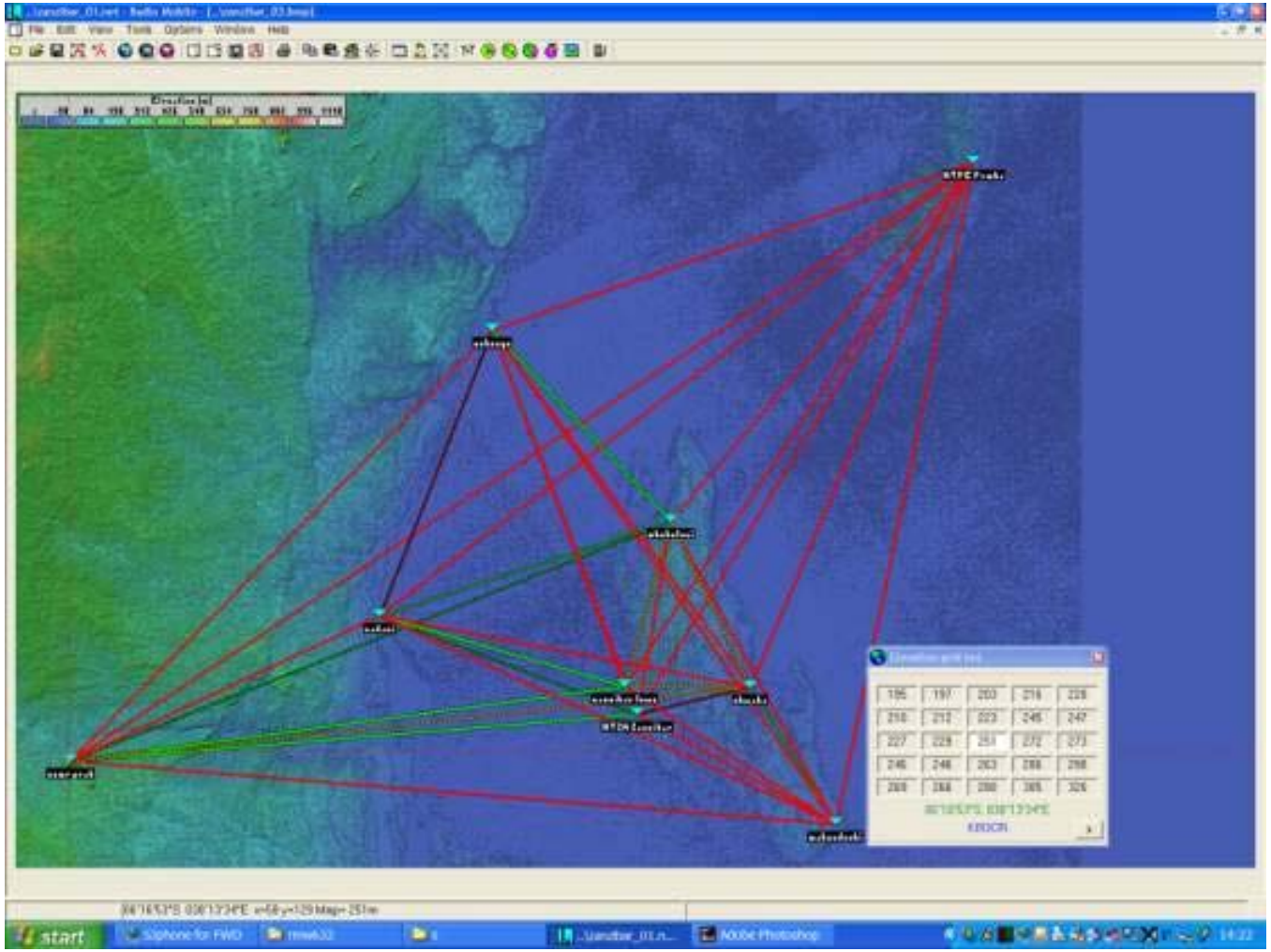

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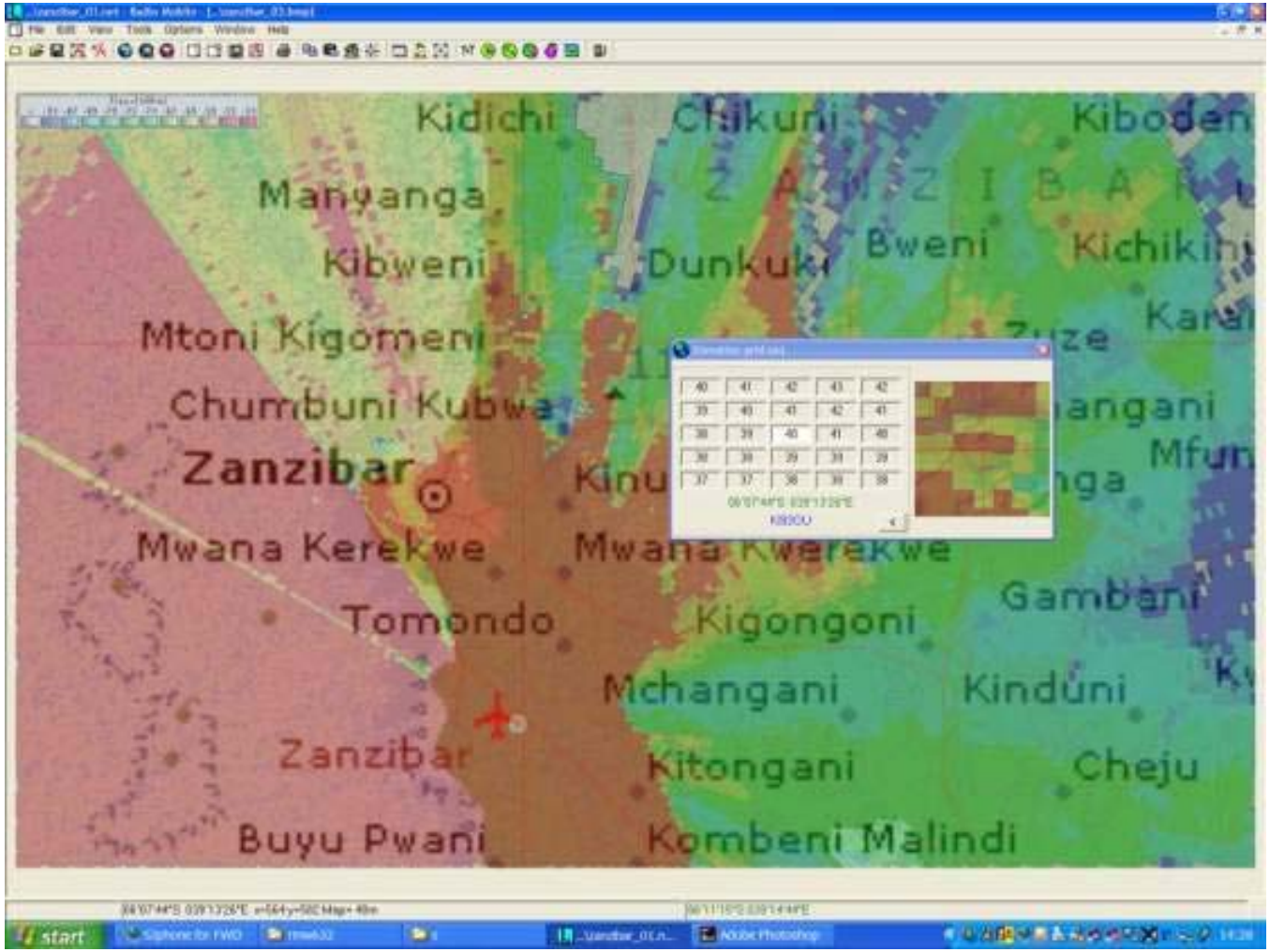

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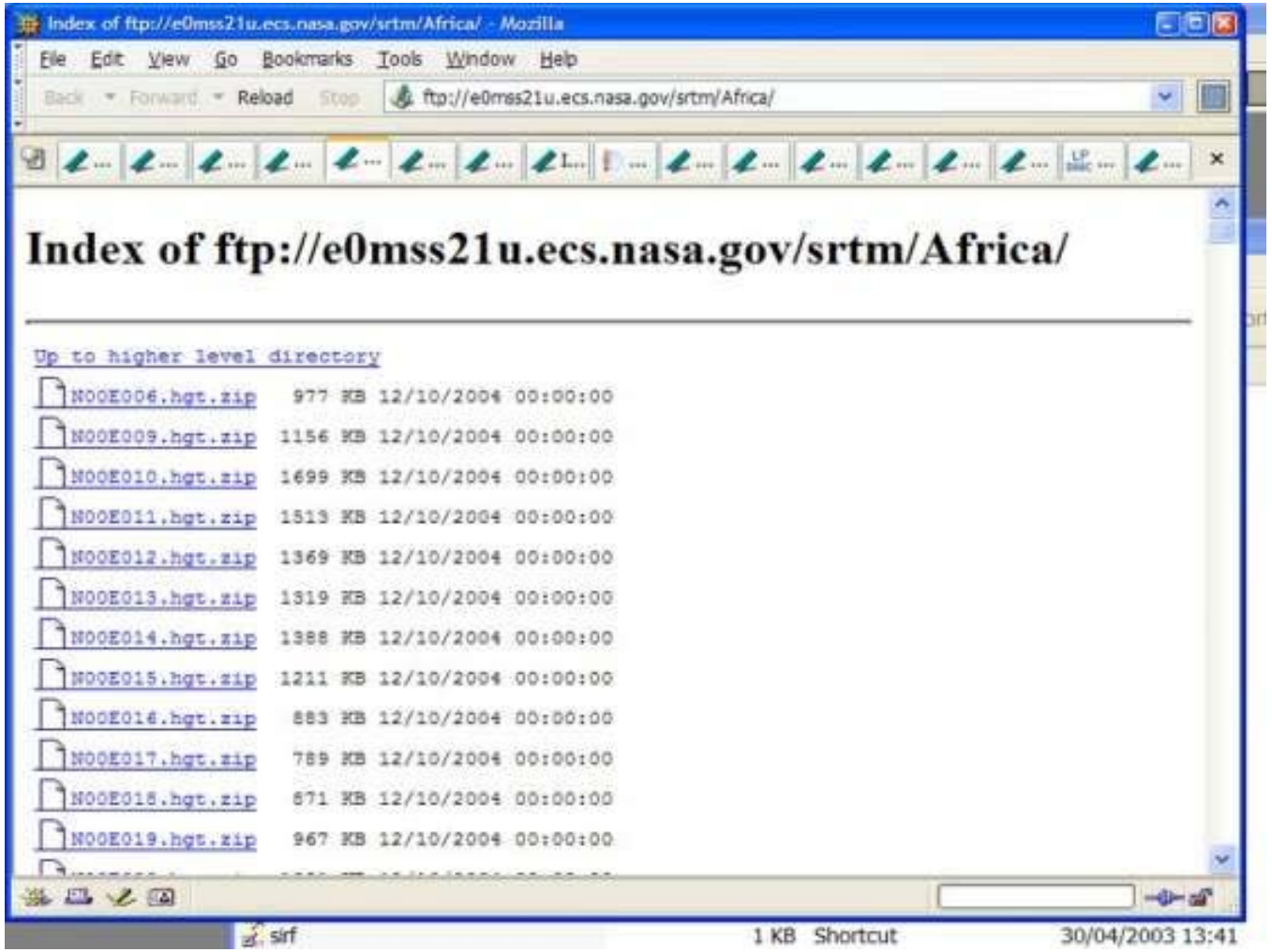

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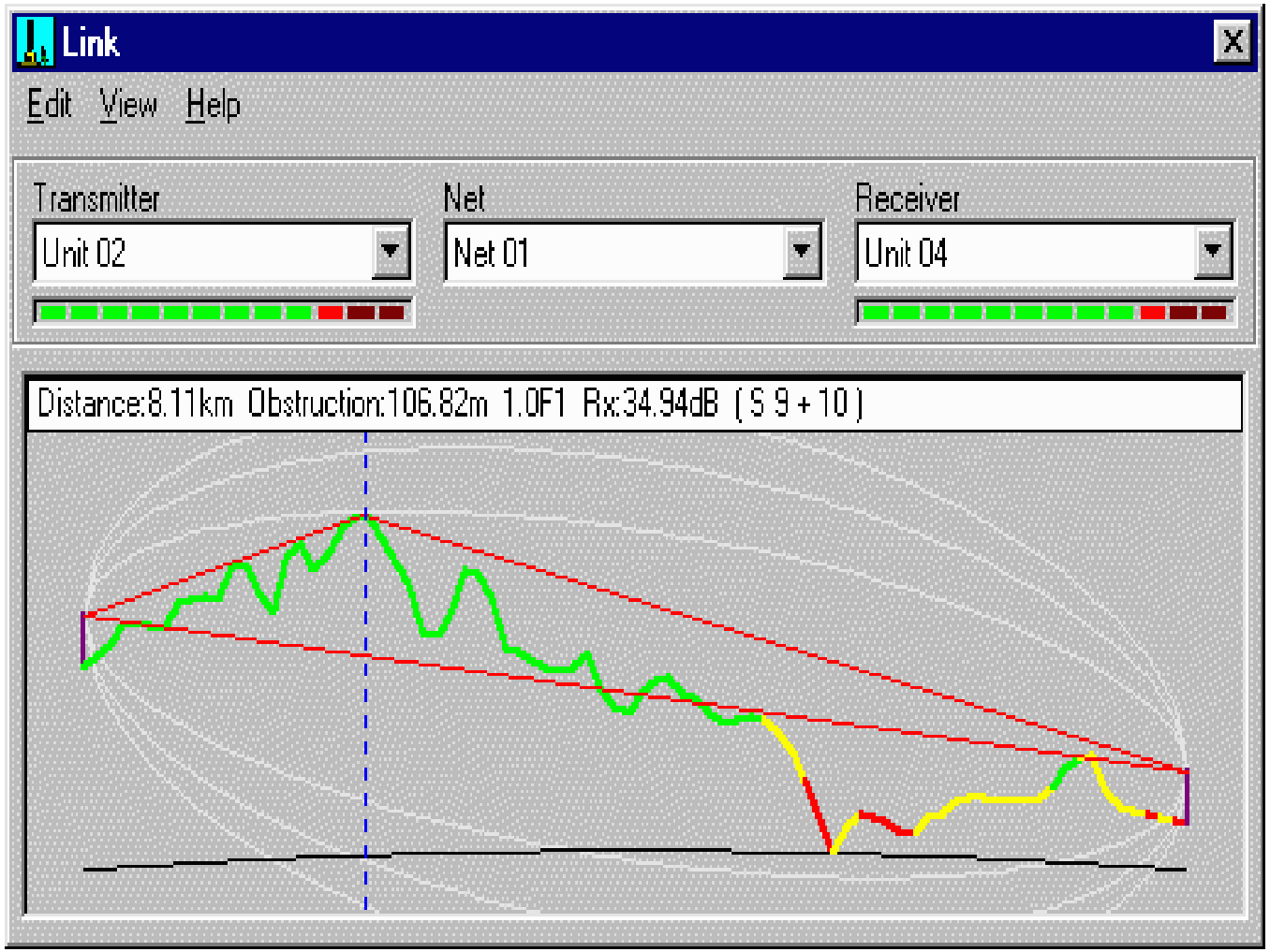

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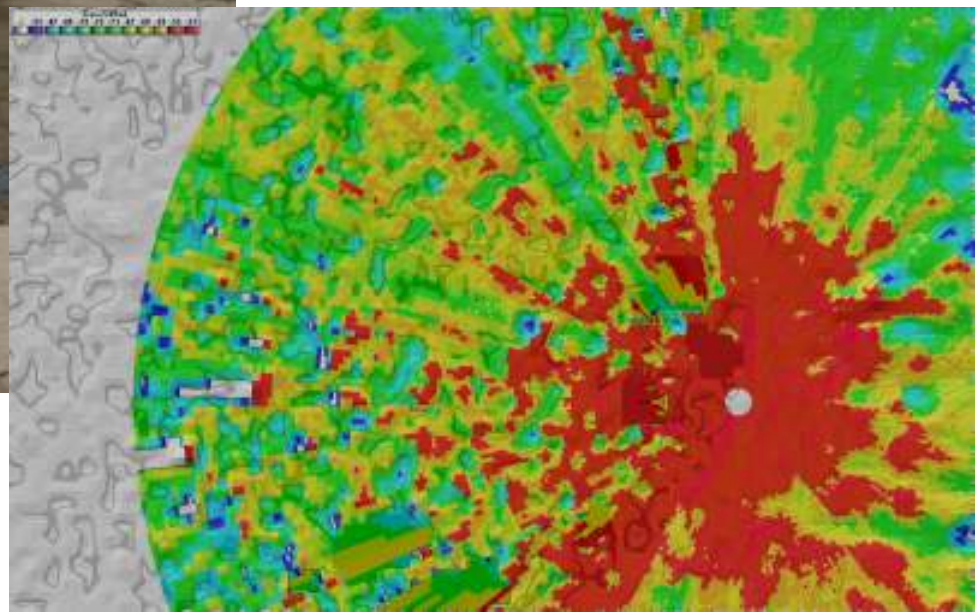

In summary

- *Remember to think about each component before keying in a number*
- *Remember to give results a reality check*
- *use online and offline tools*