

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 some of these elements in detail*
- *To enable us to evaluate results in close touch with reality*

Elements of a radio link

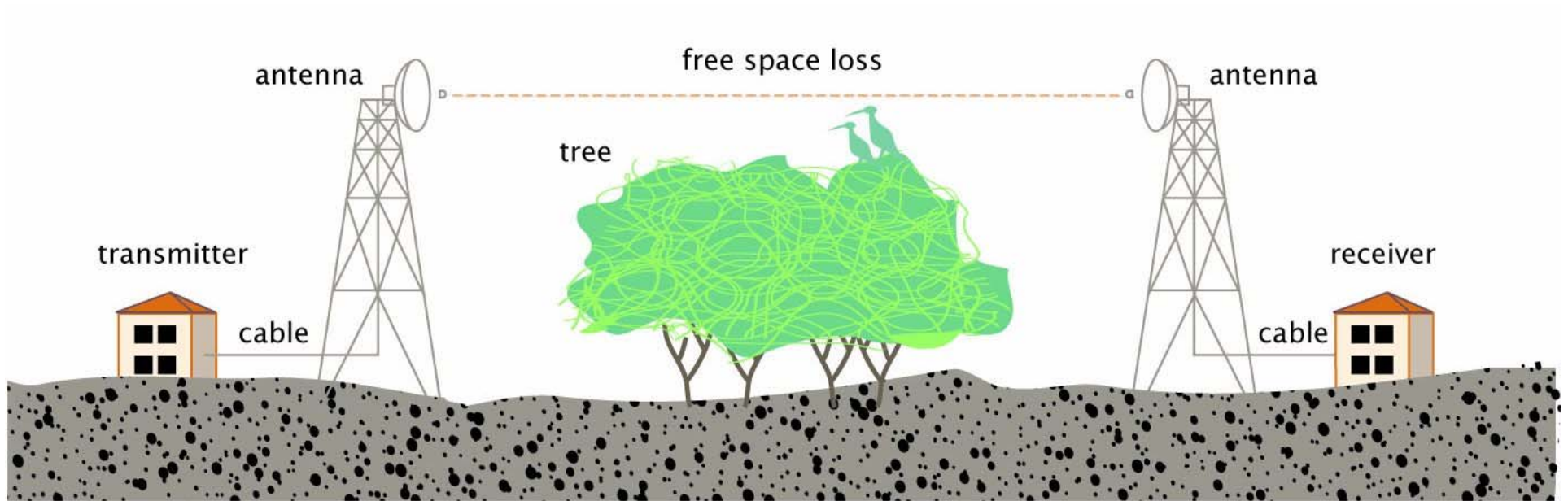
- *Making a **link budget** – what does this mean?*

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

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 than 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**

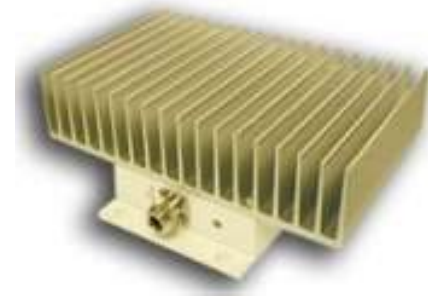
Cable loss – connectors & lightning arrestors

- **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**

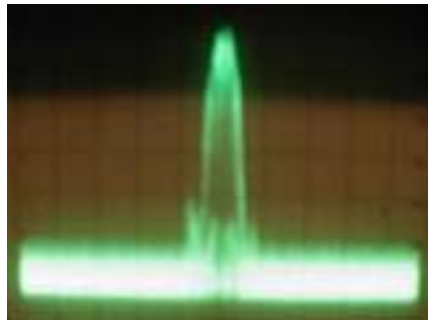
Amplifiers

- **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**

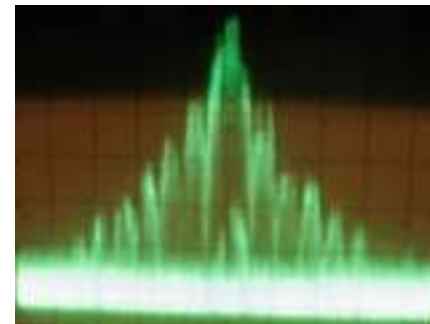
A bit off-topic: Amplifiers



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
- **$FSL [dB] = C + 20 * \text{Log}(D) + 20 * \text{Log}(F)$**

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

- $r = 17.33 \sqrt{d_1 \cdot d_2 / f \cdot d}$ radius for first zone [m]

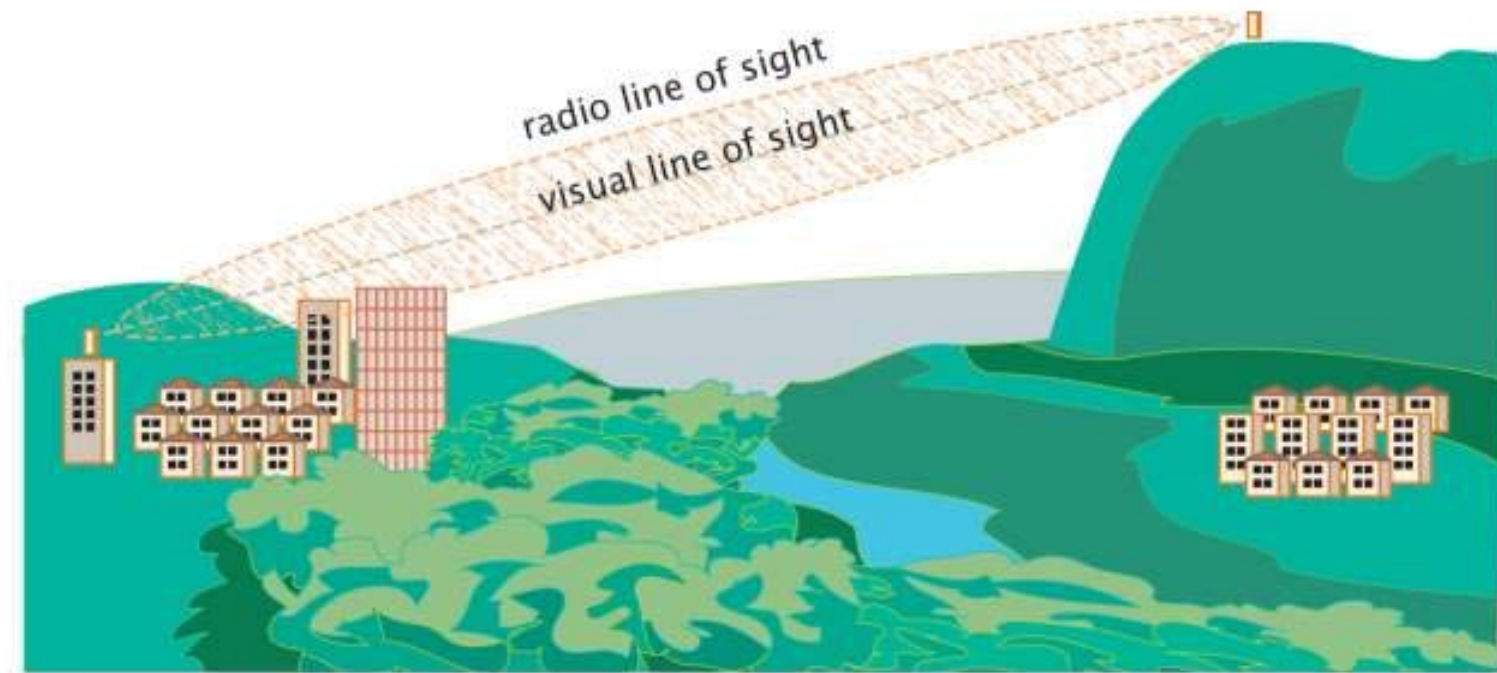
d_1, d_2 distances from obstacle to link end points,
 d link distance [km], f [Ghz]

- if $d_1 = d_2$ (= obstacle in the middle)

$$r = 17.33 \sqrt{d / 4 \cdot f}$$

- $r (60\%) = 10.4 \cdot \sqrt{d / 4 \cdot f}$

Free Space Propagation: Fresnel zones

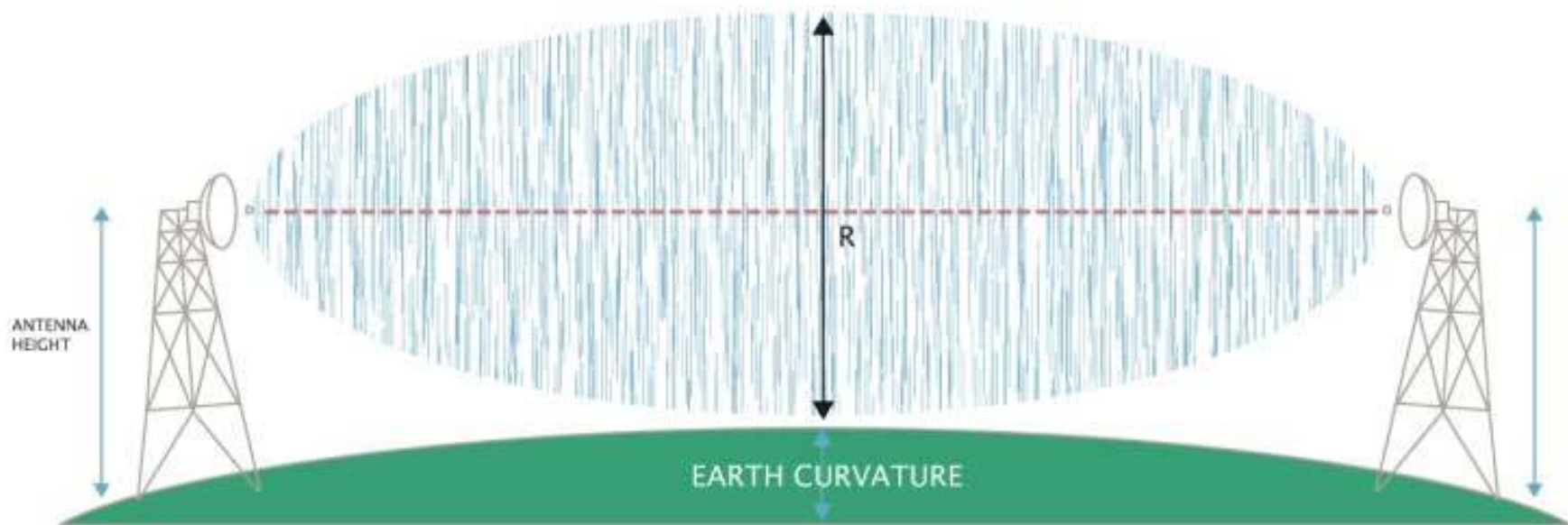


Free Space Propagation: Fresnel zones - values

	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

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 =

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

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, 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

Support :: Calculations :: Terabeam Wireless :: Home

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

The screenshot shows a web browser window titled "WLAN Link Budget Calculator". The address bar contains the URL: http://www.qsl.net/sa2hco/helix_wlflinkbudgetcalc/wlan_budgetcalc.html. The main content area is titled "The Link Budget Calculation" and contains a table with the following rows:

Category	Description	Unit
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: <input type="button" value="Calculate"/>	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

- <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

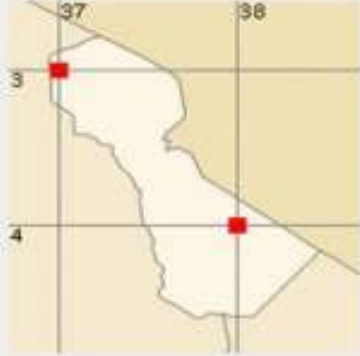
DCP: Tanzania : Kilimanjaro - Mozilla

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

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

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

7°S 39°E (visit #2)

#1: [11-May-04] (as complete)

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.

05-Feb-2005 -- As we managed to successfully visit [RS 39E](#) (near Ikwin) before noon, we had a cold Coke 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 once 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, Kiserawe 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 Themba 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.

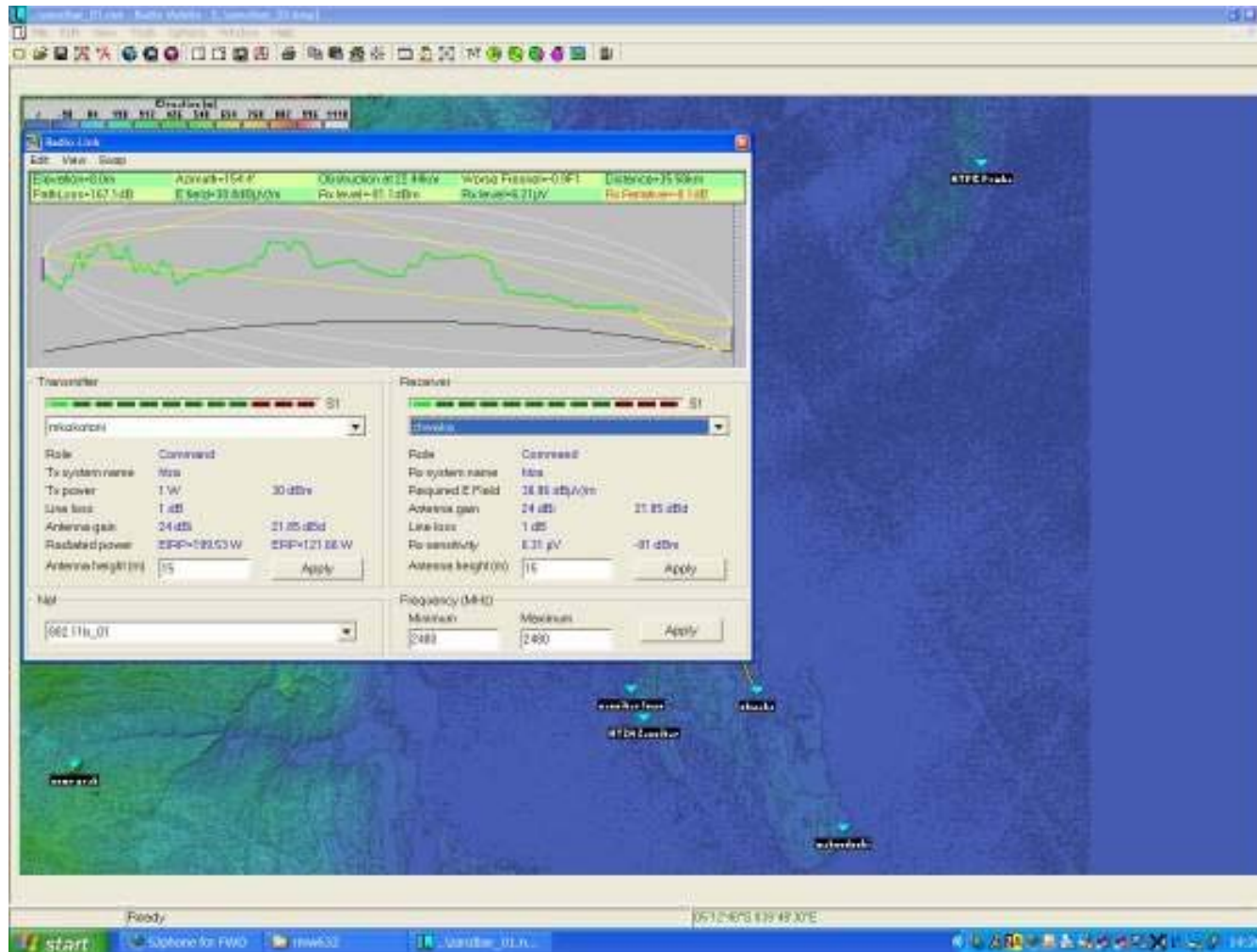
Apart from the lack of communication possibilities, we realised after some few metres that the track we saw earlier was not made to be used by any type of car. We stationed the car somewhere in a shade, filled our bag with cold drinks, and took the camera and the GPS with us. As before, we only saw puzzled 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?visit=10058&pc=1>

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>

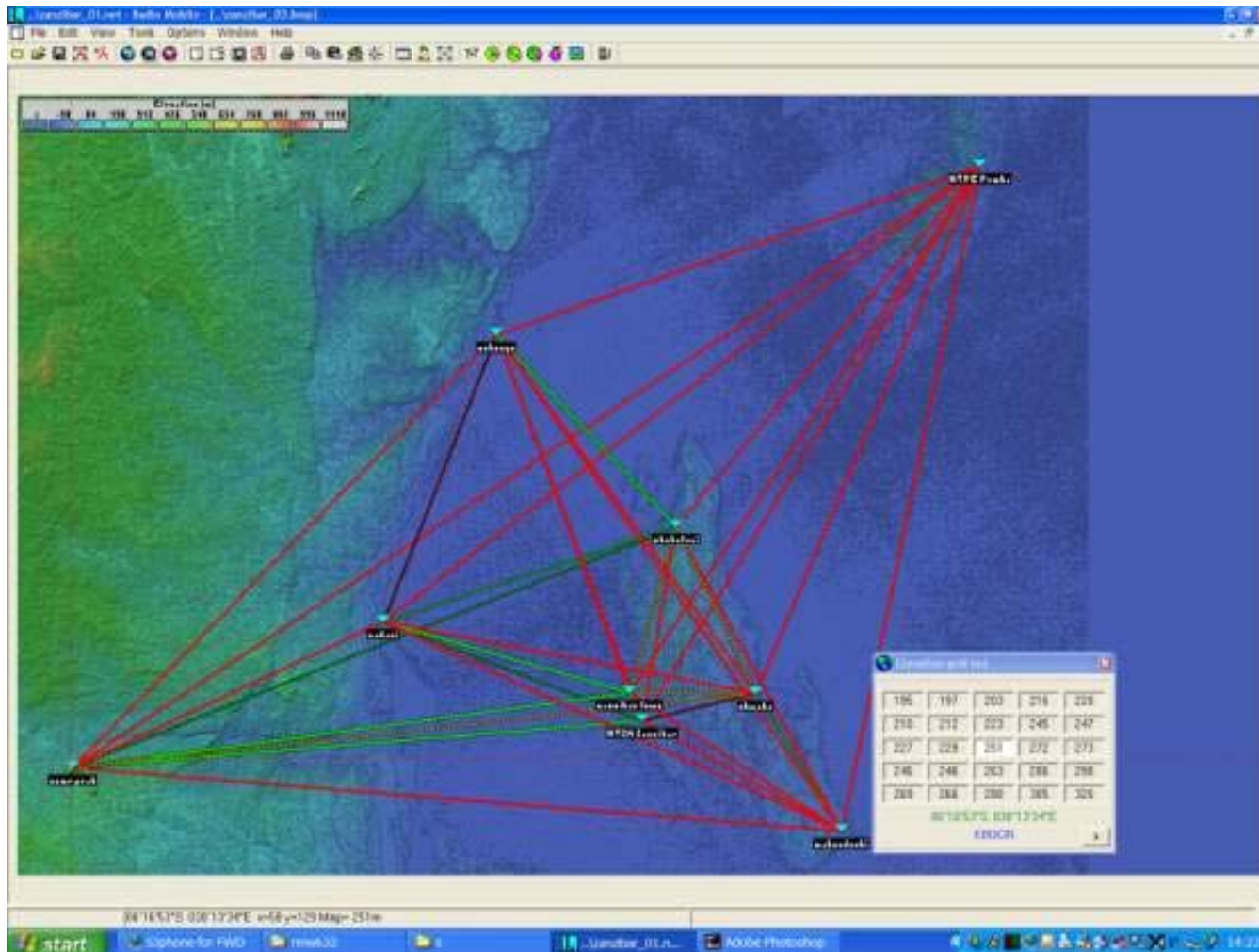
RadioMobile Software



Created September 2005
Sebastian Büttrich

ItrainOnline MMTK
www.itrainonline.org/itrainonline/mmtk

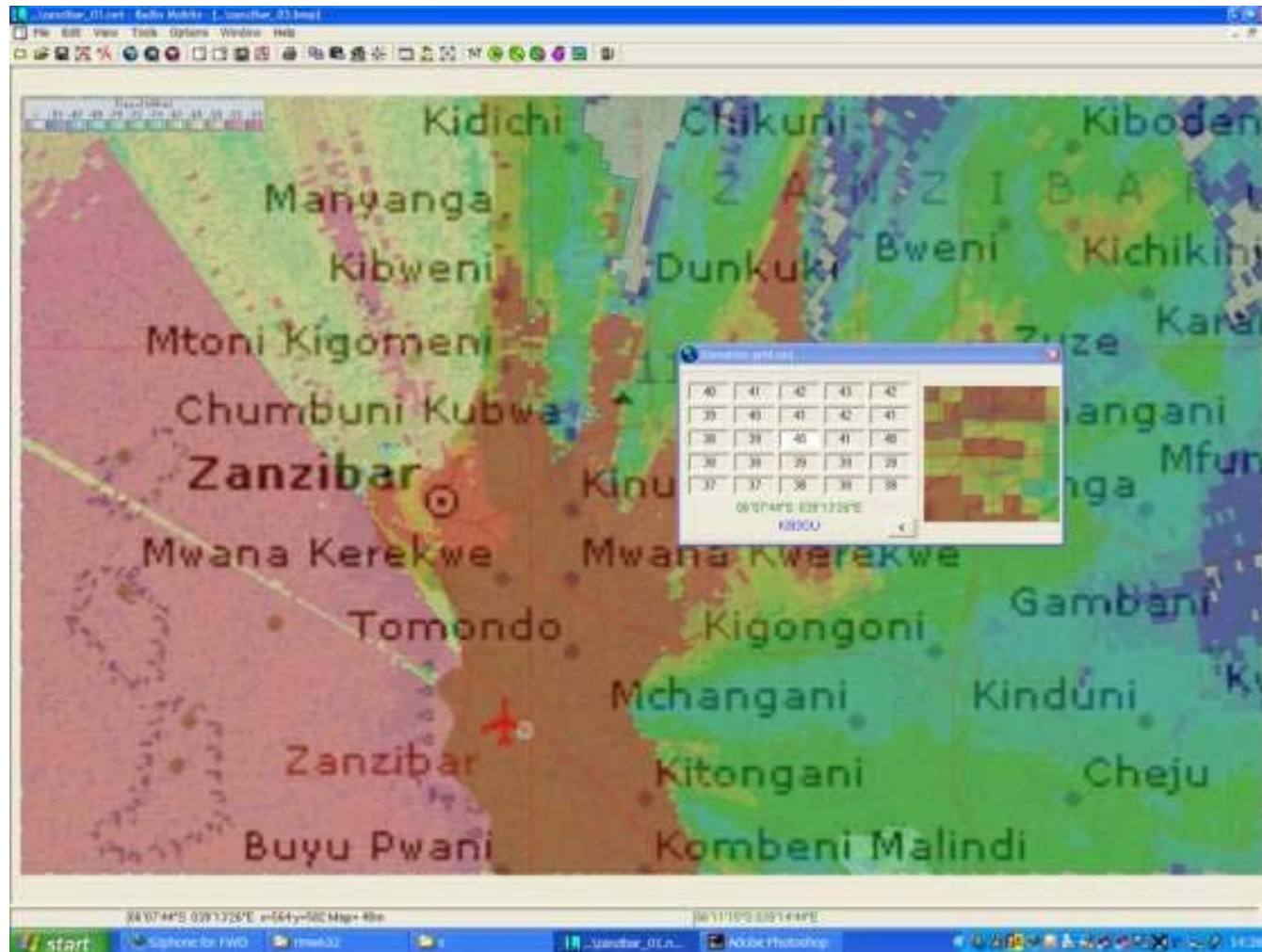
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ItrainOnline MMTK
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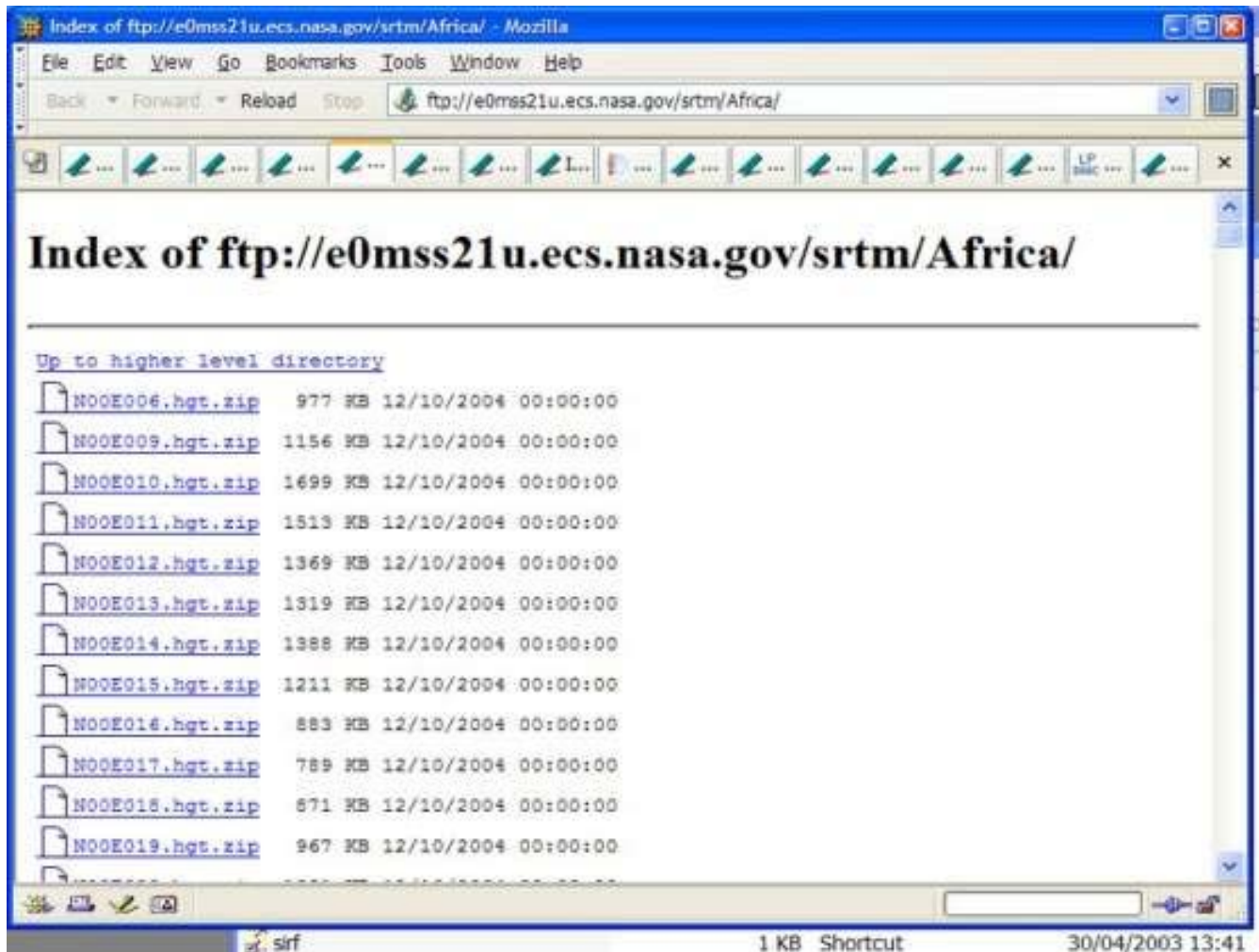
RadioMobile Software



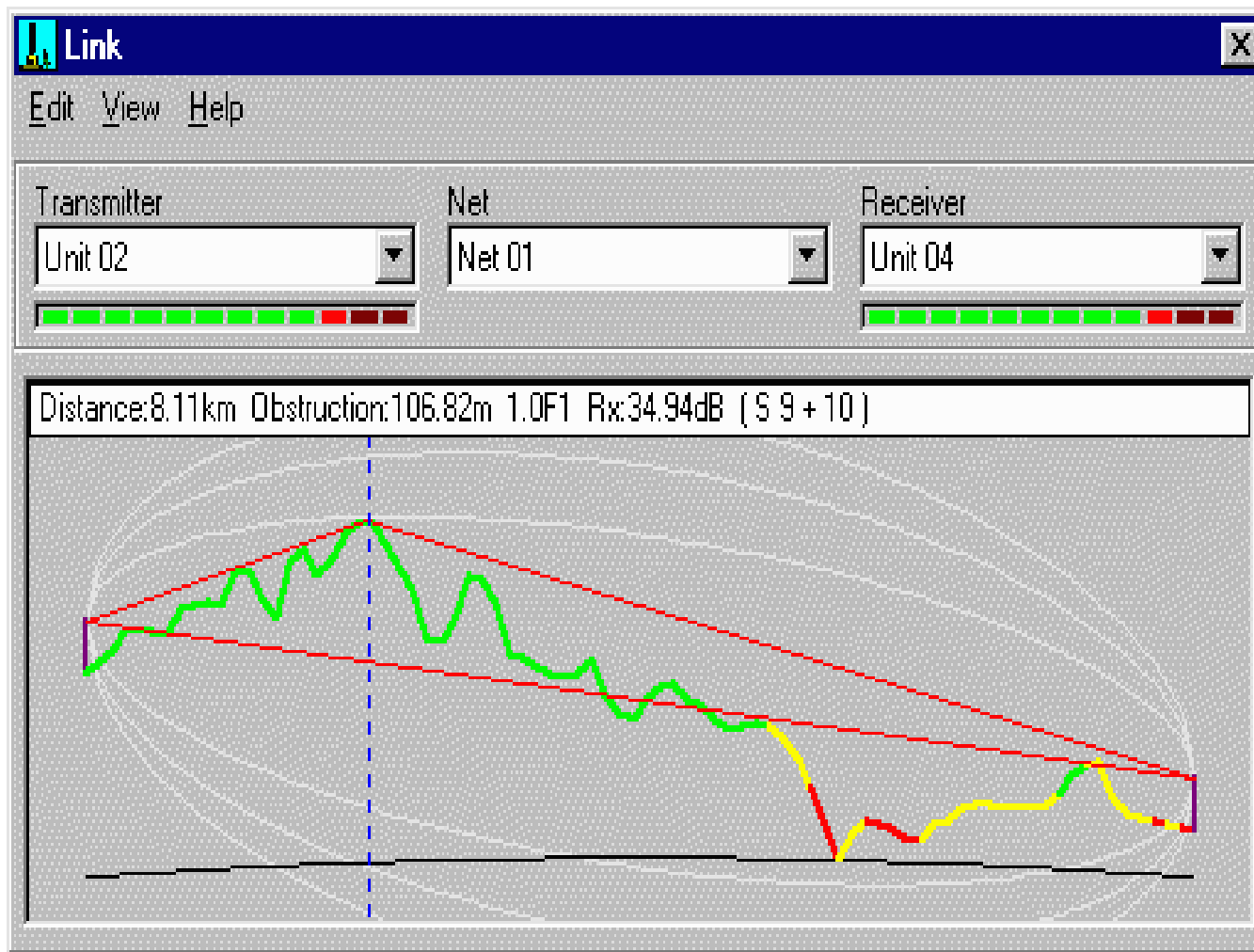
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ItrainOnline MMTK
www.itrainonline.org/itrainonline/mmtk

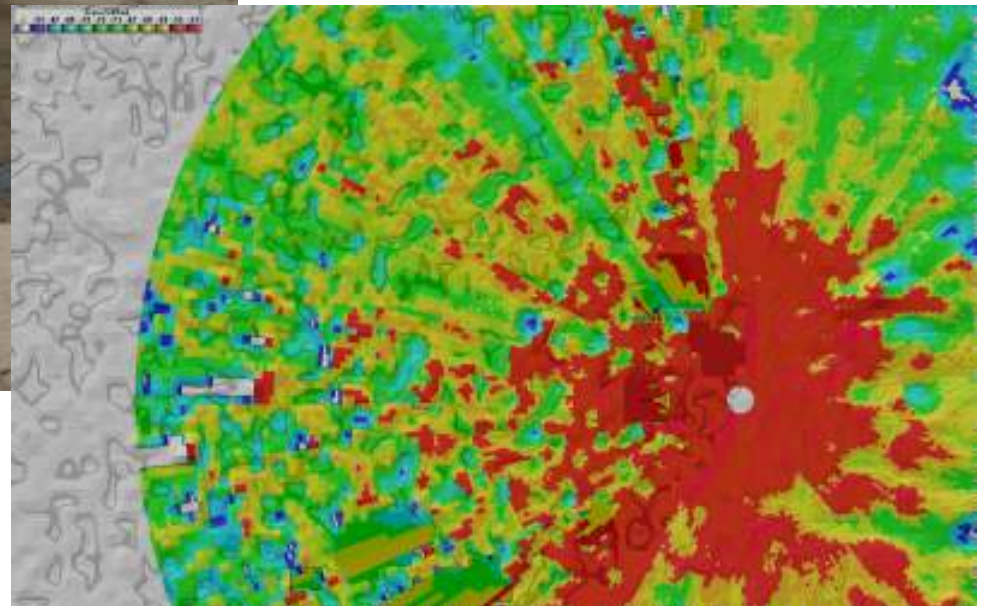
RadioMobile Software



RadioMobile Software



RadioMobile Software



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*