

# LoRaWAN Radio Planning

Simulating your network deployment

The Things Conference

January 30 and 31, 2020

Amsterdam

## Workshop instructions



**THE THINGS**  
**N E T W O R K**  
**A P E L D O O R N**

## Document history

Version	Date	Reviewer	Note/Changes
<b>1.0</b>	2-1-2020	RW	Final version ready for printing
<b>0.02</b>	21-12-2019	RW	Additions and corrections
<b>0.01</b>	24-11-2019	RW	Start of document

## About the presenter

Remko Welling is as a teacher Embedded Systems Engineering at the University of Applied Science HAN in Arnhem and has 29 years of experience in radio planning and radio network optimisation. His expertise is in many different digital and analogue radio communication technologies like Microwave links, GSM, UMTS, LTE, TETRA, and simulcast networks POCSAG and FLEX. He worked for both commercial and governmental organisations as senior RF network specialist and lead architect RF.

As a teacher at HAN he teaches Logic circuits, VHDL, Operating Systems and IoT where the LPWAN technology LoRaWAN plays an important role.

Remko is the founder of RFSee. A small company that he uses to expand and maintain his knowledge of modern digital radio networks.

Remko has 20 years of experience in using Radio Mobile. He used Radio Mobile in both non-profit projects and networks as well as for professional and commercial studies. His knowledge and experience in the use of Radio Mobile can be found on his websites documenting Radio Mobile:

<http://radiomobile.pe1mew.nl> and <http://radiomobileonline.pe1mew.nl>

## TTN-Apeldoorn

TTN Apeldoorn started in 2016 as a community. Within 6 month they installed their first full-blown LoRaWAN gateway sponsored by Wireless Things<sup>1</sup> as a pilot with the help of Kadaster Apeldoorn at a height of 65 meters. In 2017 the second gateway sponsored by INCAA, a local company in Apeldoorn, was installed in joint corporation of the local department of the Dutch association of Radio amateurs (VERON) at their repeater site.

In January 2020 TTN-Apeldoorn delivers region wide coverage which is redundant within the city of Apeldoorn with 6 primary gateways and an ever-growing number of private a company owned gateways. This coverage is also redundant within the boundaries of Apeldoorn.

The TTN-Apeldoorn Community organises regular meetings for those who are interested in everything that is related to IoT. The meetings are on average attended by 20 to 30 visitors. Topics over the last years ware: LoRaWAN security, IoT Use cases, Hiber Space, GPS, projects building LoRaWAN nodes and single channel gateways, Particle sensor project for the Citizen science project of Apeldoorn In Data. Meetings are announced at Meetup: <https://www.meetup.com/LoRa-Network-in-Apeldoorn-Growing-Meetup/>

The TTN community in Apeldoorn is supported by many local companies. They contribute with knowledge and financial support to operate the TTN LoRaWAN network and at meetups for the community members. RFSee is one of the companies that planned and optimized the radio network in Apeldoorn. RFSee installed all gateways. Using drive testing the radio coverage was verified.

---

<sup>1</sup> <http://www.wirelessthings.be/>



## Introduction

Radio Planning is a continues process of planning, realisation, and verification. Depending on the approach, you either step into the process at the planning or the realisation phase. At some point you want to know what coverage a gateway will deliver. This coverage can be verified by measuring the service using solutions like TTN Mapper and using devices like the Adeunis Field tester or by simulation radio propagation. Using TTN Mapper is labour intensive while simulation using a computer is (relative) simple and can deliver accurate predictions. In Figure 1 end Figure 2 a strong correlation can be observed between simulation and measurement.

In radio planning there are basically two options. The first is planning a radio network with clear objective in mind. The service is planned homogenously to be delivered in the target area. The second is opportunity driven. In this case a gateway is installed either on occasions where a location is offered or when a use case requires one or more gateways. For the Things network the last one is most applicable.

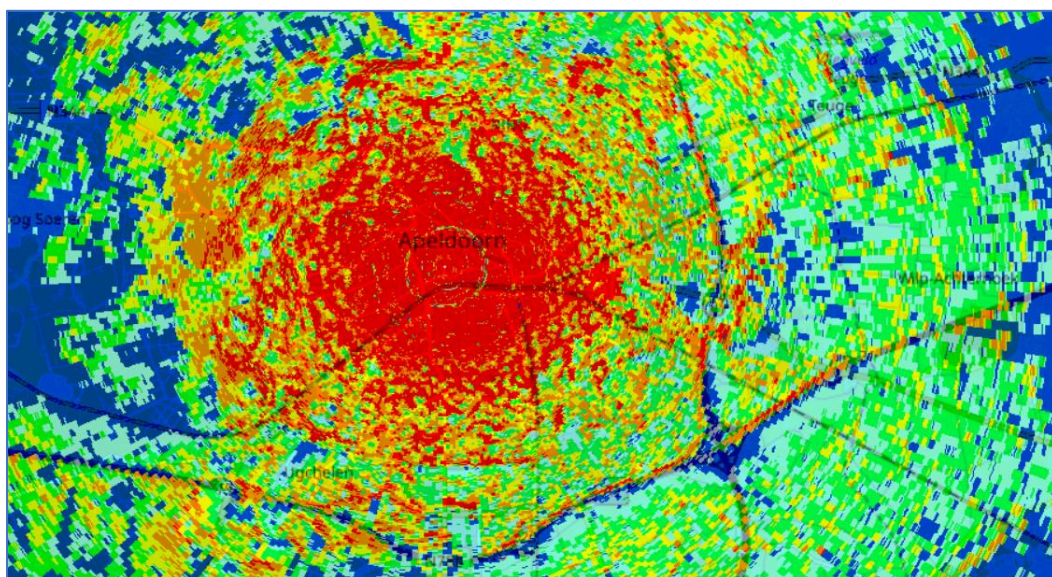


Figure 1: Simulated coverage of a gateway of TTN Apeldoorn

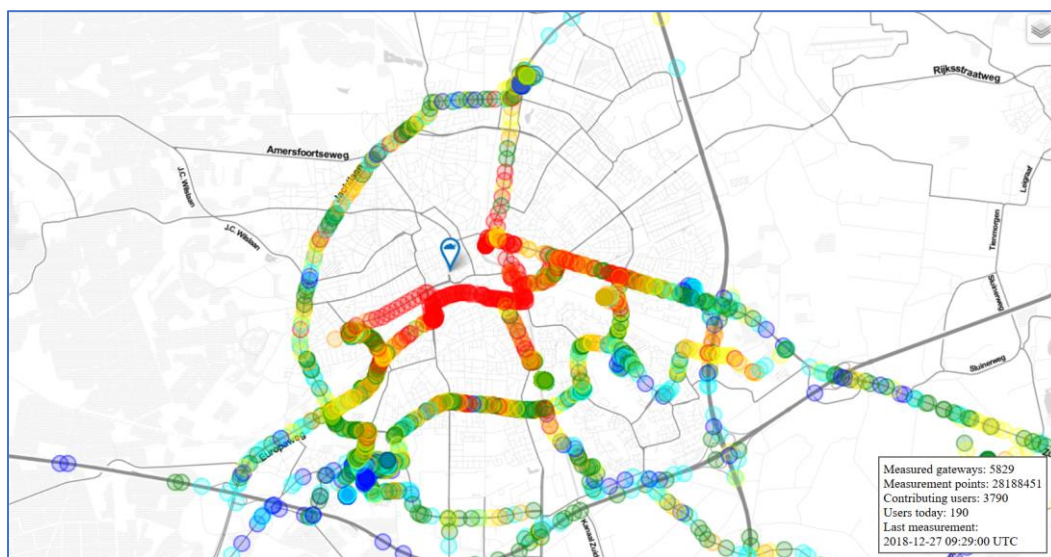


Figure 2: Coverage of a TTN Apeldoorn gateway using TTN Mapper.

After this workshop the participant will know about simulation of radio signal propagation, have basic knowledge of link budgets, and how to model a LoRaWAN gateway and node in the software installed on a Windows laptop.

This workshop will deliver a hands-on experience in simulating coverage of LoRaWAN gateways. It will not cover the complete cycle of the Radio Planning process.

The workshop duration is 45 minutes.

To participate in the workshop the participant requires a Windows laptop on which he can run the RF simulation software. The laptop shall have WiFi and a USB port. Administration rights are not required.

Any other OS is not supported during the workshop!

Participants shall have intermediate knowledge of the LoRaWAN standard, antennas, and dB calculations. As an RF engineer you know about receiver sensitivity and antenna gain.

This workshop is divided in to 3 parts:

1. Installation of radio simulation software.
2. Setup a Link budget and discuss the individual parts of the Link budget. This will result in building blocks to be used in Radio Mobile.
3. Exercise the use of Radio Mobile, simulate the coverage of a LoRaWAN gateway and what effect changes in the link budget have when we change parameters.

This workshop is available for download at:

[https://github.com/pe1mew/TTN\\_Conference\\_WorkshopRadioPlanning.git](https://github.com/pe1mew/TTN_Conference_WorkshopRadioPlanning.git)

## About this document

This document is using icons to indicate the priority or type of some information. The used icons are:



Attention: Important information about the topic that will have significant effect.



Information: Additional information about the topic, helpful for the Workshop.



Learning objective: What we will learn.



Further reading: More information is available.

## Copyright

This Workshop paper is part of the Workshop radio planning at the Things network conference.

This workshop paper is free: You may redistribute it and/or modify it under the terms of a Creative Commons Attribution-NonCommercial 4.0 International License

(<http://creativecommons.org/licenses/by-nc/4.0/>) by Remko Welling (<http://rfsee.nl>) E-mail: [remko@rfsee.nl](mailto:remko@rfsee.nl)



Radio Mobile software is a copyright of Roger Coudé VE2DBE. Radio Mobile is dedicated to amateur radio and humanitarian use. Although commercial use is not prohibited, the author cannot be held responsible for its usage. The outputs resulting from the program are under the entire responsibility of the user, and the user should conform to restrictions from external data sources.

## Disclaimer

The Workshop Radio Planning is provided in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.



## Workshop radio planning

### Part 1: Installation of the software

In this part we will setup the software. The software we use is Radio Mobile from Roger Coudé. Roger holds the copyrights of the software. Radio Mobile is free of charge but not open source. Although commercial use is not prohibited, the author cannot be held responsible for its usage.

Radio Mobile can be used as a local application or as a web service. In this workshop we use the local application because it will give better control over the parameters involved in simulation RF Signals. As soon as the fundamentals of radio propagation simulation are understood results from the web service can be interpreted. Finally, the web service only has a limited set of functionalities of the local application.

The installation instructions follow a two-step approach:

1. Download and unzip all files in the described structure.
2. Run the program and verify settings.



Radio Mobile is documented by Remko Welling (PE1MEW) at the following website <http://radiomobile.pe1mew.nl>. Here you can find more tutorials and explanation if you want to learn more about Radio Mobile.

### Installation from memory stick (TTN Conference Workshop)

You will receive a memory stick for installation during the workshop.

Where the installation instructions point to a file to be downloaded from the internet, with the use of the memory stick, these files can be copied from the memory stick.

All files for the installation can be found in folder (directory) "RadioMobile" on the memory stick.

Radio Mobile is using geodatabases like terrain-height, clutter (Land cover), and topographical maps (OSM) to make calculations and visualisations. When no internet access is possible the previously cached geodata can also be copied from the memory stick. This data can be copied from "RadioMobile\GeoData".

### Installation from scratch (Clean install)



In this paragraph we will learn how to install and configure Radio Mobile.



This installation instruction is using the instructions at <http://radiomobile.pe1mew.nl>

- ☐ Create folder "c:\RadioMobile"
- ☐ In "RadioMobile" create the following folders and subfolders:
  - Data
  - GeoData
    - LandCover
    - OSM
    - SRTM



- ❑ Download “rmwcore.zip” from <http://www.ve2dbe.com/download/download.html> and place it in folder “c:\RadioMobile”.
- ❑ Download the program in the language of your choice and place it in folder “c:\RadioMobile”. It is strongly advised to use the English version. This is file “rmw1166eng.zip”.
- ❑ Download “wmap.zip” from <http://www.ve2dbe.com/download/wmap.zip> and place it in folder “c:\RadioMobile”.
- ❑ Unzip all files in the “c:\RadioMobile” folder. To unzip files, you can use 7zip from <https://www.7-zip.org/>

The result of these steps is shown in Figure 3.

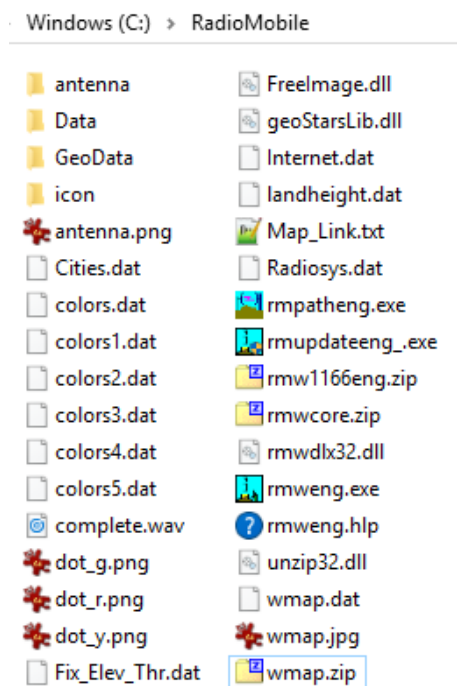


Figure 3: files and folder structure after downloading and unzipping.



To prevent Radio Mobile from using the REGISTRY of your computer create an empty file named “rmw.ini” in “c:\RadioMobile”. Radio Mobile will use this file to store its configuration instead of the registry.

To finish the installation, create a shortcut on your desktop to the file “rmweng.exe”.



Further reading on the installation procedure at:  
<http://radiomobile.pe1mew.nl/?Installation>



## Running Radio Mobile

To start Radio Mobile, open the program “rmweng.exe” as shown in Figure 4 or using the shortcut on your desktop.

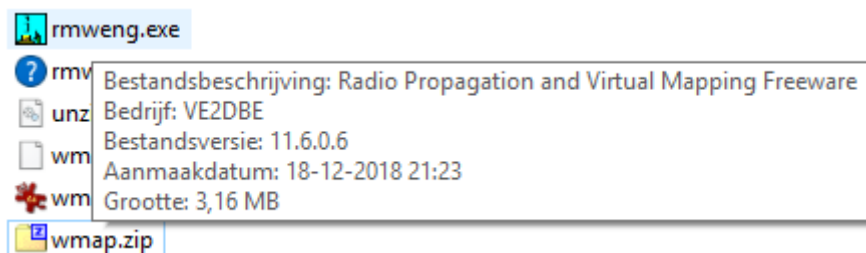


Figure 4: The executable Radio Mobile.

This will result in a new window:

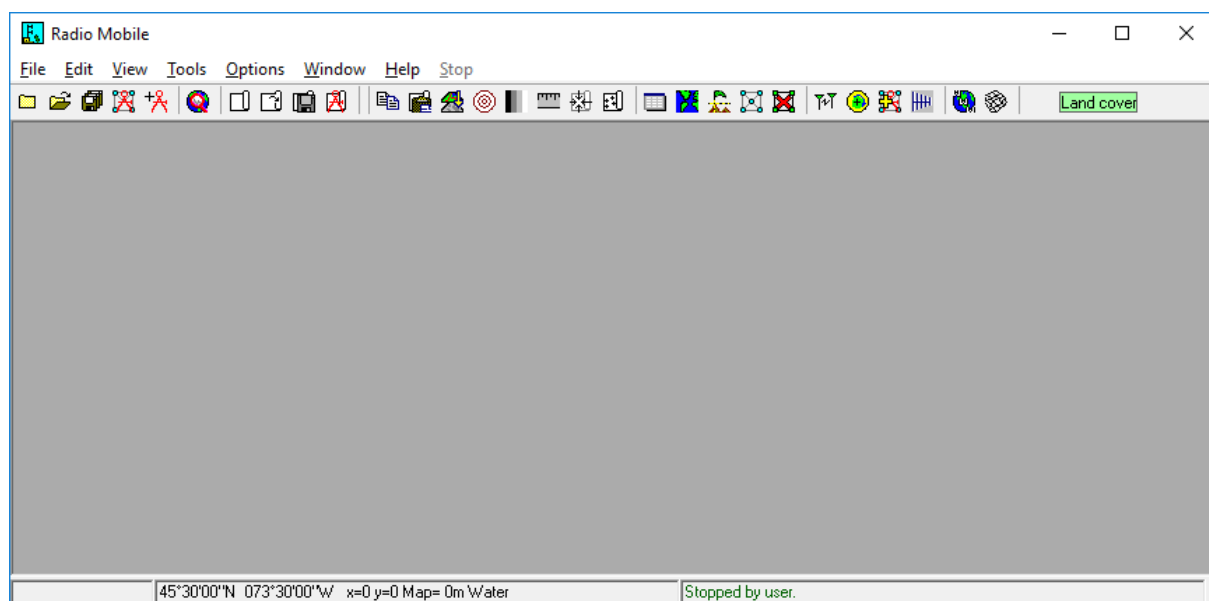


Figure 5: Radio Mobile without map.

## Configuring Radio Mobile

Radio Mobile is using data sources from the internet. This data is downloaded and cached locally but need to be configured when you performed a clean install of Radio Mobile.

In the case of this workshop Radio Mobile comes predefined from your memory stick but requires verification. This verification is done by the checklist that is similar for a clean install scenario.

### Internet options.

- ☐ Go to “Options > Internet”. A window opens with various configurable items. See Figure 6.

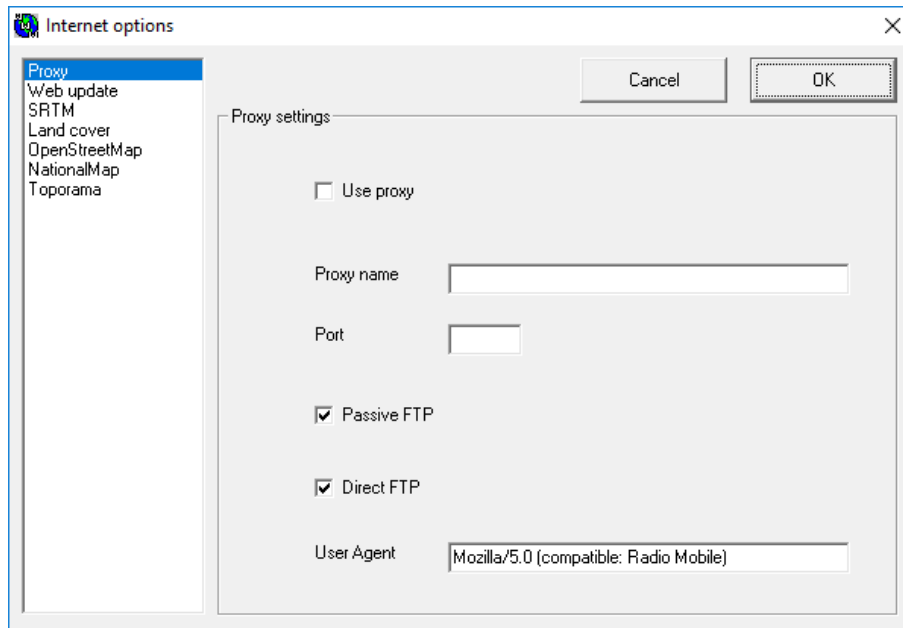


Figure 6: Internet options; Proxy

#### Proxy

Not needed for the workshop. In case you are using a proxy server to access the internet use these options

#### Web update

Not needed for the workshop. Configure to meet your needs.

#### SRTM

[Mandatory] Needed for the workshop. See Figure 7.

- ☐ Check "Download from internet if a file is not found on local path and keep local copy"
- ☐ Local files path: Browse to the folder downloaded SRTM files shall be stored. This shall be "C:\RadioMobile\GeoData\SRTM".
- ☐ Internet ftp directory: Chose "SRTM – Best data – Site 1"

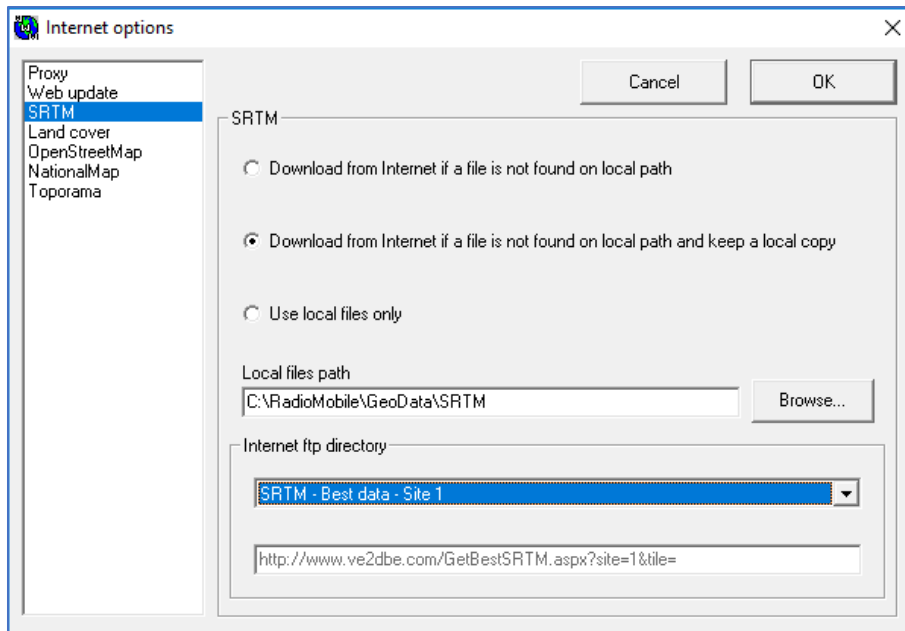


Figure 7: Internet options: SRTM

#### Land cover

[Mandatory] Needed for the workshop: See Figure 8.

- ☐ Check “Download from internet if a file is not found on local path and keep local copy”
- ☐ Local files path: Browse to the folder where downloaded Landcover files shall be stored. This shall be “C:\RadioMobile\GeoData\LandCover”.
- ☐ Internet ftp directory: Chose “Landcover – Site 1”

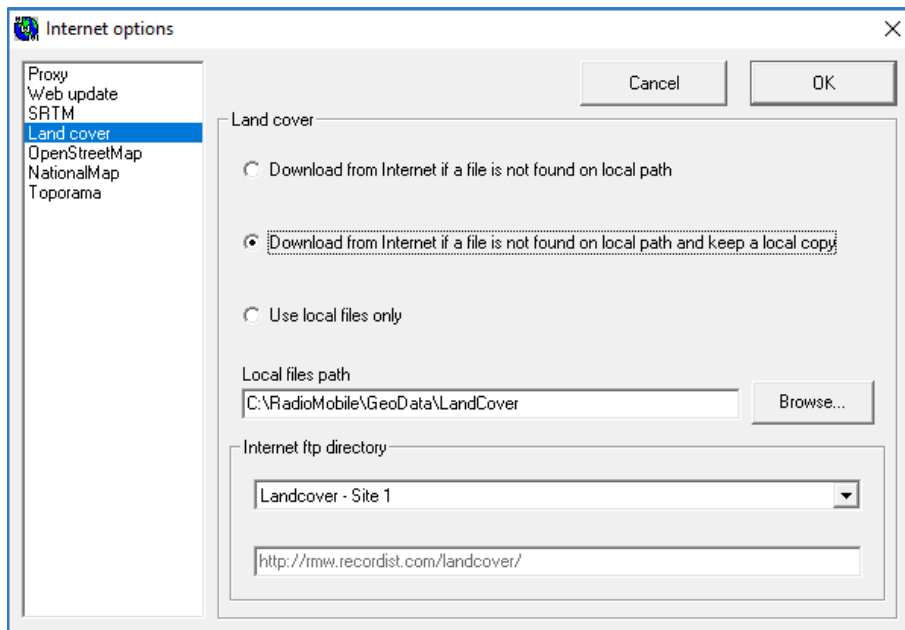


Figure 8: Internet options; Land Cover

### OpenStreetMap

[Mandatory] Needed for the workshop: See Figure 9.

- ☐ Check “Download from internet if a file is not found on local path and keep local copy”
- ☐ Local files path: Browse to the folder where downloaded OpenStreetMap files shall be stored. This shall be “C:\RadioMobile\GeoData\OSM”.

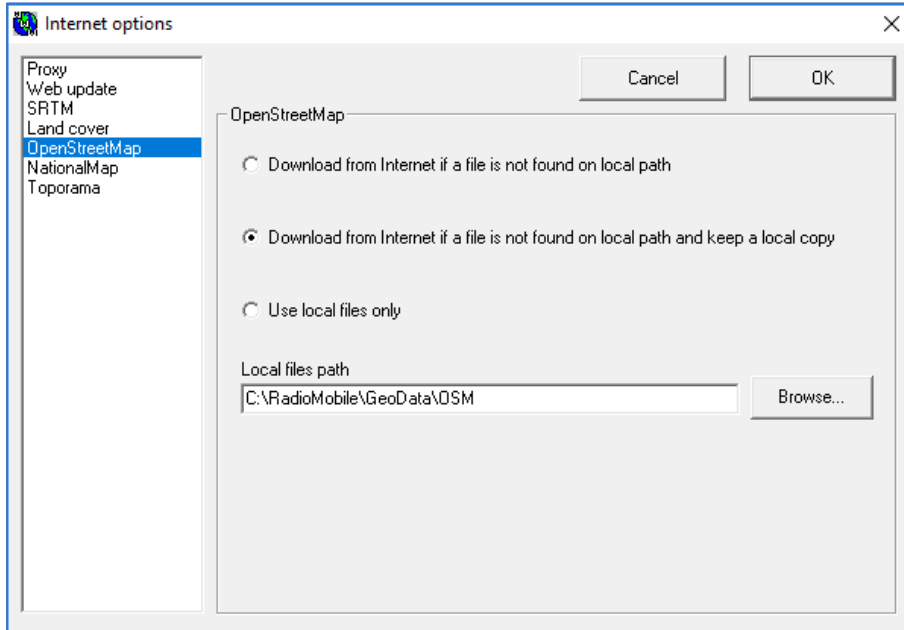


Figure 9: Internet options; OpenStreetMap

### NationalMap

[optional] Not needed for the workshop. Keep default settings.

### Toporama

[optional] Not needed for the workshop. Keep default settings.

### Map properties.

Go to “File > Map properties” or press “F8”. A window opens with various configurable items.

- In “Elevation data source” choose “SRTM” in the highest layer (See red box in Figure 10). Drive or path: Browse to the folder where downloaded SRTM files are stored. This shall be “c:\radiomobile\geodata\srtm”.

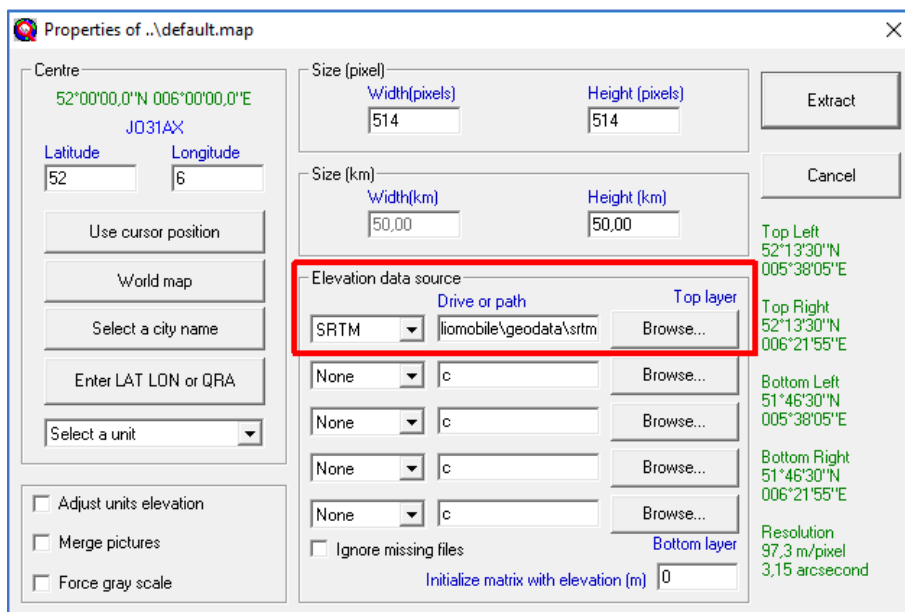


Figure 10: Map properties, Set “Elevation data source” of map window.

### First use Radio Mobile

Now we have configured the geodata sources that Radio Mobile uses, we can test if it works.

- Go to “File > Map properties” or press “F8”. A window opens. In “Centre” we fill in at “Latitude”: 52 (degrees) and at “Longitude”: 6 (degrees). See Figure 11.
- When settings are complete click “Extract” and Radio Mobile will display terrain height like Figure 12.

## Workshop LoRaWAN Radio Planning - Simulating your network deployment.

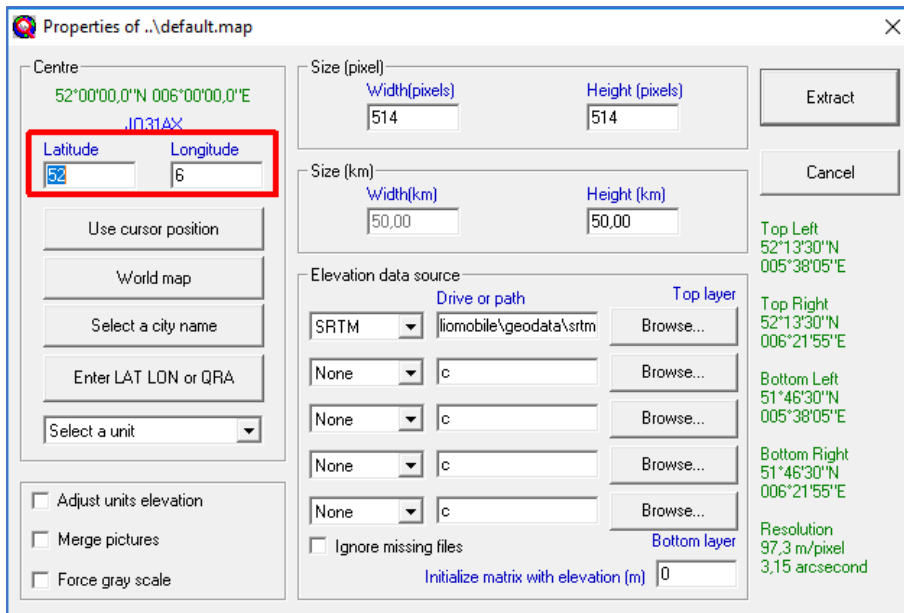


Figure 11: Map properties, Set centre coordinate of map window.

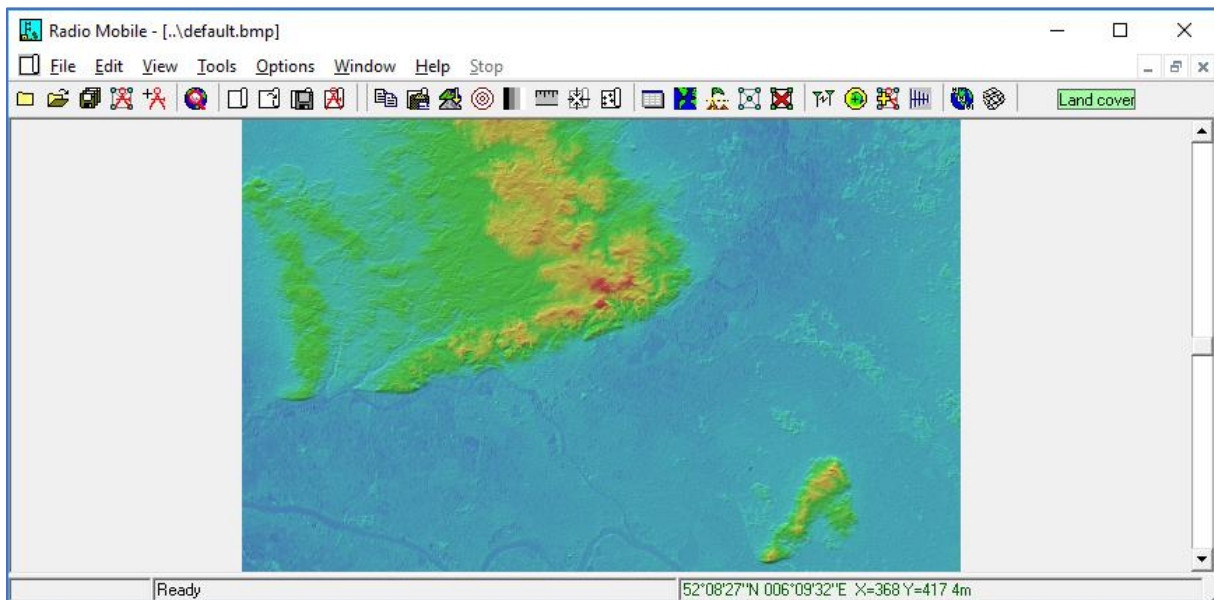


Figure 12: Loaded and displayed terrain height.

## Part 2: Parameters and building blocks.

Before we can configure Radio Mobile, we need to learn how to structure nodes and gateways and set the parameters of these devices in such a way that Radio Mobile can use them.



In this paragraph we will learn how to setup a link budget and where to get the required information

Radio Planning is using a radio propagation simulation tool like Radio Mobile to predict coverage. Our radio planning tool is a big calculator capable of performing one mathematical formula: The pathloss calculation. This pathloss calculation has more than 50 parameters that need to be set and tuned to get an accurate result. The following parameters are the most important parameters:

- Frequency
- Effective Radiated Power (Erp)
- Antenna type, gain, radiation pattern
- (effective) Height of the antenna above ground
- Polarization
- Surface Refractivity
- Permittivity
- Conductivity
- Climate zone
- Simulation variability
- Time variability
- Terrain irregularity
- Attenuations



This workshop delivers a template project that will set the most of these settings. The template project can be found in "RadioMobile\Data\TTNWorkshopTemplate". Before use, make a copy of the template folder and rename it.

### Link budget

According to Wikipedia:

*A link budget is an accounting of all the gains and losses from the transmitter, through the medium (free space, cable, waveguide, fiber, etc.) to the receiver in a telecommunication system. It accounts for the attenuation of the transmitted signal due to propagation, as well as the antenna gains and feedline and other losses. Randomly varying channel gains such as fading are considered by adding some margin depending on the anticipated severity of its effects. The amount of margin required can be reduced using mitigating techniques such as antenna diversity or frequency hopping. (Wikimedia, 2018)*

The purpose of our link budget is to determine the minimum signal level at which our node can reach the gateway.

To save time during this workshop we have reduced the number of parameters we have to modify and set most of the general parameters for a usage with LoRaWAN.

The parameters we need to adapt are related to our node (mote) and our gateway and are specific for our situation. In Radio Mobile a node or gateway is parametrized in "Systems" and "Units" who are combined in a "membership". A system describes the RF parameters while the unit describes the geographical parameters.

A link budget is created for an individual service in a specific environment. For example: Outdoor coverage for nodes using SF7 or outdoor coverages for nodes at SF12.



*Radio Mobile System parameters*

A system describes the parameters of the receiver, transmitter, antenna (type and height) and the connection (cabling) between the receiver/transmitter (radio) and the antenna. This is visualized in Figure 13.

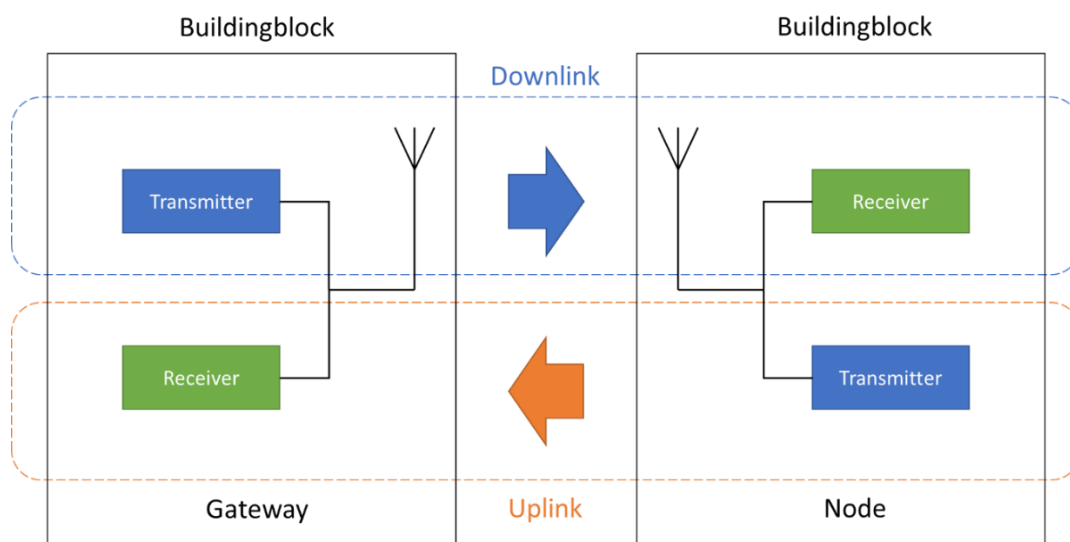


Figure 13: Principle of building blocks.

It is important to notice is that we identify the radio link from the infrastructure (gateway) to the node as downlink and the radio link from the node to the infrastructure as uplink.

For the transmitter we specify:

Parameter	Unit	Default value	Description
Transmit power	dBm	+21	The transmit power of the IMST IC880A (1)
	dBm	+14	Transmitter power of a node.

For the receiver we specify:

Parameter	Unit	Default value	Description
Receiver sensitivity	dBm	-126 (SF7)	The minimum level at which the receiver can detect a signal correctly.

For the antenna we specify:

Parameter	Unit	Default value	Description
Antenna type	-	Omni	Type of antenna
Antenna gain	dBi/dBd	0	Gain of the antenna compared to isotope (i) or dipole (d)
Antenna height	Meter	1,5 (node) 45 (gateway)	Height of the antenna above ground level.

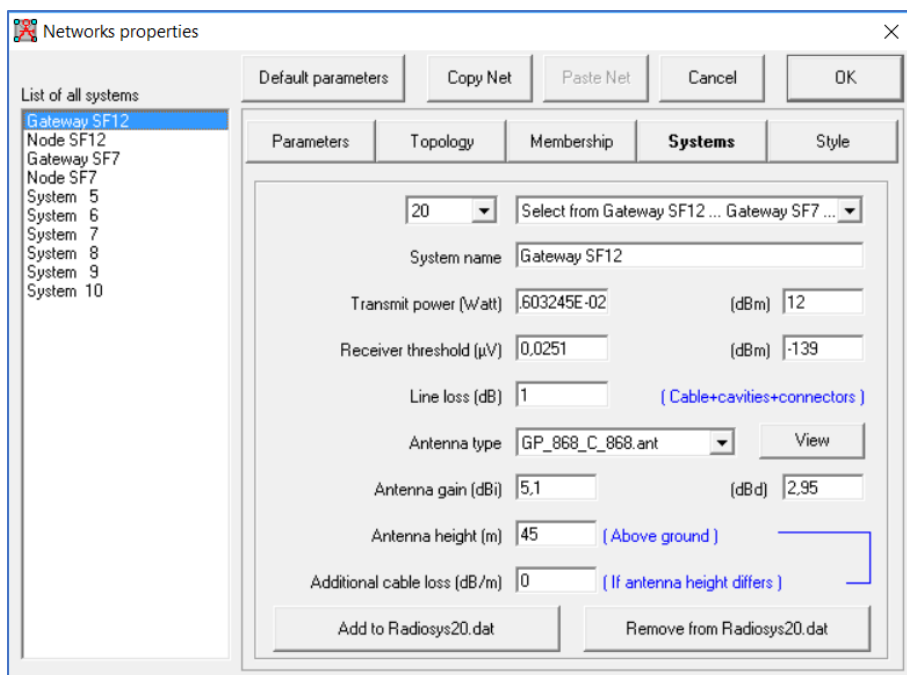


Figure 14: Gateway characterised for SF12 in Systems.

The following paragraphs provide background information on these parameters.

#### Gateway characteristics.

**GATEWAY RECEIVER SENSITIVITY:** A LoRaWAN gateway is using for reception the SX1301 digital baseband chip of Semtech in combination with the SX1257 or SX1255 Tx/Rx/ front-end. These chips have the following sensitivities associated with their SF that we specify for the receiver sensitivity of the gateway.

Modulation	Signal level	
SF = 7	-126,5	dBm
SF = 8	-129,0	dBm
SF = 9	-131,5	dBm
SF = 10	-134,0	dBm
SF = 11	-136,5	dBm
SF = 12	-139,5	dBm



Semtech, SX1301 Datasheet: <https://www.semtech.com/uploads/documents/sx1301.pdf>.

**GATEWAY TRANSMITTER POWER:** The LoRa Gateway we use in this workshop is an IMST IC880a concentrator board. This board is using the Semtech SX1257 Low Power Digital I and Q RF Multi-PHY Mode Transceiver. According to the specification of IMST this board can have the maximum TX power of:

Max TX power	unit
+20	dBm



IMST IC880A Datasheet:

[https://wireless-solutions.de/downloads/Radio-Modules/iC880A/iC880A\\_Datasheet\\_V1\\_0.pdf](https://wireless-solutions.de/downloads/Radio-Modules/iC880A/iC880A_Datasheet_V1_0.pdf)

Semtech SX1257 datasheet:

[https://www.semtech.com/uploads/documents/DS\\_SX1257\\_V1.2.pdf](https://www.semtech.com/uploads/documents/DS_SX1257_V1.2.pdf)

### **Meeting the ERP<sup>2</sup> power limit from your regulator.**

Whenever you use the ISM-licensed frequency band restrictions will apply. These restrictions are:

- Duty cycle restriction (which is not part of this workshop) and
- Maximum radiated power.

We use the Dutch example and use the restrictions as specified in the telecommunications law:



“Regeling gebruik van frequentieruimte zonder vergunning en zonder meldingsplicht 2015, Bijlage 11: <https://wetten.overheid.nl/BWBR0036378/2016-12-28>”.

Here it is stated that the maximum radiated power 25 mW E.R.P. is which equals +14 dBm. Please note that ERP specification uses a dipole antenna as a reference.

When using a 5,1 dBi (isotropic!) antenna the actual antenna gain is  $5,1 - 2,15 = 2,95$  dBd. This is the value we will use. Now we can calculate the maximum transmitter power of our LoRaWAN gateway:

ERP [dBm]	14,00
Antenna gain [dBd]	-2,95
Cable attenuation [dB]	1,00 +

---

**Maximum TX power [dBm] 12,05 <- This value we use for our transmitter power!**

### Node characteristics

In our example we use the RFM95 LoRa radio. This radio is comparable to Semtech SX1276/SX1277/SX1278/SX1279. Please observe the differences in sensitivity between HopeRF and Semtech specification. We use HopeRF in our workshop.

HopeRF RFM95:

Modulation	Signal level	
SF = 6	-121	dBm
SF = 7	-126	dBm
SF = 8	-129	dBm
SF = 9	-132	dBm
SF = 10	-135	dBm
SF = 11	-137	dBm
SF = 12	-139	dBm

Semtech SX1276/77/78/79:

Modulation	Signal level	
SF = 6	-123	dBm
SF = 7	-128	dBm
SF = 8	-131	dBm
SF = 9	-134	dBm
SF = 10	-135	dBm
SF = 11	-137	dBm
SF = 12	-140	dBm



HopeRF RFM95 datasheet:

[https://cdn.sparkfun.com/assets/learn\\_tutorials/8/0/4/RFM95\\_96\\_97\\_98W.pdf](https://cdn.sparkfun.com/assets/learn_tutorials/8/0/4/RFM95_96_97_98W.pdf)

Semtech SX1276/77/78/79 datasheet:

[https://www.semtech.com/uploads/documents/DS\\_SX1276-7-8-9\\_W\\_APP\\_V5.pdf](https://www.semtech.com/uploads/documents/DS_SX1276-7-8-9_W_APP_V5.pdf)

---

<sup>2</sup> Effective Radiated Power

**ANTENNA PARAMETERS:** The antenna is specified in:

- Antenna type (to which is linked antenna gain and radiation pattern)
- Antenna height in meters.
- Additional losses of (internal) cabling.

### Gateway antennas

For antennas the rule of thumb is: The, bigger, the better. Gateway antennas are antennas installed on buildings and towers and shall be installed free of obstructions so they can “look around freely”. In this workshop we assume this. In this workshop we can use the following antennas:

Manufacturer	Type	Gain	Note
Mars antennas	MA-WO850-5 860	5 dBi	
Sirio	GP 868 C 868	3 dBi – 5.15 dBi	
Radio Mobile	Dipole	0 dBd	Reference

Together with the antenna gain the radiation pattern is provided. The radiation pattern of the Sirio and Mars antenna are shown in Figure 15.

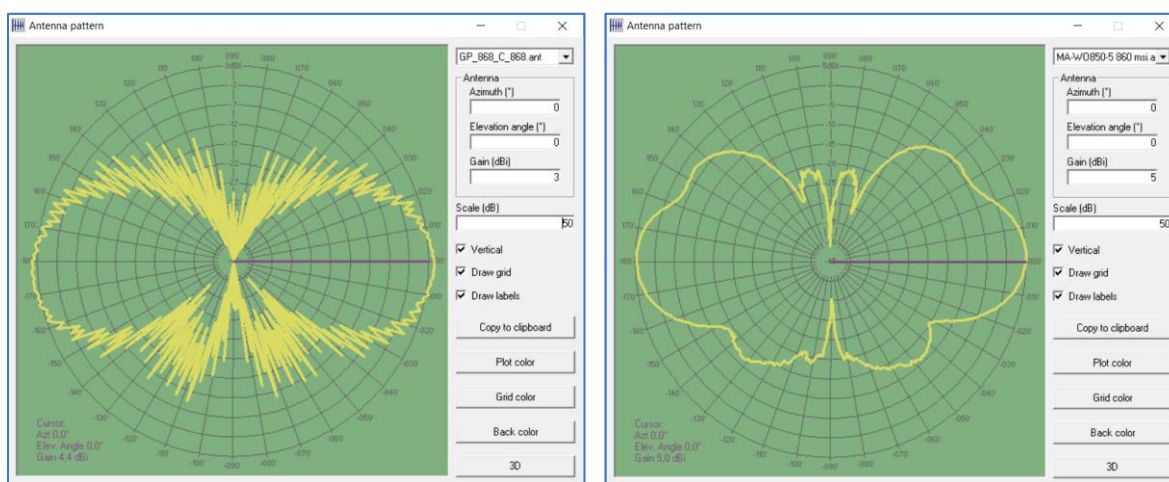


Figure 15: Sirio GP 868 C 868 and Mars MA-WO850-5 antenna radiation pattern



To use the antennas in Radio Mobile copy folder “RadioMobile\antenna” to “c:\RadioMobile\”

To see radiation patterns in Radio Mobile, go: “Tools > Antenna pattern viewer”.



Mars antennas: <https://mars-antennas.com/>

Sirio: <http://www.sirioantenne.it/en/products/cellular/gp-900-c-gp-901-c-gp-868-c>

### Node antennas

Antennas on nodes are almost never capable to come even near the performance of the “full size brothers” on gateways. Good antenna design is very important for the range of a node. As antenna design is out of scope of this workshop, we provide some practical examples of antennas that can be used and the gain of these antennas. The antennas give are visualised in Figure 16.

Antenna type	Gain [dB]
GP antenna	0,0
Long duck	0,4
Short duck	-2,8
Helical	-1,1
Chip antenna	-2,5
Puck antenna	-3,5

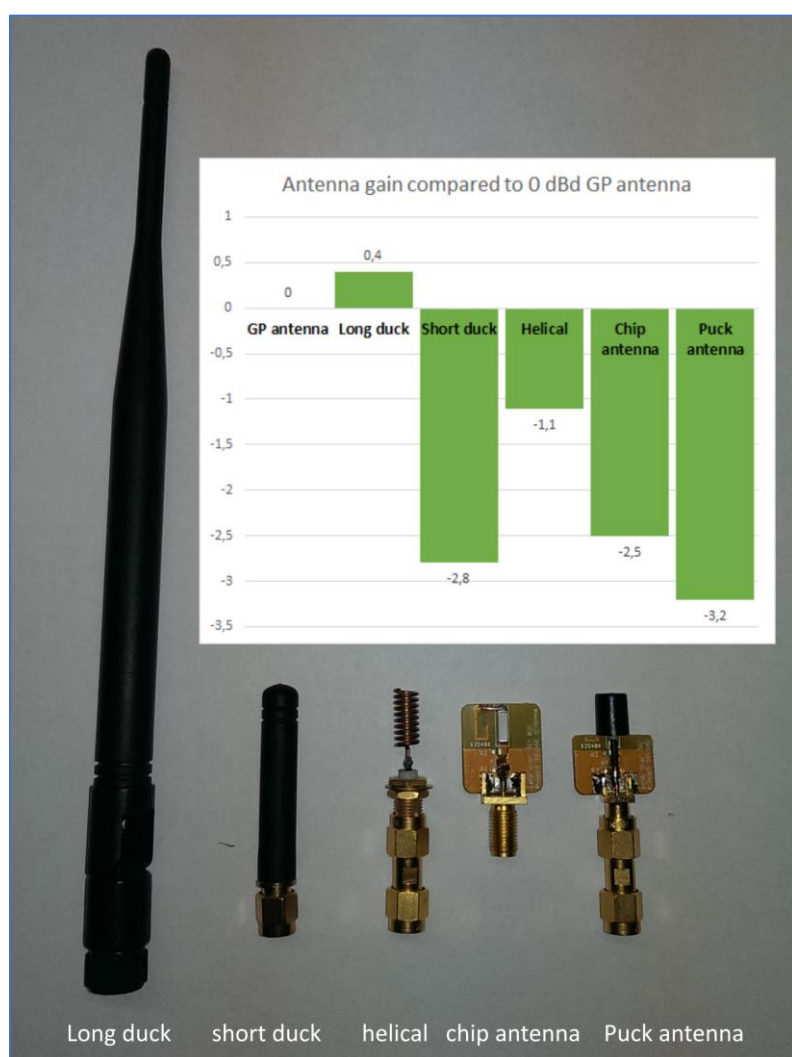


Figure 16: Node antennas

**Additional losses.** Additional losses are the losses caused by coax cables between the antenna and the gateway. This attenuation is highly dependent on the type of coax cable and the length of cable used. The following table shows 4 types of coax cable that are generally used. For each type the attenuation in dB per 100m is specified.

Type	dB/100m
Ecoflex 10	12,5
Ecoflex 15	8,6
LMR400	12,8
LMR600	2,5

Please lookup the exact cable attenuation at the manufacturer.

#### Radio Mobile Unit parameters

The unit contains the geographical information of the location where the gateway or node is located. Also, we can set here icon of the unit that will be presented on the maps.

For the unit we specify:

Parameter	Unit	Default value	Description
Location	degrees	-	Coordinate of the unit.
Icon	-	-	Icon

#### Link budget Margins

Margins in the link budget are required to compensate for additional attenuation or loss of radio signals by the environment. The margins we will describe are:

- Loss of signal due to multipath fading,
- Loss of signal due to indoor penetration loss.

#### Multipath fading

All radio coverage is based on probability theory. Radio coverage at a specific location from a distant transmitter can be specified for a 50%, 90% or higher probability of successful communication. Radio coverage cannot be guaranteed 100% of the time.

If we take no margin in the link budget for probability, there is a 50% chance at the cell edge that reception is successful. By adding a fading margin, we reduce the cell size and coverage, however we can state that the reliability of the served coverage increases by a higher probability.

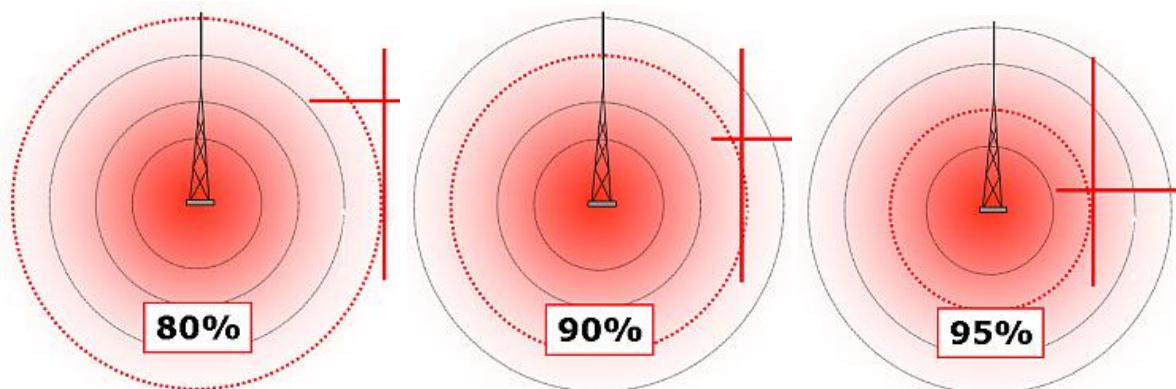


Figure 17: Higher probability results in smaller cell size

As a rule of thumb, the following margins can be applied in the link budget to represent our service objectives.

Margin over minimum RX level (dB)	Coverage probability at the cell-edge (%)	Coverage probability over the entire cell (%)
0	50	77
5	75	90
7	84	96
9	90	97
12	95	99



To compensate for 90% probability the sensitivity of the receiver is reduced with the margin. This means that for example at SF12, sensitivity is lowered from -139 to -130 dBm!

#### Indoor penetration loss

Radio signals that penetrate a building suffer from the attenuation by the building. The following table shows some values to indicate the severity of these attenuation losses.

These values are arbitrary and need thorough verification. Use at your own risk!

Measured Losses at Building floor	UHF
Basement	-27 dB
1st	-23,5 dB
3rd	-20 dB
5th	-15 dB
10th	-3,5 dB
14th	+2 dB

#### Link budget calculation

With the important physical parameters know we can setup our link budget. The link budget is created for up- and downlink.

Because 99% of LoRaWAN communication is uplink traffic we will simulate only uplink coverage.

Because downlink ERP power is stronger than uplink ERP power, we have link unbalance in favour of the gateway. This ensures that the gateway will be better capable of reaching the node than the node the gateway.

Figure 18 shows the link budget for a LoRaWAN downlink. Here the Gateway transmit power is adapted to meet the +14 dBm ERP limit. Please note that ERP is expressed with an isotope as reference. To use a dipole, add 2,15 dB to the antenna gain.



Downlink					
Gateway	TxPower		11,15	dBm	a
	Cabletype	RG214			d
	Frequency [MHz]	800	5		c
	Cable Length [m]	1			d
	Cable loss		-0,021	dBm	e
	AntennaGain		5	dBi	+ f
	Eirp		16,129	dBm	g
Node	Clutter type				
	Penetration loss				
	Coverage probability [%]	90			
	Fast fading margin		8	dB	h
	AntennaGain		-2	dBi	i
	Loss		0		j
	Sensitivity	SF7	-126	dBm	k
	Bitrate [bps]	5468			l
	Planning level target		-116	dBm	m
	MAPL		132,13	dB	n

Figure 18: Downlink link budget example

Figure 19 shows the uplink link budget. We can see that the poor antenna performance of the node results in a lower Erp.

Uplink					
Node	TxPower		14	dBm	o
	Additional loss		0	dB	j
	AntennaGain		-2	dBi	+ i
	Eirp		12	dBm	p
Gateway	Clutter type				
	Penetration loss				
	Cable loss		-0,021	dBm	e
	Fast fading margin		8	dB	h
	AntennaGain		5	dBi	f
	Loss		0		j
	Sensitivity	SF7	-126,5	dBm	k
	Bitrate [bps]	5468			l
	Planning level target		-123,5	dBm	m
	MAPL		135,48	dB	n

Figure 19: Uplink link budget example



This workshop delivers a template project that contains building blocks for a generic node and gateway at SF7.

#### *Notes on the Default network*

The default network is set up for 868 MHz and for two services types:

- Outdoor coverage with a probability of coverage of 90% and SF7 and SF12.

When you want to use the project at a different frequency this shall be modified at: File > Network properties, Parameters button. Set here minimum and maximum frequency.

The propagation is setup for Dutch Climate. For use in other environments see:



[http://radiomobile.pe1mew.nl/?The\\_program:File\\_menu:Network\\_prop..\\_Parameters](http://radiomobile.pe1mew.nl/?The_program:File_menu:Network_prop.._Parameters) or  
[http://radiomobile.pe1mew.nl/?Calculations:ITM\\_model\\_propagation\\_settings](http://radiomobile.pe1mew.nl/?Calculations:ITM_model_propagation_settings)

### Part 3: Simulating exercises


In this paragraph we will do exercises the get familiar with Radio Mobile. We will first use the default network that is prepared for the workshop and then tailor it to our own needs.

#### Exercise 1: Navigating through maps.



In this paragraph we will learn the essentials of navigating through Radio Mobile. Create and adjust maps and save one.

*Modify map window properties or open a new one when none is opened.*

- ☐ Open a new map in: “file > Map properties” or click: 
- ☐ 1: Enter the new centre coordinates of the map window. (See Figure 20)  
Latitude: 52,20568, Longitude: 5,975069
- ☐ 2: Enter the size of the map window in pixels. (See Figure 20)  
Width(pixels): 1000, Height(pixels): 1000
- ☐ 3: Enter the map height in km. (See Figure 20)  
Width will be proportional to the pixel dimensions. Height(km): 50,00
- ☐ Display the new map: Click on button: “Extract”

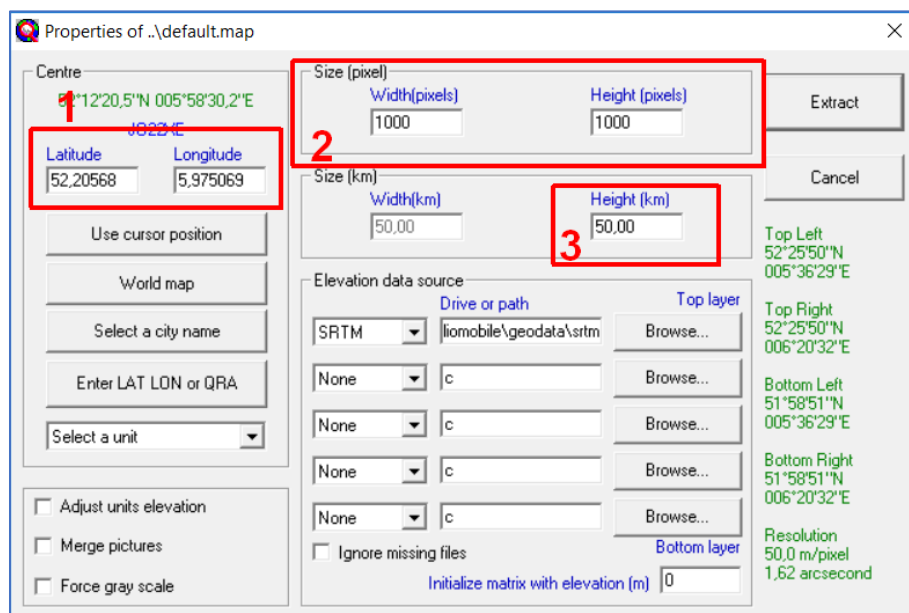


Figure 20: Modify map properties.

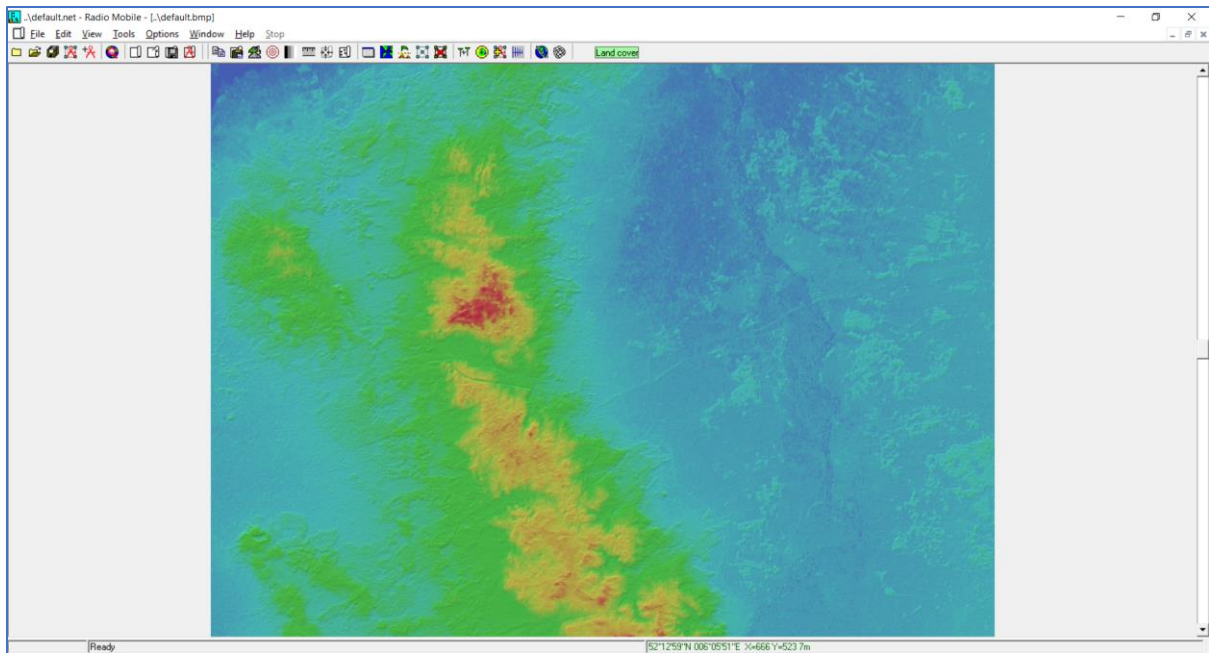



Figure 21: Result of modifying map properties

Overlay a topographical map in the map window.

- ☐ Open Merge pictures “Edit > Merge pictures” or click: 
- ☐ 1: Select the topographical map. Check “Internet OpenStreetMap”
- ☐ Display the modified map: Click on button: “Draw”
- ☐ 2: Accept the changes: Click “OK”

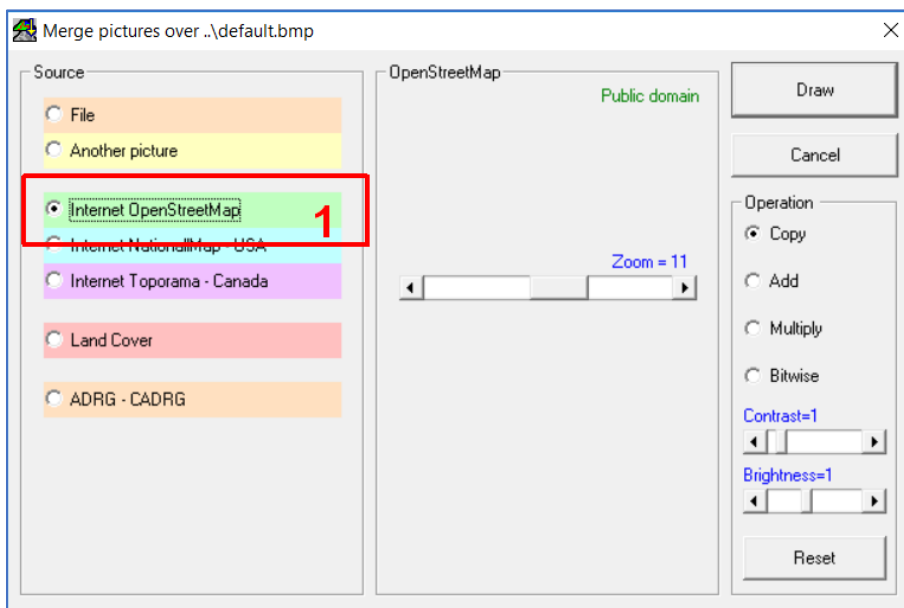


Figure 22: Merge pictures over map.

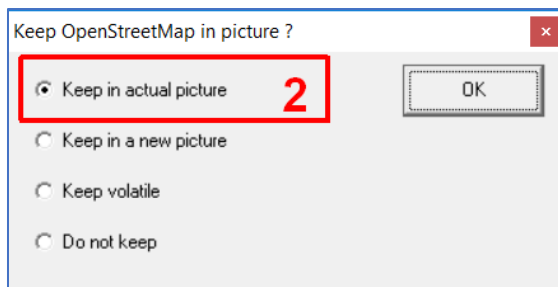


Figure 23: Sure? pop-up

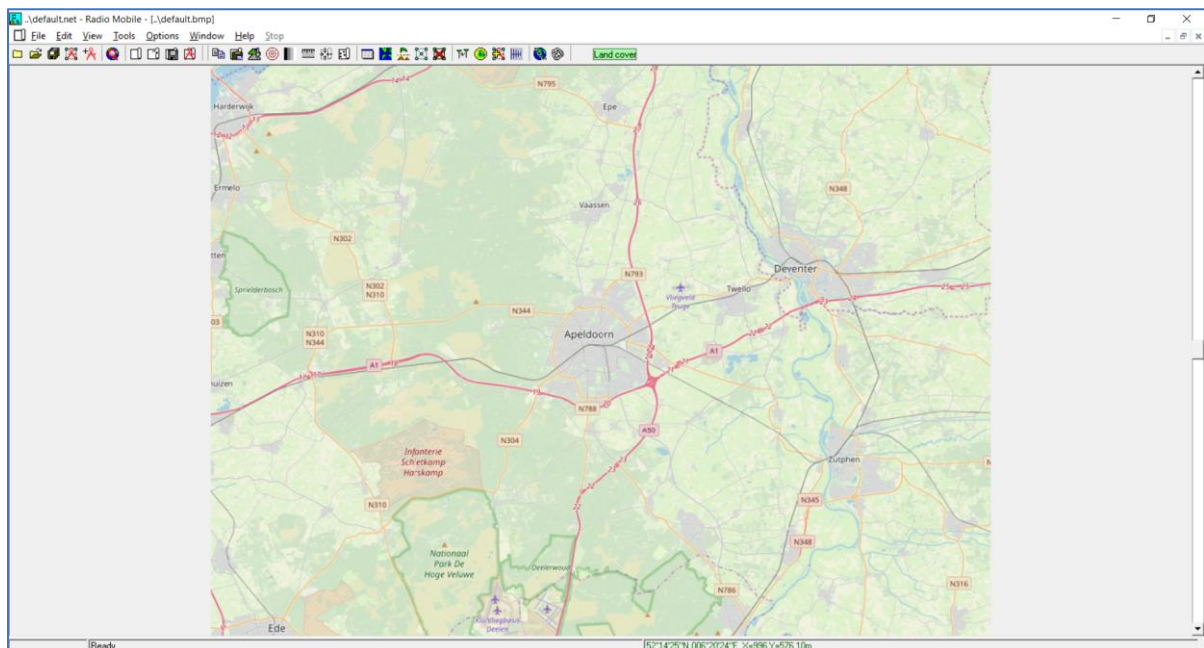



Figure 24: Result of overlaid map.

*Zoom in or out on a map.*

- ☐ Click in the map on the location to which you wish to centre and zoom in to (see Figure 25).
- ☐ Open a new map in “file > Map properties” or click: 
- ☐ 1: Select the centre pointed at by the previous click in the map window      Click button: “Use cursor position”. (see Figure 26)
- ☐ 2: Enter the map height in km. Height(km): 5,00 to zoom in or a bigger value than before to zoom-out. (see Figure 26)
- ☐ Display the new map: Click on button: “Extract” (see Figure 26).
- ☐ Again, overlay the topographical map:  
Do instruction: “Overlay a topographical map in the map window.”.

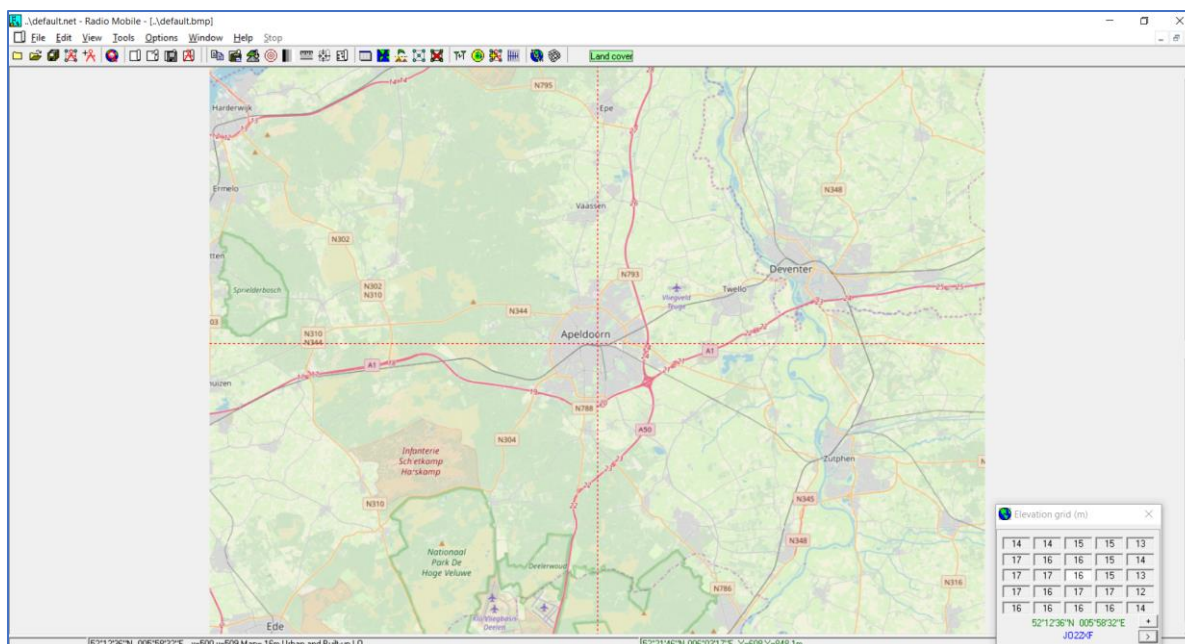


Figure 25: New centre by cursor in map window.

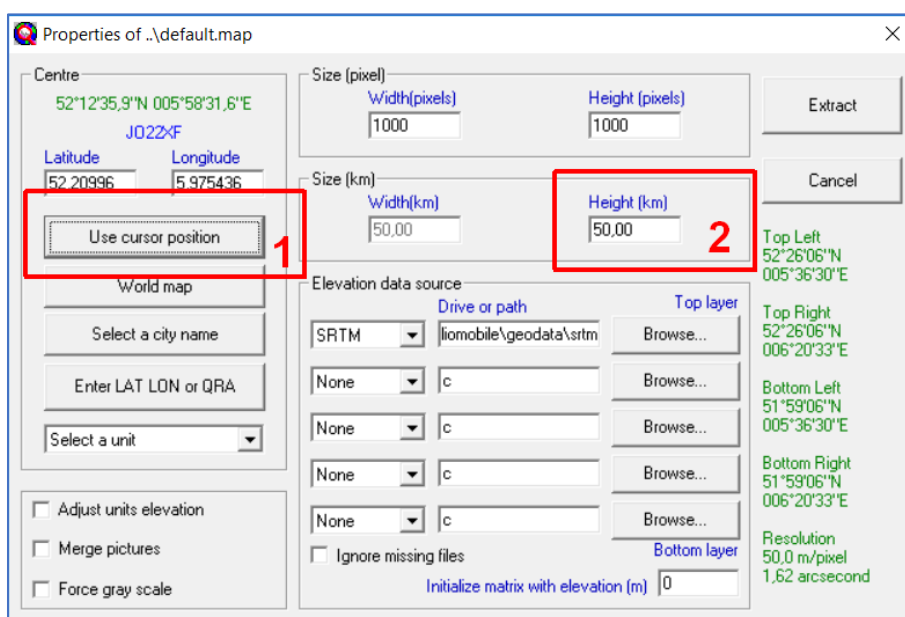



Figure 26: Steps in map properties.

#### Centre map on a unit.

- ☐ Open map properties in “file > Map properties” or click: 
- ☐ 1: Select the centre pointed at by the previous click in the map window Select a unit using the drop-down menu. (see Figure 27)
- ☐ 2: Enter the map height in km. (see Figure 27)  
Height(km): 5,00
- ☐ Display the new map: Click on button: “Extract” (see Figure 27)



- Overlay again the topographical map.  
Do instruction: “Overlay a topographical map in the map window” (see paragraph before)

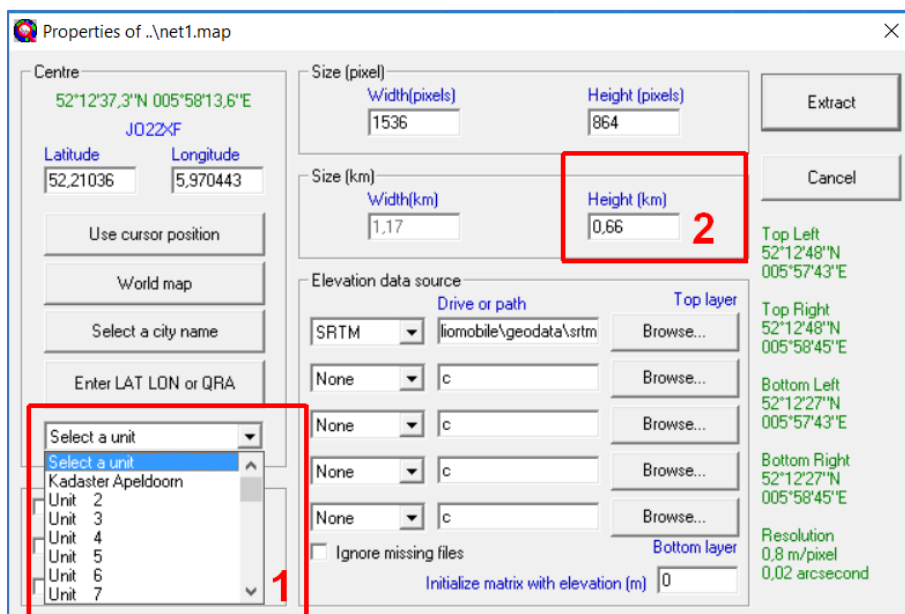


Figure 27: Steps in map properties

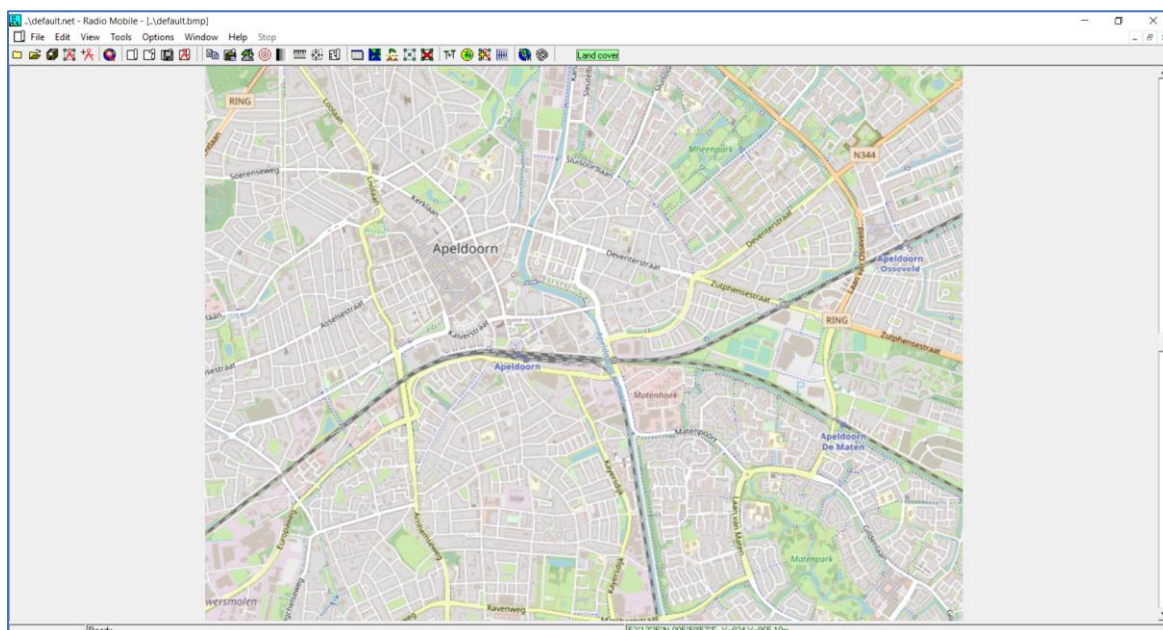


Figure 28: New zoomed map.

#### Save picture of a map.

Once you have the result of your simulation on the map you want to save the result for further use.

- Make sure you have the map on top you want to save a picture of
- Open: “File > Save Picture as...”



- ☐ Provide the name of the picture
- ☐ Select the image type
- ☐ Click save.



It is advised to use the PNG format. This format is lossless compressed and capable of storing transparency.

Exercise 2: Simulate a gateway in the default network.



In this paragraph we will learn the essentials of simulating coverage in Radio Mobile.

In this exercise we will simulate the (uplink) coverage of a gateway using “Network Style”. Network style presents in three colours the coverage.

- When a bin is coloured green the predicted received signal is  $\geq 3$  dB stronger than the receiver threshold.
- When a bin is coloured yellow the predicted received signal is between 3 dB stronger than the receiver threshold and 3 dB weaker. This shows where reception is less probable than 90%.
- When a bin is coloured red the predicted received signal is  $< 3$  dB weaker than the receiver threshold. This shows where there is no coverage.

Network style thresholds can be configured in: File > network properties, “Style” button. See Figure 29.

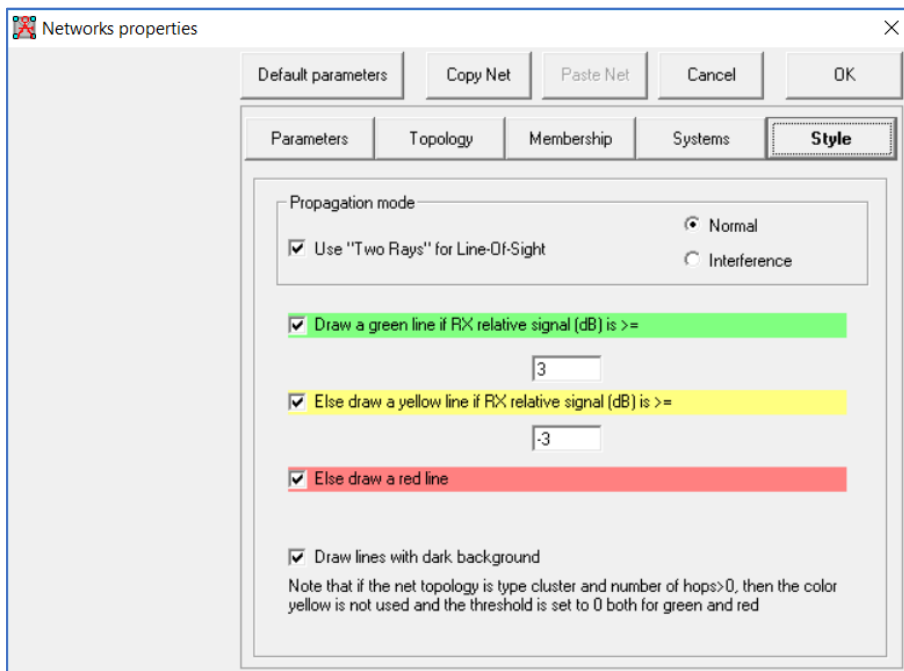


Figure 29: Network style setting in Network properties.

### Preparations

- ☐ Open default network: File > Open networks and open “ttnconferenceworkshoptemplate.net”
- ☐ Make a copy of this network in a new folder “MyFirstNetwork” and give it a new name:  
Open: File > Save Network as...“  
Create a new project directory in “c:\RadioMobile\Data”  
Save in this new directory the network using the name “MyFirstNetwork.net”

Open a new map “

- ☐ Modify map window properties or open a new one when none is opened.” And start working in the copied network.

### Simulate gateway at SF7

- ☐ Open a new map centred at unit “Kadaster Apeldoorn”  
Use “Centre map on a unit.” exercise and select height: 50 km.  
Make sure you have checked “Force grey scale” in Map properties window.  
Click the “Draw” button.
- ☐ Accept the new drawn window by checking “Keep in actual picture” and click “OK”.
- ☐ Overlay a topographical map using “Overlay a topographical map in the map window.”.
- ☐ In the “Operation” box check “Add” and click the “Draw” button.
- ☐ Open the “Single Coverage” Open: Tools > Radio Coverage > Single Polar.
- ☐ 1: Select centre unit “Kadaster Apeldoorn”, Mobile unit: “Unit 1”, and network “LoRa 868 MHz SF7” (See Figure 30)
- ☐ 2: check “centre RX mobile TX” because we are simulating uplink (See Figure 30)
- ☐ 3: Plot type; check “Fill Area”, and “Network Style” (See Figure 30)
- ☐ 4: check “use network antenna settings” (See Figure 30)
- ☐ Click “Draw” button.
- ☐ Accept the changes: Click “OK”

You now have simulated the (uplink) coverage of a gateway that is receiving nodes at a SF7. (see Figure 31)

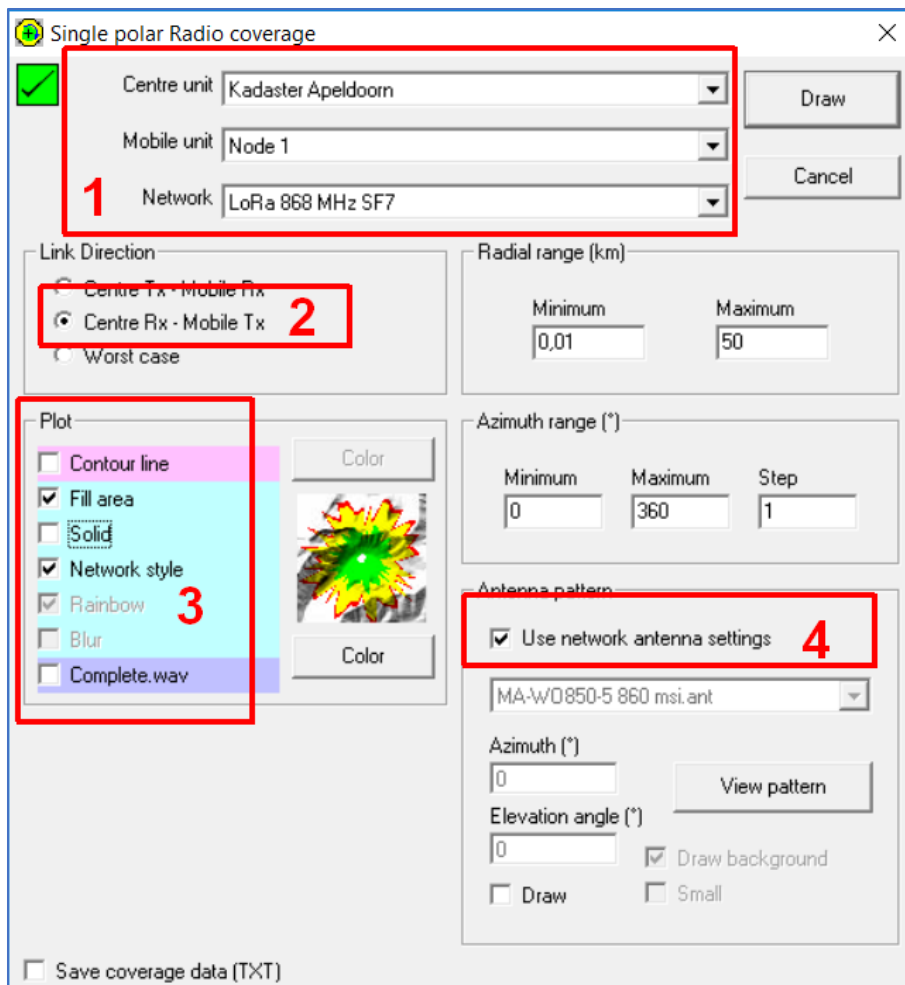


Figure 30: Settings Single polar plot

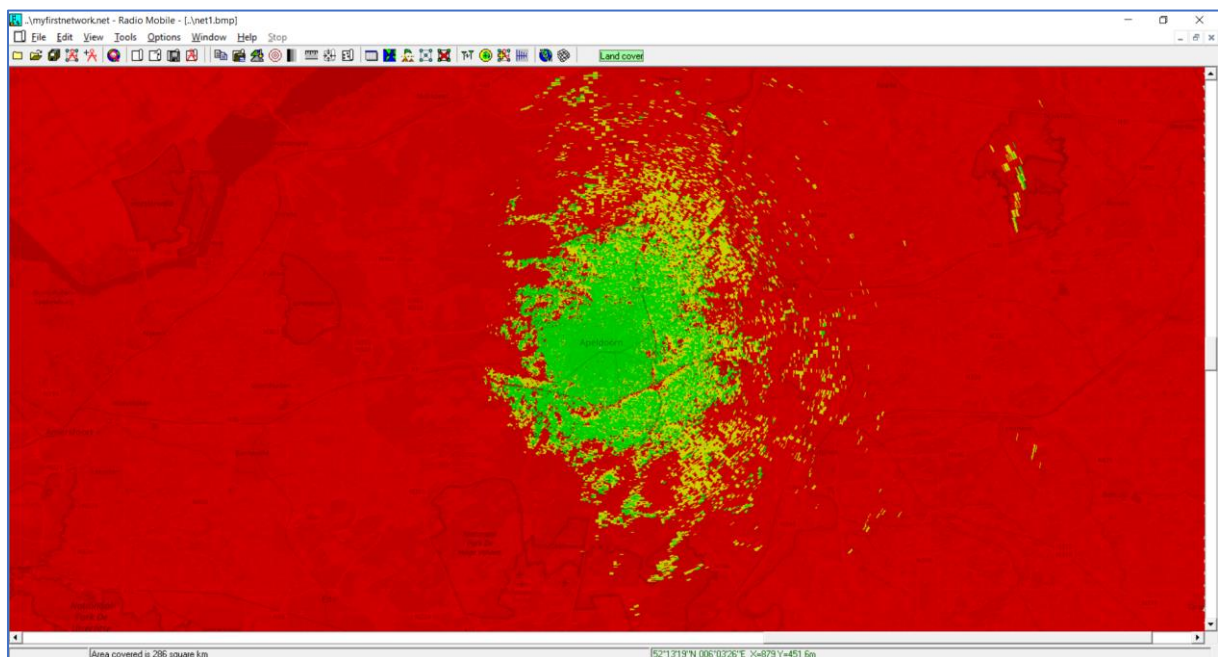


Figure 31: Simulation result Single polar plot, Gateway Kadaster Apeldoorn at SF7

### *Simulate gateway at SF12*

- ☐ Overlay a topographical map using “Overlay a topographical map in the map window.”.
- ☐ In the “Operation” box check “Add” and click the “Draw” button.
- ☐ Open the “Single Coverage” Open: Tools > Radio Coverage > Single Polar.
- ☐ 1: Select centre unit “Kadaster Apeldoorn”, Mobile unit: “Unit 1”, and network “LoRa 868 MHz SF12” (See Figure 30)
- ☐ 2: check “centre RX mobile TX” because we are simulating uplink (See Figure 30)
- ☐ 3: Plot type; check “Fill Area”, and “Network Style” (See Figure 30)
- ☐ 4: check “use network antenna settings” (See Figure 30)
- ☐ Click “Draw” button.
- ☐ Accept the changes: Click “OK”

You now have simulated the (uplink) coverage of a gateway that is receiving nodes at a SF7. (see Figure 32)

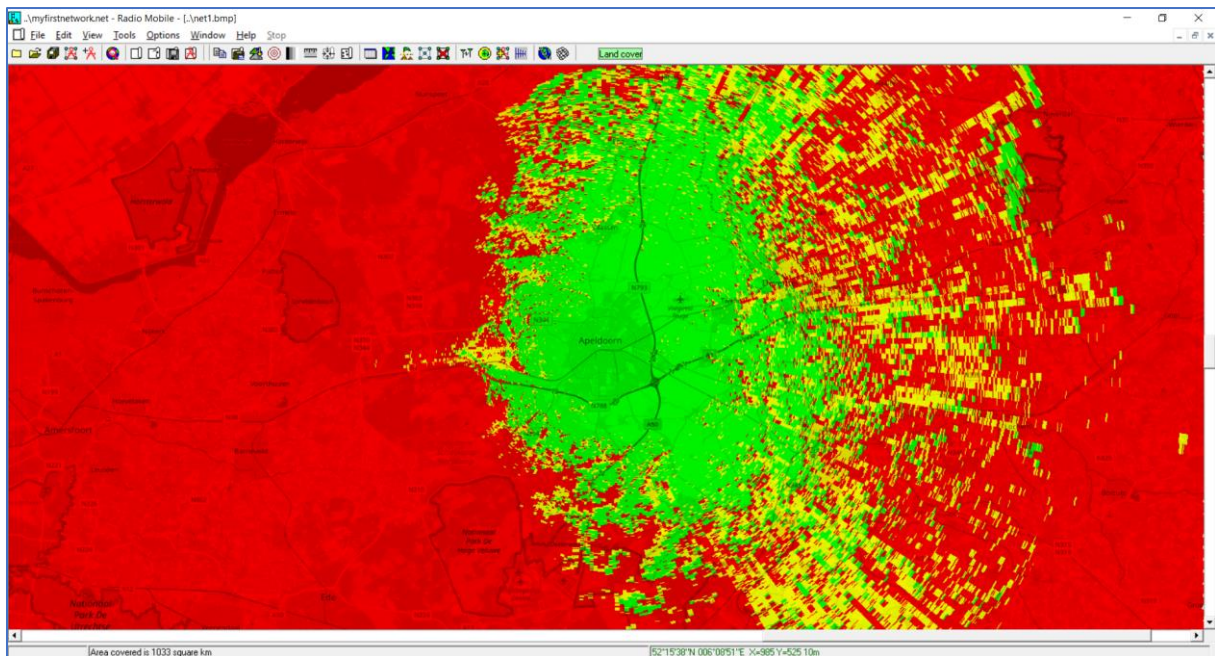


Figure 32: Simulation result Single polar plot, Gateway Kadaster Apeldoorn at SF12

### Exercise 3: Manipulate your network



In this paragraph we will learn how to add a gateway to a network. This method is equal to adding a node to the network.

#### *Add or modify a unit to the network*

We will setup and add a unit to the network.

- ☐ Open a map at the location of your desire.  
At the workshop we will use the following coordinates: Lat: 52,18369 Long: 5,983754 (see Figure 33).

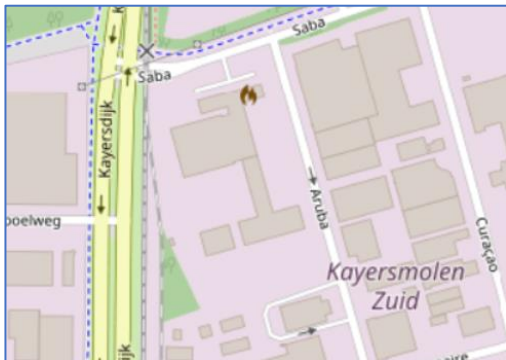


Figure 33: Centre of the created map

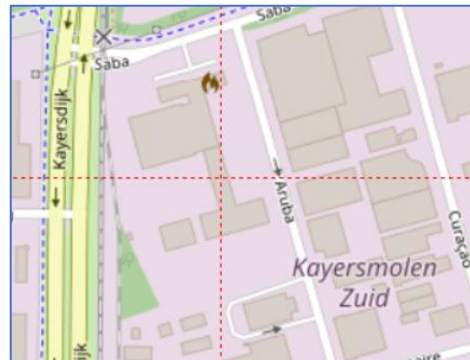


Figure 34: Building selected where we will place a gateway.

- ☐ We will now select the building as can be seen in Figure 34.



- ☐ Open unit properties: File > Unit properties
- ☐ 1: "Place unit at cursor position" (see Figure 35)
- ☐ 2: give the unit a name. We use "Werkgebouw zuid" (see Figure 35)
- ☐ 3: Set label "transparent" (see Figure 35)
- ☐ 4: choose foreground colour of the label black (see Figure 35)
- ☐ klik OK (see Figure 35)



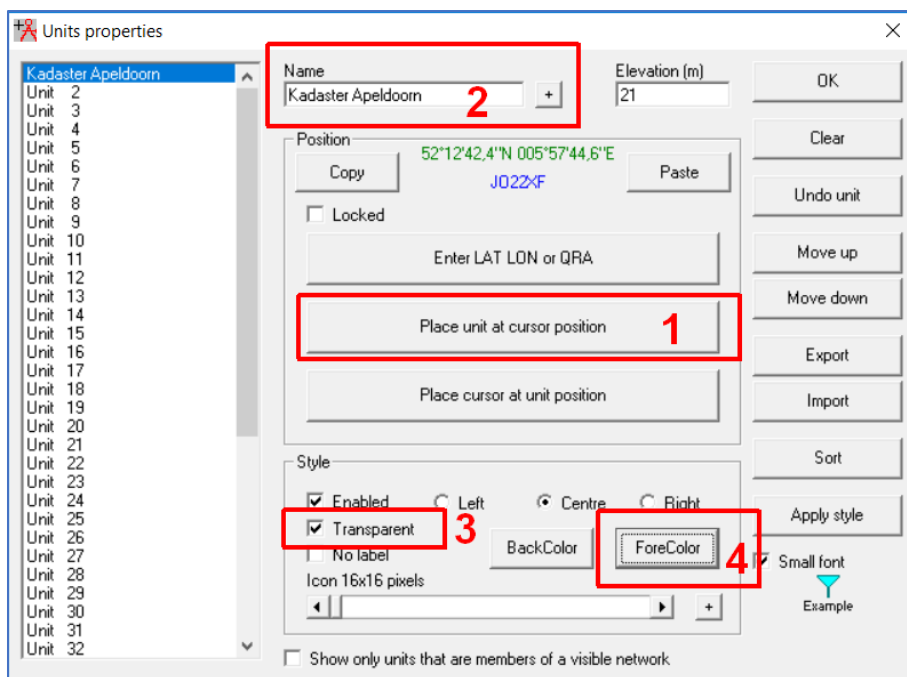


Figure 35: Unit settings

The result is shown on the map: a new gateway. See Figure 36.

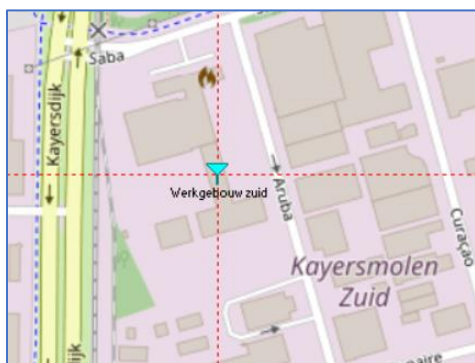


Figure 36: new unit

#### Add unit to network and configure

- ☐ Open Network properties: File > Network properties.
- ☐ Click the “membership” button.
- ☐ 1: Select network “LoRa 868 MHz SF7”. We will add the new unit only to the SF7 network. (See Figure 37)
- ☐ 2: check our new unit “Werkgebouw zuid” to make him member of this network. (See Figure 37)
- ☐ 3: Choose the initial System type “gateway SF7 (90%)” We will change this later. (See Figure 37)
- ☐ 4: set the initial antenna height to 12 meters. (See Figure 37)

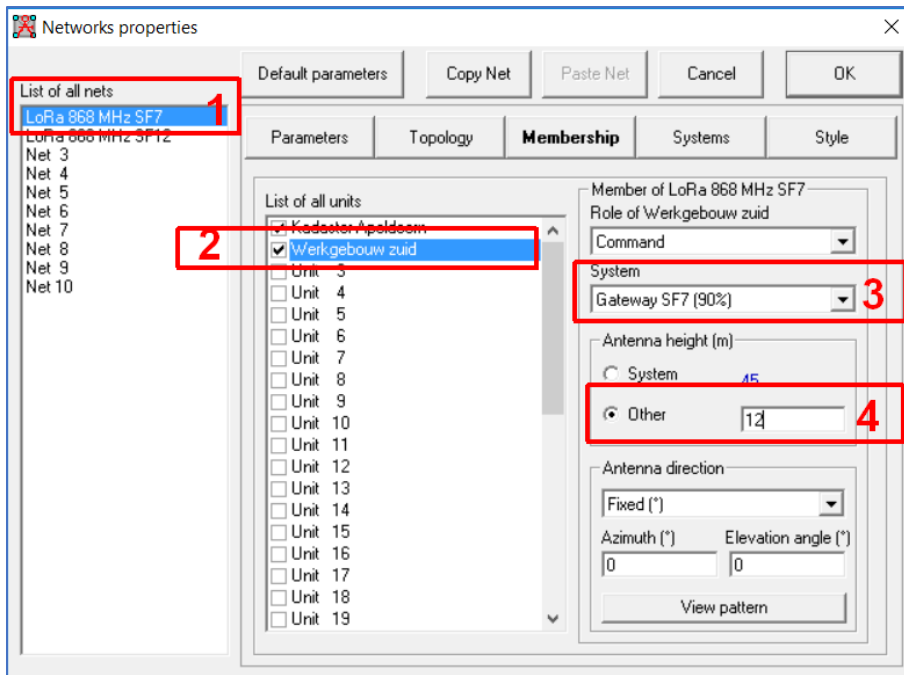


Figure 37: Network properties, membership.

- ❑ Click the “Systems” button.

Because we use different antenna, we need to change type and antenna gain. Also, we need to set power of our gateway. See Figure 38.

- ❑ 1: Select “System 10”, the name will change later.
- ❑ 2: choose the preset system “Gateway SF7 (90%)” from the drop-down menu.
- ❑ 3: change the name of the system to “Werkgebouw zuid SF7 (90%)”  
The system name at (1) will change now too.
- ❑ Set the power of the gateway to +14 dBm.  
Because we use a low gain antenna the power may go up a bit.  
Is this the right power setting? Calculate!
- ❑ 5: Choose the new antenna type “GP\_868\_C\_868.ant”
- ❑ 6: set the antenna gain of this antenna: 0 dBd
- ❑ 7: set the antenna height for this gateway to 12 meters.



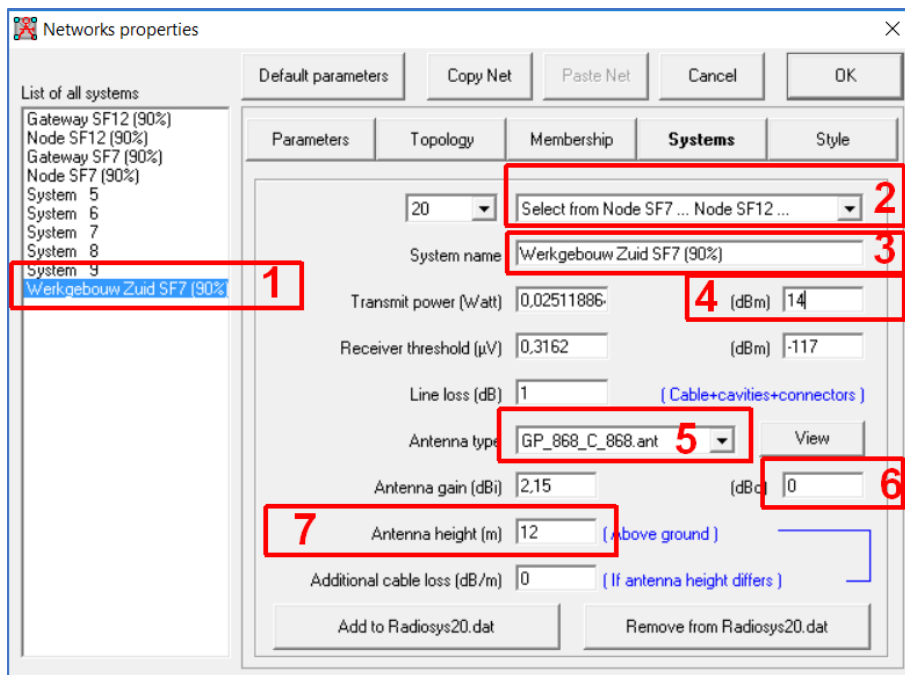


Figure 38: Network properties, Systems settings

- ☐ Click the “membership” button. (see Figure 39)
- ☐ 1: Select system “Werkgebouw Zuid SF7 (90%)”
- ☐ 2: Check system at antenna height to 12 meters

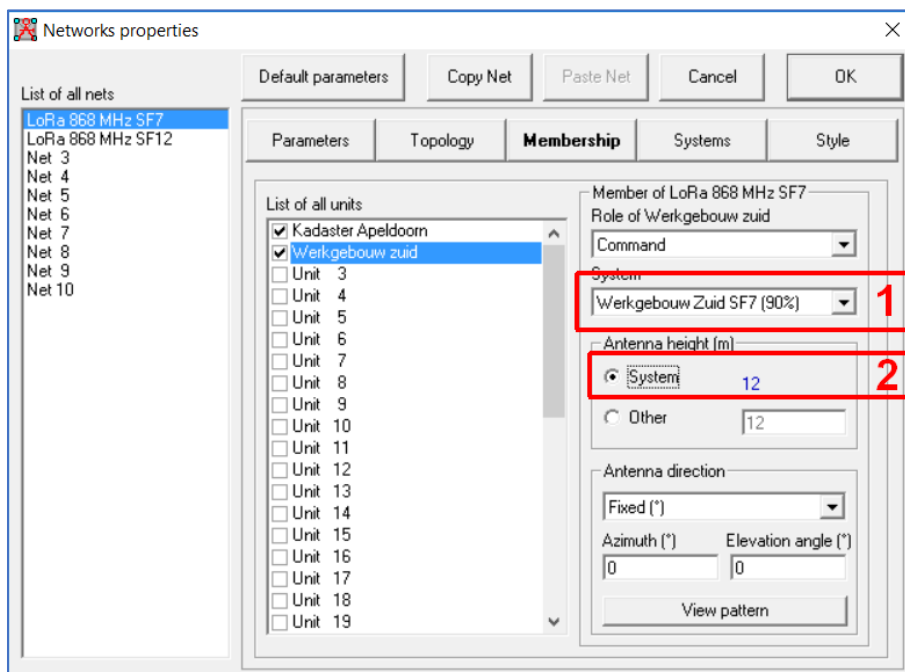


Figure 39: Network properties, membership, verification.

### *Simulate coverage*

You can now simulate the new gateway using: Simulate gateway at SF7.

### Exercise 4: Optional activities



In this paragraph we will learn how to setup Radio Mobile to display RF coverage using a custom colour scheme.

### *Set coverage plot to TTN Mapper colour scheme*

If you want to compare results of TTN Mapper you must set Radio Mobile to the right colour scheme. The TTN Mapper colour scheme is given at Figure 40.

Colour	RSSI
Red	> -100dBm
Orange	-100 - -105
Yellow	-105 - -110
Green	-110 - -115
Cyan	-115 - -120
Blue	< -120dBm

Figure 40: TTN Mapper colour scheme

Preparations.

- ☐ Create a map using “centre unit” and overlay a topographical map.

### *Setting a new colour scheme*

- ☐ Open the “Single Coverage” Open: Tools > Radio Coverage > Single Polar.
- ☐ 1: Check “Fill area” and check “Rainbow”. (see Figure 41)
- ☐ 2: Set threshold to “dBm”, From value to: -120.0 and to: -100.0. Leave “To” unchecked! (see Figure 41)
- ☐ Click the “Color” button. (see Figure 41)  
A new window opens. (See Figure 42)

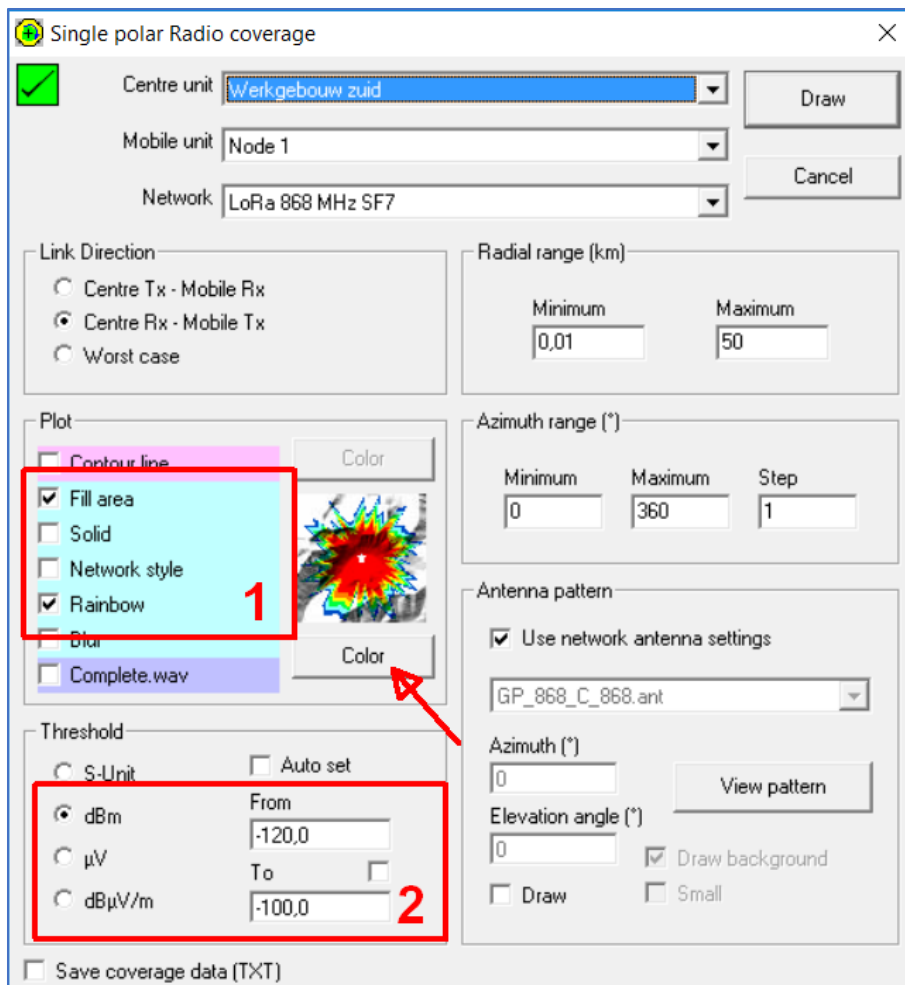


Figure 41: Settings Rainbow colour scheme

- ☐ 1: Select 6 from the drop-down menu.
- ☐ 2: Configure all colours per step; click on the button and choose the colour required. Make the colours as shown in Figure 42.
- ☐ 3: Save the colour scheme for future use.
- ☐ Click OK to finish defining colour scheme.

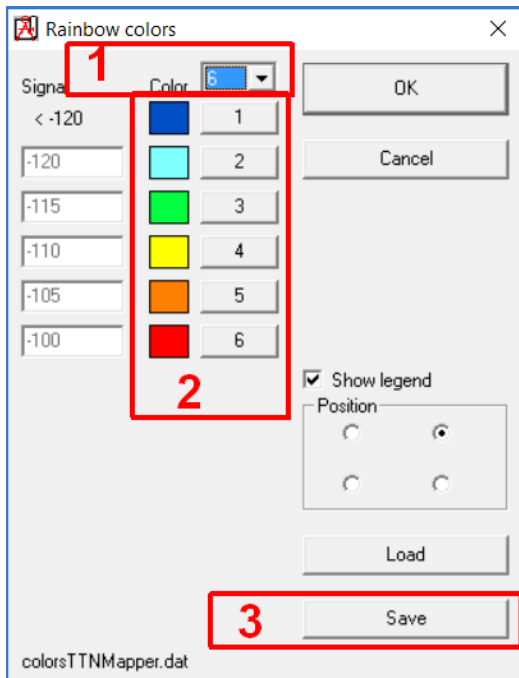


Figure 42: Defining colours of the colour scheme

- Now we can simulate coverage using the new colour scheme.

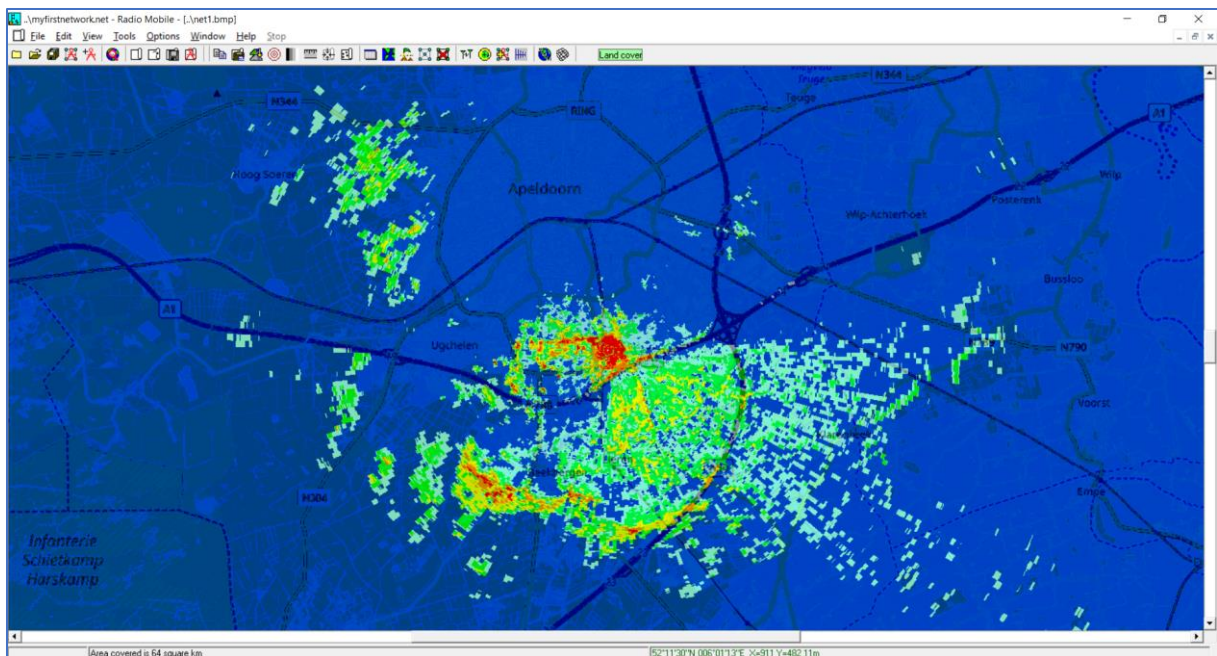


Figure 43: RF Coverage in TTN-Mapper colour scheme

## Other Exercises

With the skills and experience learned you now can continue in the exciting world of Radio Planning and Network Optimisation.

To exercise your skills, we propose the following exercises:

1. [Beginner] Create a link budget for other SF than the ones in this workshop.  
For an instruction see the Radio Mobile website of PE1MEW:  
[http://radiomobile.pe1mew.nl/?How\\_to:Linkbudgets](http://radiomobile.pe1mew.nl/?How_to:Linkbudgets)
2. [Beginner] experiment with antenna height.  
Alter the antenna height of your gateway antenna to see the influence antenna height.
3. [Beginner] experiment with antenna gain of your gateway.  
The antenna gain of your gateway will influence the uplink range of your gateway. What will be the effect on the downlink when we obey the ERP restrictions of the local regulator?
4. [Expert] Create a link budget for indoor coverage.  
Do research on the internet for penetration loss of 900 MHz frequencies and setup a link budget that accounts for indoor penetration loss.
5. [intermediate] Add extra gateway(s) to your network.  
When you have multiple gateways in your network you can create a combined coverage plot using Cartesian coverage. For an instruction see the Radio Mobile website of PE1MEW:  
[http://radiomobile.pe1mew.nl/?How\\_to:Combined\\_Cartesian](http://radiomobile.pe1mew.nl/?How_to:Combined_Cartesian)

## Appendix

### References

Wikimedia. (2018, 12 24). *Link budget*. Retrieved from Wikipedia:  
[https://en.wikipedia.org/wiki/Link\\_budget](https://en.wikipedia.org/wiki/Link_budget)

### Further reading



Radio Mobile is documented by Remko Welling (PE1MEW) who has delivered this workshop to you.

You can find all information about Radio Mobile and Radio Mobile Online at:

<http://radiomobile.pe1mew.nl/> and <http://radiomobileonline.pe1mew.nl/>

Radio Mobile has an active user group at Groups.io:

<https://groups.io/g/Radio-Mobile-Deluxe>

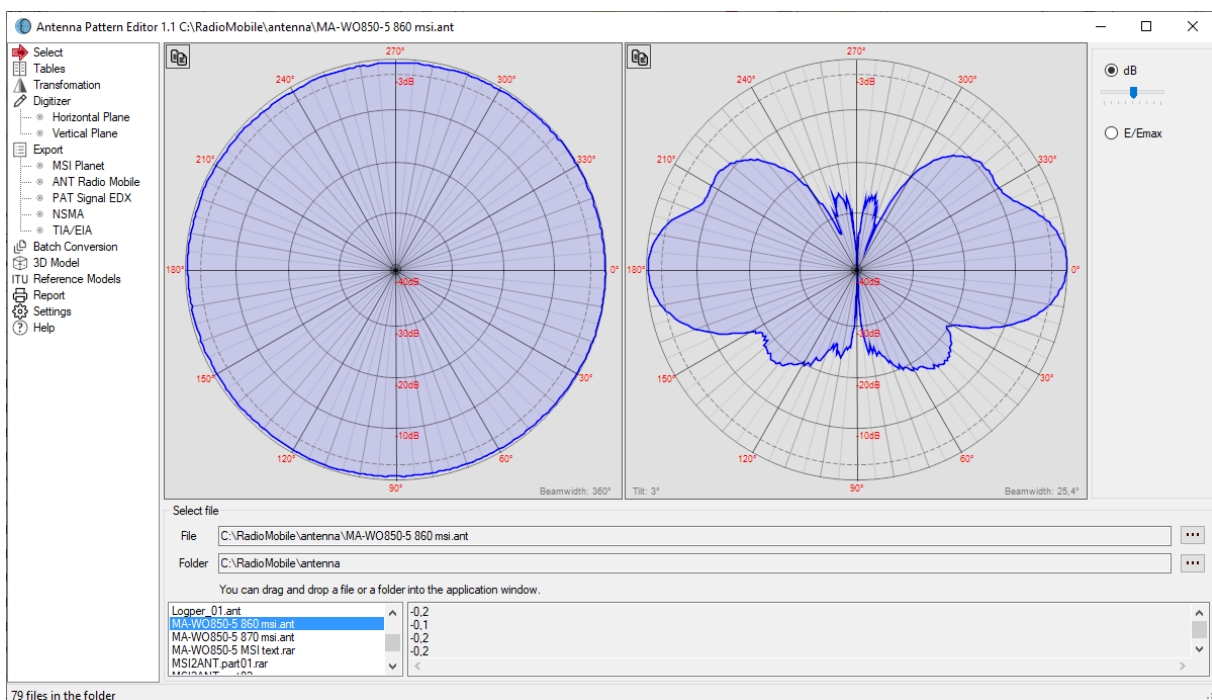
## Antenna pattern software

Conversion of antenna radiation patterns for usage in Radio Mobile is an important step towards higher accuracy of prediction and analysis results. CTT is offering Antenna Pattern Editor<sup>3</sup> for download. A Free Tool to edit, transform, normalize the antenna pattern, as well as several other functions described below.

- View 2D and 3D antenna patterns in linear and logarithmic scales
- View text information from antenna pattern file
- Generation vertical and horizontal antenna patterns
- Perform various transformations of antenna pattern (rotation, mirroring, normalize, etc.)
- Creation of antenna patterns on various reference models
- Antenna pattern report in Word, Excel, and PDF
- Export antenna patterns to various formats
- Batch convert antenna pattern files between formats

Supported antenna pattern file formats:

- MSI Planet (\*.msi, \*.pla, \*.pln, \*.ptn, \*.txt, \*.ant)
- Radio Mobile V3 (\*.ant)
- NSMA WG16.99.050 (\*.adf \*.dat \*.nsma \*.nsm \*.txt)
- TIA/EIA-804-B (\*.adf)
- EDX (\*.pat)



Download the software from: <https://www.wireless-planning.com/antenna-pattern-editor>

<sup>3</sup> <https://www.wireless-planning.com/antenna-pattern-editor>

## Considerations on Radio planning and propagation simulation software

A word on other RF propagation and simulation software (RF-tooling).

This workshop is using Radio Mobile for the simulation and presentation of RF signals. Radio Mobile is freeware and there is no support on the software other than what the user community is providing through their personal websites or on the Radio Mobile forum on groups.io<sup>4</sup>. This lack of support may be a risk that needs to be managed.

Support is not the only property of software that might require mitigating measures or different choices. There are more considerations when selecting and using RF-tooling. In the end all choices are the result of a risk assessment where the chance is expressed in money. Although I do have an opinion on money with respect to RF propagation and simulation tooling I can and will not express my opinion in this writing.

As this workshop is either the first time that the participant goes hands on with RF-Tooling or an attempt to learn more from the expert that is delivering the workshop I will point to the alternatives to Radio Mobile.

When it comes to the selection of radio network simulation software several considerations shall be addressed. There are more topics to consider than those we will discuss here but these are important to be addressed first when selecting tooling. The following topics shall be considered:

1. Data confidentiality
2. Knowledge and expertise of the RF engineer
3. Technology specific support of the tooling
4. Accuracy of the generated results

**Data confidentiality.** Today many applications are running in the cloud and RF propagation and simulation tools are no exceptions to that. Currently Radio Mobile also has an online version as well as commercial software like CloudRF, and Tower coverage.com (who is running the Radio Mobile engine of Radio Mobile Online). With the cloud applications the valuable data of your network or of your customer goes into the cloud.

With data in the cloud there is an increased risk of revealing it on the internet and breaching confidentiality. Do you want to allow your service provider to have access to your data? What is the price when your fellow competitor knows your strategy when gaining a contract?

When the risk and effect is low or when you trust your cloud partner and mitigating measures are in place you may consider using a cloud solution.

**Knowledge and expertise of the RF engineer.** Radio Planning is the craft of an RF engineer. With a link budget that is tailored to the technology being used, simple tooling can be applied to predict radio coverage at high probability.

A skilled radio planner or network optimizer can use any RF propagation and simulation tool to predict coverage at high accuracy. The knowledge and expertise of a RF engineer is also needed to evaluate the simulation results of a tool. His knowledge cannot be substituted by a RF propagation and simulation tool. Please remember: "Shit-in, Shit-out".

---

<sup>4</sup> <https://groups.io/g/Radio-Mobile-Deluxe>



**Technology specific support of the tooling.** RF propagation and simulation tools can be equipped with specific features to implement the studied technology and thus reducing the chance of misconfiguring the tool and decreasing accuracy of a simulation.

The method of implementing technology specific features is known for a long time and beneficial for complex cellular networks like GSM, UMTS and LTE. The cost for implementing these complex features is paid for by the large group of cellular operators that finance these developments. Because money is the driver of these developments, operators of niche technologies like LoRaWAN cannot afford to pay for the development of technology specific additions. Only in rare cases like in S\_IoT of Siradel and HTZ communications of ATDI IoT technologies like LoRaWAN are supported.

Choosing commercial RF-Tooling is highly dependent on the money involved with network deployment or optimization. For a single site in rural terrain at a farm it is likely that common sense and a trial and error method is the most cost-efficient approach.

When deploying or optimizing a large area or nationwide network, it is beneficial to minimize the cost of errors in the planning phase. Because of the amount of work automating the planning process by using technology specific features is also beneficial.

**Accuracy of the generated results.** RF-Tooling is using mathematical models to predict RF propagation. However, there is not a single model that can predict with high accuracy in any situation.

RF propagation models can be divided in two groups: Statistic- and empiric models. Statistic-models are models that use a minimum set of environmental data like terrain height and clutter and have a minimum of variables that can be tuned. Empiric models are more sophisticated models that can use a variety of environmental data such as high-resolution clutter data or even 3D building data. One specific model type in the group of empiric models is the ray tracing model. This model can make accurate predictions inside a building or in dense urban areas.

Statistical models are models used by ITU and for example the Longley-Rice Propagation model from which other models are derived (For example the Irregular Terrain Model (ITM) in Radio Mobile). These models are well documented and are in almost all RF-tooling implemented. Statistical models need a minimum effort in tuning (verification) and deliver good results when used within the given constraints.

Empirical models like MYRIAD a Volcano are mostly used in commercial RF-Tools and can produce predictions with high accuracy. These models require an extensive process of model tuning before they can be used. Model tuning is a process where the mathematical formula is tweaked in such a way that the predicted value at a specific location is with high accuracy equal to the measured value at that location. This process of data collection (drive testing) and model tuning can take up to 6 months or a year before the model, and thus the RF-tool is usable.

**Conclusion.** The selection of a RF-Tool is dependent on many conditions and considerations. If you have the money and the scale of your project implies a high financial risk, the investment in a commercial RF-Tool can be legitimate.

When data confidentiality has no high priority and your RF-analyses are exemplary it is likely that a low-budget on-line service or hiring a radio planning- or network optimizing consultant on hourly basis is much more effective.

## Radio planning and propagation simulation software



This list of RF propagation and simulation programs is a quick pick of the more popular programs. This list was never intended to deliver 100% coverage of all available programs.

### *Freeware and open source*

- **Radio Mobile** (Freeware) <http://www.ve2dbe.com/english1.html>
- **Radio Mobile Online** (freeware) [https://www.ve2dbe.com/rmonline\\_s.asp](https://www.ve2dbe.com/rmonline_s.asp)
- **Splat** (open Source) <https://www.qsl.net/kd2bd/splat.html>

### *Commercial online services*

- **CloudRF** <https://cloudrf.com/>
- **Tower coverage.com**, <https://www.towercoverage.com/>

### *Commercial programs and services*

- **S\_IoT**, Siradel [https://www.siradel.com/software/connectivity/s\\_iot/](https://www.siradel.com/software/connectivity/s_iot/)
- **Mentum Planet**, Infovista <https://www.fovista.com/planet/rf-planning-software>
- **Asset**, Teoco <https://www.teoco.com/products-services/ran-solutions/planning/radio-planning/>
- **Atoll**, Forsk <https://www.forsk.com/>
- **HTZ communications**, ATDI <https://atdi-group.com/htz-communications/>
- **TAP 7**, Softwright <https://www.softwright.com/>
- **RadioPlanner 2.1**, CTT <https://www.wireless-planning.com>



Another list can be found here: <http://rsl.ece.ubc.ca/planning.html>  
This list is outdated when inspected (January 2010)