ATDI

■ White Paper
May 2008

Wimax propagation in ICS telecom *nG*

Solutions in Radiocommunications

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1 – General considerations

1.1 LOS, nLOS, NLOS: notions

Propagation aspects can be divided in three different topics:

- LOS propagation (Line Of Sight): The transmitter and the receiver are in visibility one with each other.
- NLOS propagation (NON Line Of Sight): The transmitter and the receiver are not in visibility one with each other. A typical example is a WiMAX BTS located in Outdoor environment, when the CPE is located inside a building. The signal between the BTS and the CPE is then diffracted, diffused, or both.
- nLOS propagation(near Line Of Sight): This case is a mix between the LOS and the NLOS case. The transmitter and the receiver can be for instance in visibility one with each other, but part of the Fresnel ellipsoid is obstructed. A transmitter and a receiver almost in visibility one with each other is all a possibility: the signal can then propagate using diffraction or multi-reflection on building sides.

1.2 Propagation aspects

- LOS (Line of Sight)

The propagation in LOS is based upon clearly defined propagation methods, such as the ITU-R P 525 model. Note that in ICS Telecom nG, taking full advantage of the quality of the cartography loaded, **deterministic** propagation models, have proved to give the best correlation when correlated with on-field measurements.
Of course, additional effects, such as attenuations due to the rain or gas are also considered.

- NLOS (Non Line Of Sight)

The building file describes the building height above ground level. In ICS telecom nG, the Digital Terrain Model is now separated from the above-the-ground features (buildings, trees…). Specific attenuation coefficients can be applied to the buildings in order to simulate the diffusion effect when the Outdoor signal penetrates an Indoor environment.
For a thorough description of this model, please refer to ATDI’s White-paper called "Mixed absorption-diffraction propagation models for wireless proximity networks".

- NLOS (near Line Of Sight)

Diffraction effect:
The diffraction models in ICS telecom nG do quantify the losses due to obstacles between the BTS and the CPE, avoiding the two entities to be in Line of Sight one with each other.

Subpath attenuation effect:
The subpath model in ICS telecom nG quantifies the losses due partial obstructions of the Fresnel zone. Such an attenuation term can be defined for partial obstruction in the Z axis only, or in full 3D.

Multi-reflection effect:
This model calculates the field strength at all point of the simulation area according to reflected signals contribution, taking into account a reflection coefficient defined by the user. Note that the multipath calculation engine of ICS telecom nG also allows dedicated analysis of **power delay spread** effect.
This refers to the maximum difference in arrival times at the receiver when there is more than one signal received via different transmission paths. Studies show that for delays limited to a fraction of the symbol time, the amount of signal degradation depends not in the actual delay profile, but on the rms value of the delay, weighted by their respective power levels.

2 – Cartographic data

A radio-planning tool such ICS Telecom requires to use a cartographic environment in order to simulate a certain technology as accurately as possible. Depending on the data available (none, meaning flat earth, low resolution, medium resolution, or high resolution), the kind of output will be completely different.

2.1 Low resolution data

Low-resolution data roughly describes the terrain with an accuracy of 300m and above. These kinds of datasets are usually used for coordination purposes and fast network dimensioning. Since a city would be limited to only a few pixels using these kinds of cartographic datasets, accurate urban planning cannot be performed with low-resolution cartographic data.

2.2 Medium resolution data

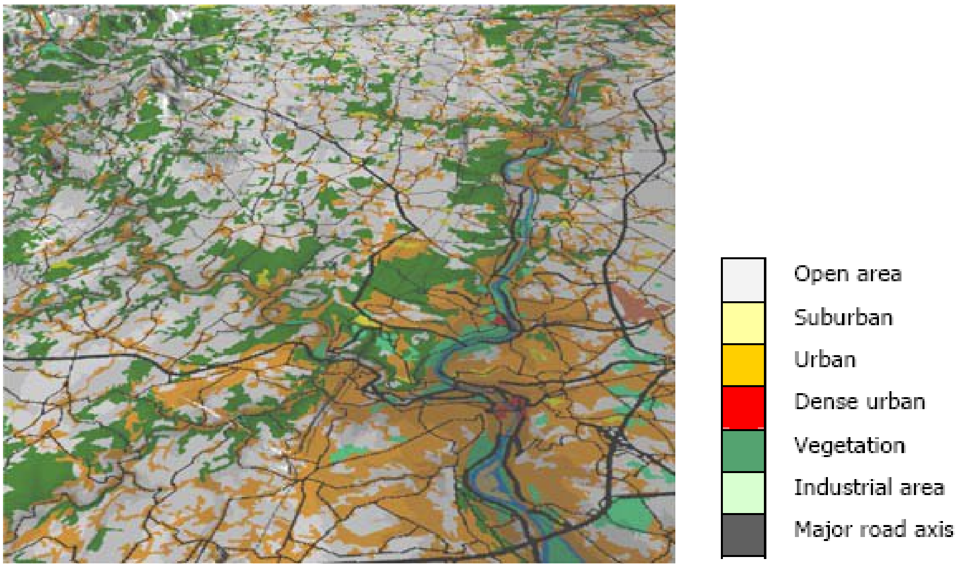
2.2.1 Rough description of MR data

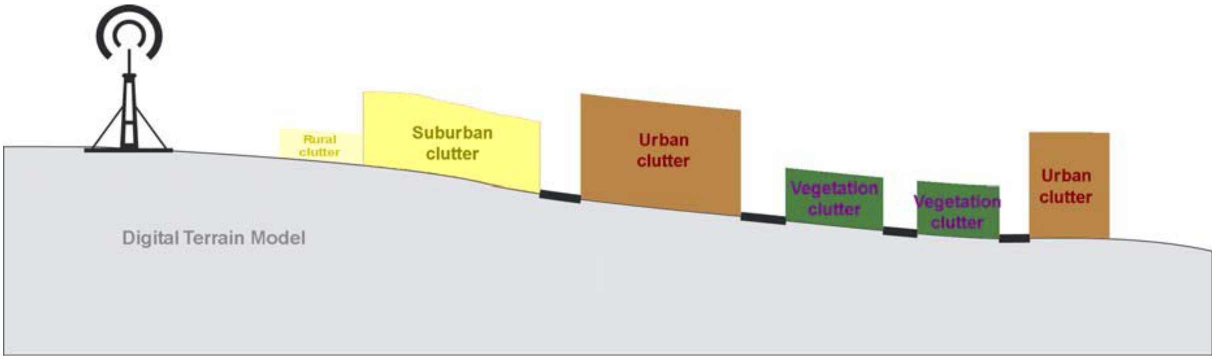
Medium resolution datasets describe the terrain with an accuracy between 10m and 50m. A coverage prediction using a medium resolution dataset is based upon two different cartographic files:

- The Digital Terrain Model: that describes each pixel with an altitude above sea level

- The clutter file, that describes the ground occupancy above the terrain. This file is used by the propagation model to refine its prediction according to a statistical ground occupancy of the area analyzed. Each type of ground occupancy can be defined using their own propagation parameters: the height of the clutter, the diffraction factor, a potential additional attenuation…

As we can see, a medium resolution cartographic dataset does not describe each building outline. Only the major road axis can be outlined on this kind of dataset, as the pixel size is quite large with respect to the width of a street.



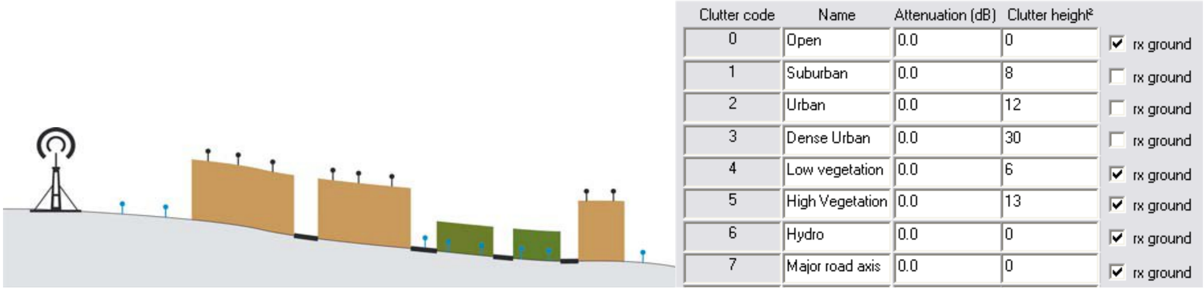


Using this kind of cartography, two kinds of propagation models can be used for network design purposes:

- Deterministic models
- Statistical models

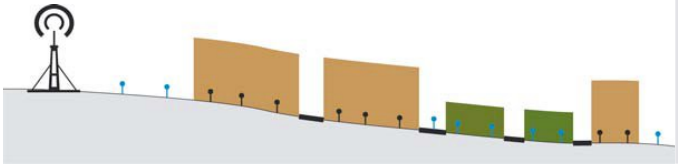
2.2.2 Deterministic models and planning margins

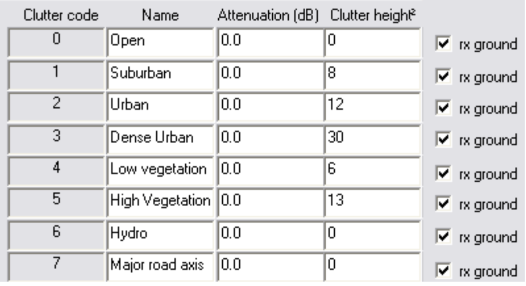
The deterministic models make use of the laws governing electromagnetic wave propagation to determine the received signal power at a particular location. They require a 3-D map of the propagation environment: the more compatible the accuracy of the cartography with a certain technology to simulate, the better the coverage accuracy (for a given set of technical parameters for the Best stations / Terminals / CPEs). Typical examples are the ITU-R 525/526 models, used with appropriate additional propagation effects (diffraction, sub-path attenuation, ray tracing)…
Depending on the type of technology to simulate, the receiver can be placed either above the urban clutter codes (Fixed Wireless Access type of networking), or "dug" into the clutter. In this case, attenuation associated to the signal strength received at each pixel will be attenuated based upon the selected diffraction model.



Clutter code	Name	Attenuation (dB)	Clutter height	
0	Open	0.0	0	☑ rx ground
1	Suburban	0.0	8	☐ rx ground
2	Urban	0.0	12	☐ rx ground
3	Dense Urban	0.0	30	☐ rx ground
4	Low vegetation	0.0	6	☑ rx ground
5	High Vegetation	0.0	13	☑ rx ground
6	Hydro	0.0	0	☑ rx ground
7	Major road axis	0.0	0	☑ rx ground

Rx placed either on top or into the clutter





Clutter code	Name	Attenuation (dB)	Clutter height	
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4	Low vegetation	0.0	6	☑ rx ground
5	High Vegetation	0.0	13	☑ rx ground
6	Hydro	0.0	0	☑ rx ground
7	Major road axis	0.0	0	☑ rx ground

Rx forced to be placed into the clutter: an attenuation is calculated by diffraction effect

As we have seen earlier, Medium Resolution cartography does not describe the "real" height of each building, but a statistical ground occupancy. It means that a fully deterministic propagation model might be limited for technologies using high frequencies, where each above the ground feature can become a physical obstacle to the propagation of the signal (diffraction, absorption…).

Note that the clutter files used by a medium resolution dataset are not made in order to calculate the Indoor propagation loss by diffusion effect, neither by ray tracing methods, as the outline of each building is not described in the cartographic files. Other methods, such as using one of the diffraction models of the planning tool or applying user attenuation per clutter code must therefore be setup if medium resolution cartography is used.

2.2.3 Empirical models and their requested tuning

Empirical models model the environment as a series of random variables. These models are the least accurate but require the least information about the environment and use much less processing power to generate predictions. An example of these types of model are the Stanford University Interim (SUI) channel models developed under the Institute of Electrical and Electronic Engineers (IEEE) 802.16 working group. These models are not available on purpose in ICS Telecom: medium resolution cartography can indeed be processed very easily (from SRTM/Landsat data for instance), making this propagation modeling without detailed cartography not accurate enough with regards to the results that could be obtained using other models. Other examples of empirical models are ITU-R 1546, Hata and the COST-231 Hata model. Although empirical propagation models for mobile systems have been comprehensively validated (mainly macrocell 2G/3G planning, but not for detailed microcell analysis), it has not been fully established if they are appropriate for FWA systems.

These models are less dependant on the quality of the cartography: they try to re-create the urban environment and the resulting mean path loss using typical inputs such as the distance, the average building height (giving by the clutter file), the average street width…

The cartographic dataset loaded in ICS Telecom will differentiate the signal propagation between downtown Hong Kong or in a medium size French city using a deterministic model, whereas it is the tuning of the empirical model itself that will make the difference. Requiring less cartographic input is a major asset for the empirical models, but their main drawback is the fact they require tuning in order to be accurate. And this model-tuning phase cannot be achieved without accurate measurements, that need to be performed according to the same technology and the same urban environment as the one that will be simulated afterwards.

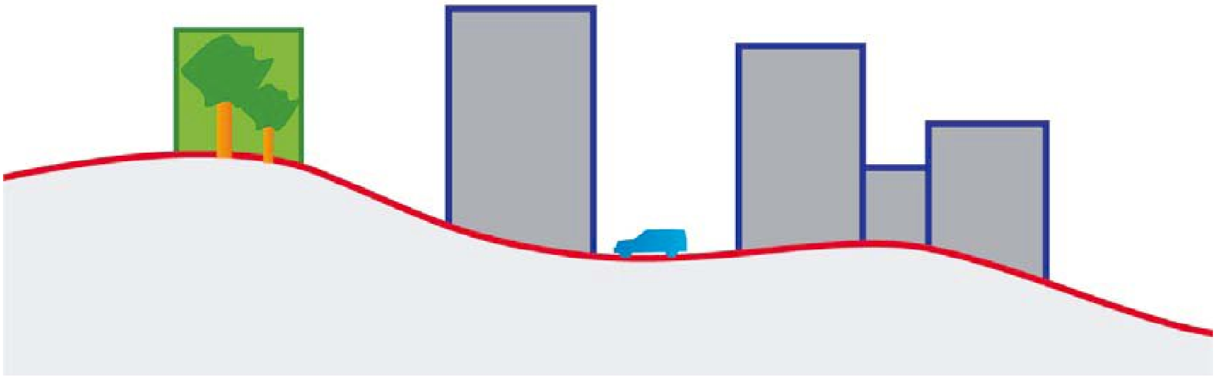
2.3 High resolution data

2.3.1 Rough description of HR data

In opposition to low resolution or medium resolution cartography, high-resolution cartography aims to describe the urban environment as accurately as possible. All objects that might generate a change to the propagation environment (Buildings, trees…) are modelized.

Different HR datasets can be outlined:

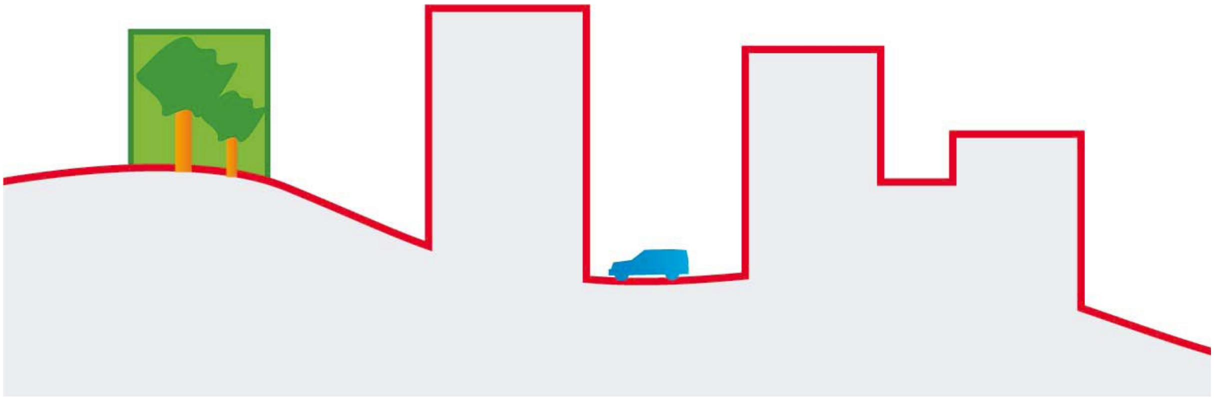
- DTM, building and clutter files



In ICS Telecom, the terrain (DTM in red) is modelized as a .geo file, providing all terrain altitudes above sea level. The exact height (according to the vertical accuracy of the file) of each building and tree is given by the .blg file, whereas the type of building or tree (concrete or glass building, tree resistant in winter…) is given by the .sol file (blue and green).

The .blg cartographic input is used in the nG version of ICS Telecom, enabling the Outdoor to Indoor simulation, in addition to all other standard outdoor simulation available in the previous versions of the tool.

- DEM and clutter files



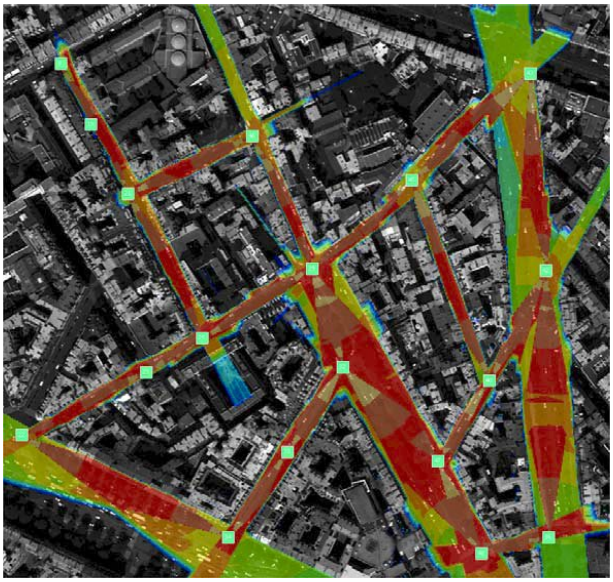
The Digital Elation Model models the terrain and the above the ground features (in red) with the same cartographic layer. The buildings have the same obstructive properties as the terrain. Only the trees are handled separately in the clutter file by applying them an average height. Outdoor simulations (on rooftops or the streets) can be performed, whereas the signal obtained into the buildings need to be calculated by applying an attenuation offset on the signal received on the rooftops.

- DSM

The Digital Surface Model features all objects within the same layer. Due to processing methods, some noise avoids the building rooftops to be flat, without post treatment. The main issue with this kind files is the fact that all above the ground features, whatever their nature are extracted. The trees, the buildings and the bus and car traffic are obstacles to the signal propagation. Predictions at the street level (mobile…) cannot be therefore considered as meaningful using DSM files, only Line Of Site validation for fixed technologies can be performed.

2.3.2 Deterministic models and the "canyon effect"

High-resolution data in an urban environment allows the radio-planning tool to simulate effects such as the canyon effect. As the resolution of the files is quite high, the distinction can be made between the streets and the buildings. A transmitter placed at the street level is "narrowed" by the building facades, thereby creating a waveguide effect (enhanced with ray tracing modeling, see § 2.3.3).



Canyon effect in ICS Telecom: the outline of each building in 3D generates "propagation corridors" in the streets, when the transmitters are placed at this level

Off course, such an effect can only be obtained if the street is clearly defined on the cartographic dataset. As an example, 5m accurate high resolution cartographic data might not be accurate enough in order to simulate the canyon effect: the street itself might be large enough in order to be outline in the dataset. This is especially important for old European cities, where some streets are not large at all. For this reason, ATDI advises the use of 2m accurate HR datasets, in order to simulate the canyon effect.

2.3.3 The limitation of statistical models with HR data

Empirical models are used in order to simulate by mathematical terms topographical characteristics that are not available on the cartographic dataset used as a basis for the propagation calculation, such as the average height of the buildings in the area, the width of the streets… All of these are already available in a High Resolution cartographic dataset, making the characteristics of the empirical model redundant with the cartographic dataset itself. The urban environment is described as close to reality as possible, making deterministic models much more efficient in terms of accuracy than empirical models when HR data is used.

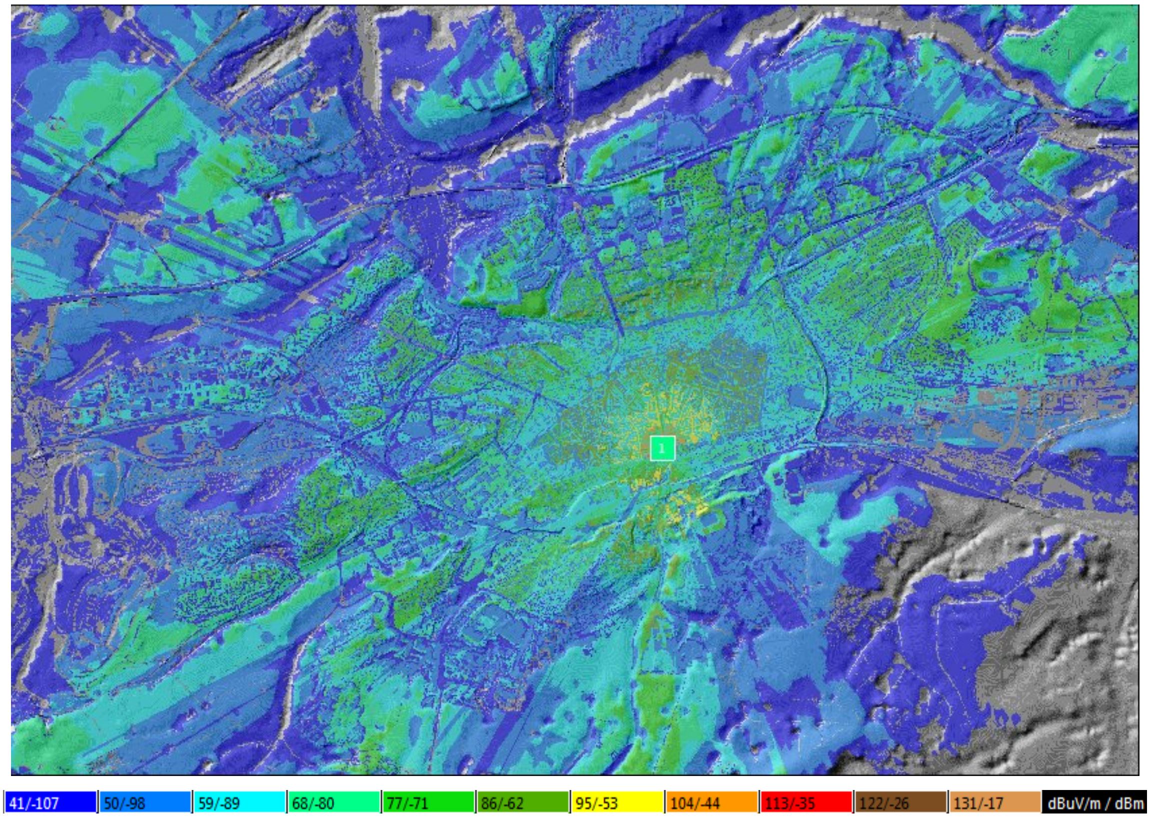
3 – Model tuning examples

3.1 – Model tuning in Germany - WiMAX in the 3.5GHz band

Simulations with ICS telecom

Cartographic database with 2m resolutions with: DTM, Clutter and building layers. The propagation model used was including:

- Free space model (Line Of Sight (LOS)) : the ITU-R P.525 model;
- Diffraction model (Non Line of Sight (NLOS) model) : Deygout 94;
- Subpath attenuation model (Near Line of Sight (nLOS) modeling) : "Standard integration method";
- 3D ray tracing on reflected signals turned off;
- Specific penetration losses for trees, forest and buildings.



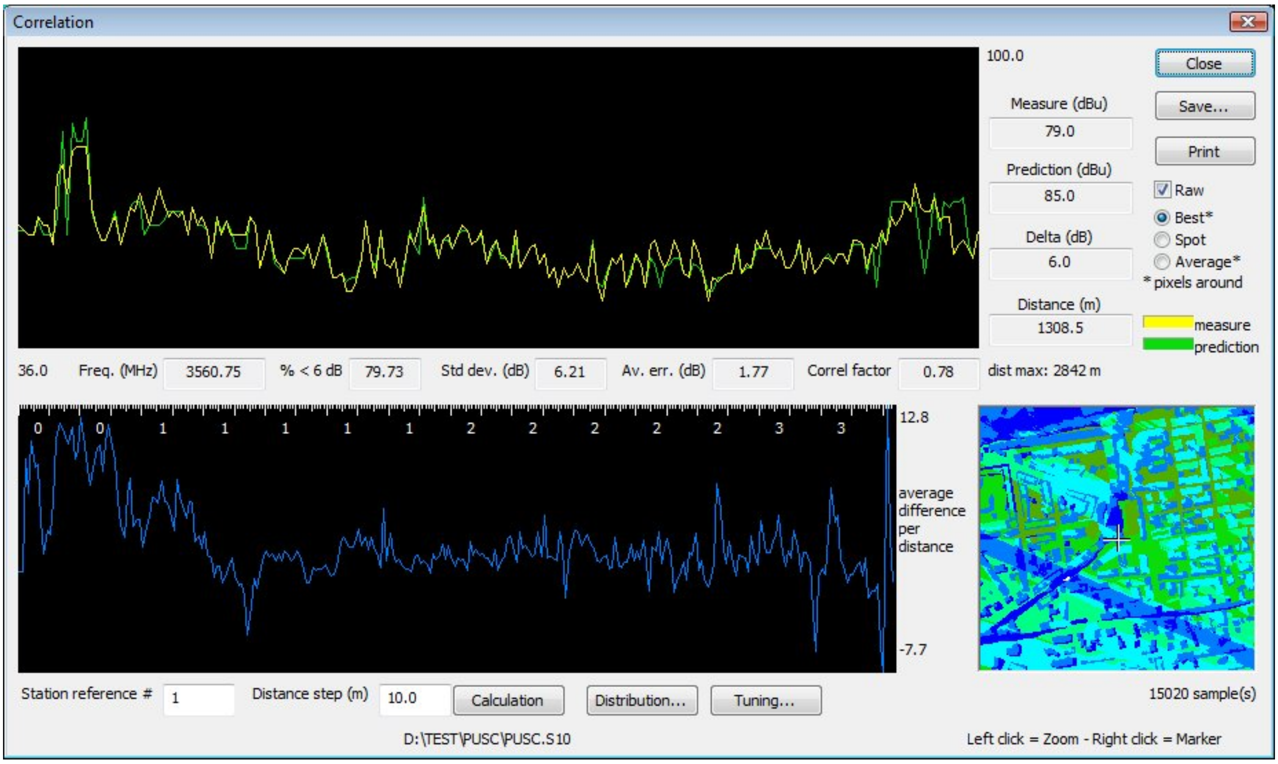
Coverage result of the base station transmitter

Field test measurements

The field test components consisted of a fixed base station WiMAX transmitter (3.5GHz band) and a mobile terminal.

Results achieved

A standard deviation of 6.21 dB was obtained with 80.0% of samples within a 6 dB variation limit to achieve an average error of 0.78 dB. Fifteen thousand fixed sample points were recorded over one week.



Measure (dBu) 79.0

Prediction (dBu) 85.0

Delta (dB) 6.0

Distance (m) 1308.5

☑ Raw

● Best*

○ Spot

○ Average*

* pixels around

🟨 measure

🟩 prediction

Freq. (MHz) 3560.75 % < 6 dB 79.73 Std dev. (dB) 6.21 Av. err. (dB) 1.77 Correl factor 0.78 dist max: 2842 m

Station reference # 1 Distance step (m) 10.0

15020 sample(s)

D:\TEST\PUSC\PUSC.S10

Left click = Zoom - Right click = Marker

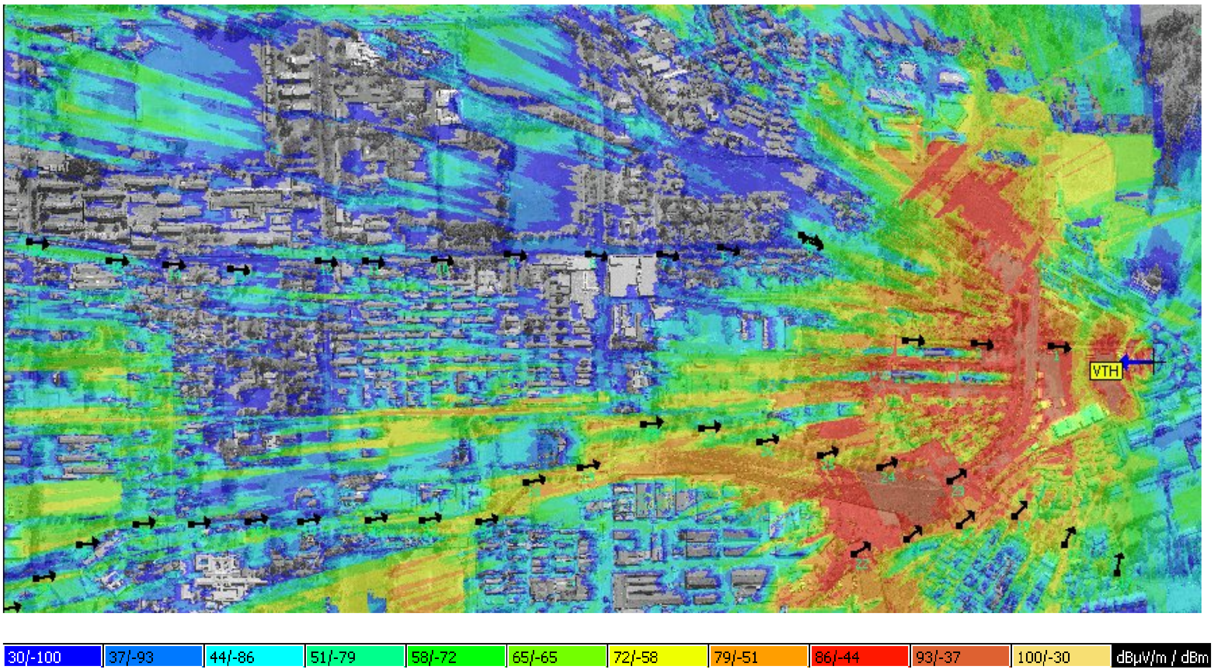
ICS telecom's correlation window

3.2 – Model tuning in RSA – WiMAX in the 3.5GHz band

Simulations with ICS telecom

Propagation model including:

- Free space model (Line Of Sight (LOS)) : the ITU-R P.525 model;
- Diffraction model (Non Line of Sight (NLOS) model) : Deygout 94;
- Subpath attenuation model (Near Line of Sight (nLOS) modeling) : "Standard integration method" including obstructions to the 3D spherical wave;
- 3D ray tracing on reflected signals turned on
- Indoor signal penetration: Additional Clutter losses with specific levels for brick and concrete structures. Vegetation divided in two categories: vegetation up to 6 meters and above 6 meters.



Coverage result of the base station transmitter used with field test points (black arrows)

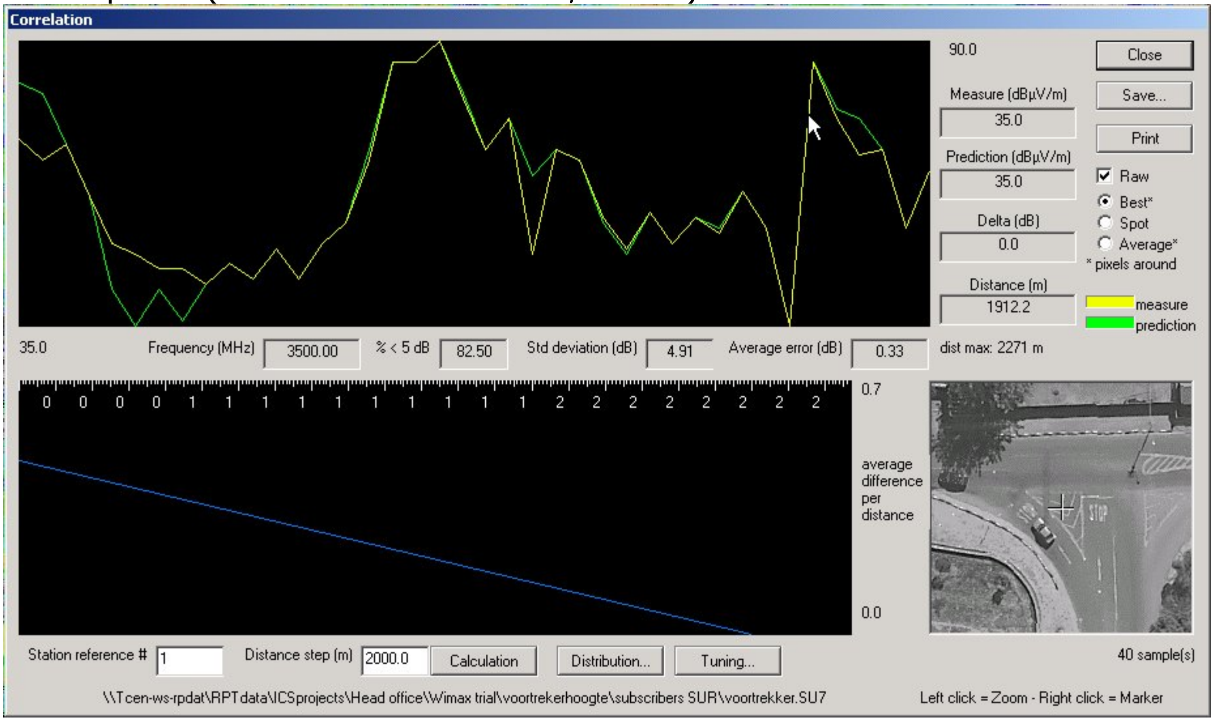
Field test measurements

The field test components consisted of a fixed base station WiMAX transmitter (3.5GHz band) and a fixed peripheral station receiver or CPE mounted on a pickup. The base station was installed at 28m with a 90° sectorised antenna. Measurements were taken approximately every 100m in the area of the coverage. The CPE was mounted on a tripod and was panned to the base station for every sample taken. A laptop was connected to the CPE that listed various real-time link conditions. A second laptop with the planning tool software and GPS was used to record the link information and position. A scribe also recorded all data in case of computer failure.

There are various tools in ICS telecom that help find possible anomaly signals and deal with map inaccuracies, measurement equipment offsets and GPS resolution. Some issues were detected and dealt with in the field.

Results achieved

A standard deviation of 4.91 dB was obtained with 82.5% of samples within a 5 dB variation limit to achieve an average error of 0.33 dB. Forty fixed sample points were recorded in an 8-hour period (static weather conditions, no rain).



Measure (dBµV/m) 35.0
Prediction (dBµV/m) 35.0
Delta (dB) 0.0
Distance (m) 1912.2
☑ Raw
● Best*
○ Spot
○ Average*
* pixels around
🟨 measure
🟩 prediction
Frequency (MHz) 3500.00
% < 5 dB 82.50
Std deviation (dB) 4.91
Average error (dB) 0.33
dist max: 2271 m
Station reference # 1
Distance step (m) 2000.0
40 sample(s)
\\Tcen-ws-rpdat\RPTdata\ICSprojects\Head office\Wimax trial\voortrekerhoogte\subscribers SUR\voortrekker.SU7

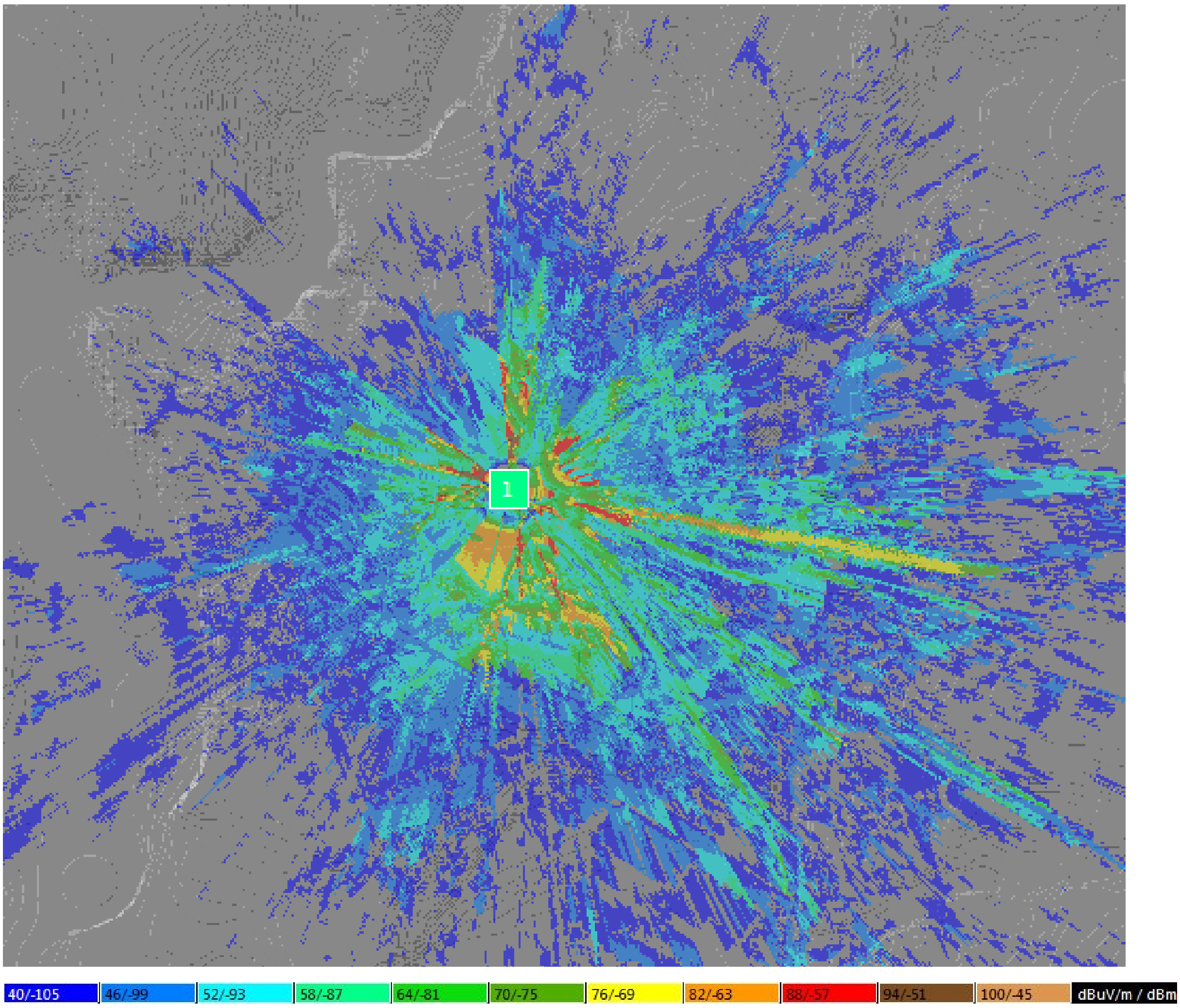
ICS telecom's correlation window

3.3 – Model tuning in Russia - WiMAX 2.5GHz

Simulations with ICS telecom

Cartographic database with 2m resolutions with: DTM, Clutter and building layers. Propagation model used included:

- Free space model (Line Of Sight (LOS)) : the ITU-R P.525 model;
- Diffraction model (Non Line of Sight (NLOS) model) : Deygout 94;
- Subpath attenuation model (Near Line of Sight (nLOS) modeling) : "Standard integration method" including obstructions to the 3D spherical wave;
- 3D ray tracing on reflected signals turned off;
- Specific penetration losses for trees, forest and buildings.



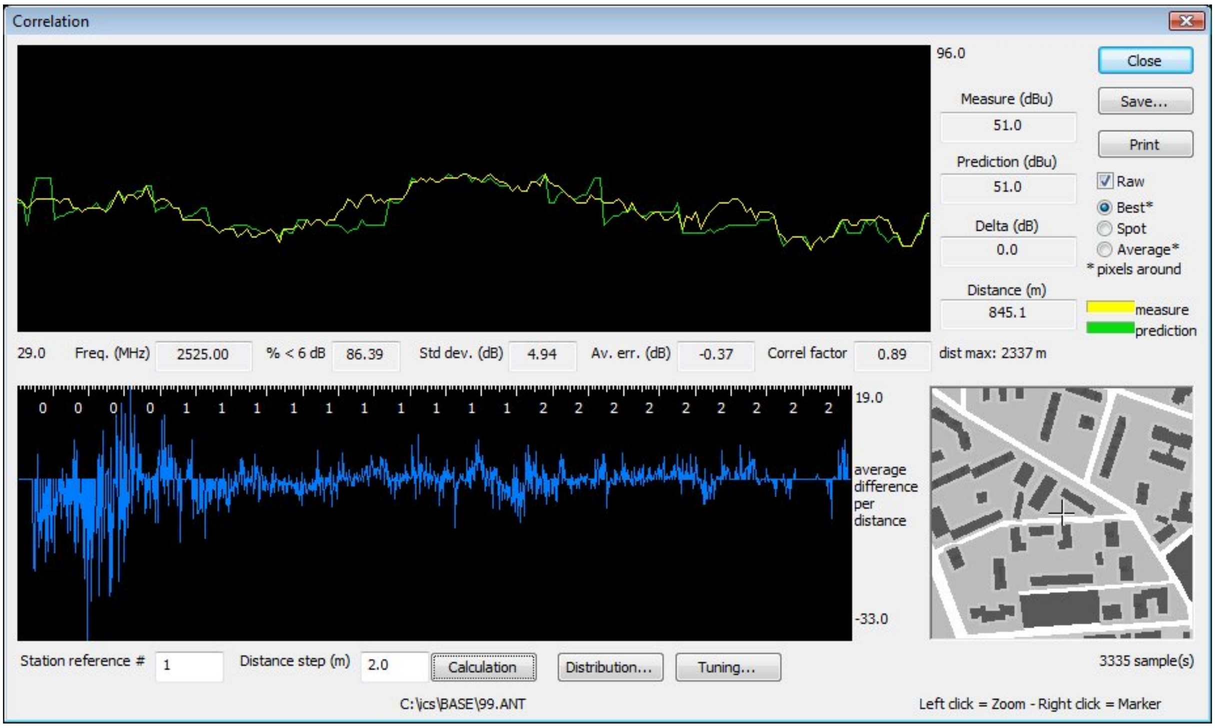
Coverage result of the base station transmitter

Field test measurements

The field test components consisted of a fixed base station WiMAX transmitter (2.5GHz band) and a mobile terminal.

Results achieved

A standard deviation of 4.94 dB was obtained with 86.4% of samples within a 6 dB variation limit to achieve an average error of 0.89 dB. Forty fixed sample points were recorded over one week.



Measure (dBu) 51.0
Prediction (dBu) 51.0
Delta (dB) 0.0
Distance (m) 845.1
☑ Raw
● Best*
○ Spot
○ Average*
* pixels around
29.0 Freq. (MHz) 2525.00 % < 6 dB 86.39 Std dev. (dB) 4.94 Av. err. (dB) -0.37 Correl factor 0.89 dist max: 2337 m
Station reference # 1 Distance step (m) 2.0
3335 sample(s)
C:\ics\BASE\99.ANT

ICS telecom’s correlation window

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