ATDI

White Paper
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Signal propagation modeling In Urban Environment

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Solutions in Radiocommunications

Signal propagation modeling in Urban Environment

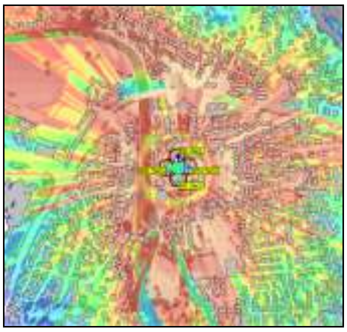
When working with ICS Telecom to simulate wireless propagation in an urban environment, a user must make the following key decisions:

- Selection of a type of cartographic data input
- Selection of a propagation model
- Determination of a type of technology to simulate

Propagation in Medium Resolution Urban environment:

- **Empirical models with appropriate tuning**
- **Deterministic model with appropriate margins**

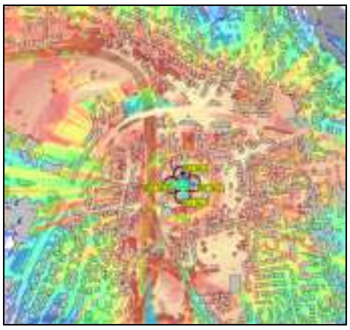
Medium resolution data does not describe each building location and height, but describes the ground occupancy as aggregates. Whatever the propagation model used, whether it is an **empirical model** (with a proper tuning) or a **deterministic model** (with appropriate planning margins), the type of coverage prediction will be rough.



Canyon effect in High Resolution Urban environment (deterministic model)

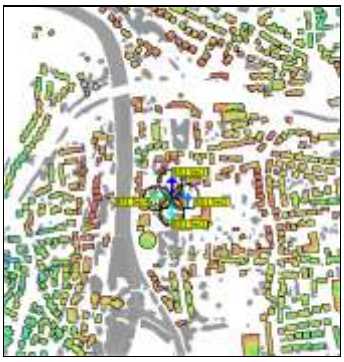
High Resolution data provides all building outline and heights. This type of simulation must be entirely deterministic in order to represent the **canyon effect**. The buildings here are physical obstacles to the standard signal propagation in ICS Telecom.

OFDM-types of technologies can also be simulated using the **3D ray-tracing** module of ICS Telecom, in order to simulate the **destructive or constructive field strength** effect, depending on the difference in time of arrival between the direct path and the reflected paths. The **power delay spread** can also be analyzed that way. ICS Telecom is also able to model both Inter channel Interference (**ICI**) and Inter Symbol Interference (**ISI**)



3D ray tracing effect in High resolution Urban environment (deterministic model)

The indoor propagation loss due to **building absorption** can be simulated by applying a diffusion coefficient per building type. The data rate calculated by ICS Telecom is then reliable in both Outdoor and Indoor environments, in the same project.



Indoor diffusion effect in High resolution Urban environment

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Wireless technologies are evolving, so must radio planning methods. These last years have highlighted emerging wireless technologies, with goal that are globally similar: providing multimedia-type of content to potential customers. Off course, the type of networking (Fixed, nomadic, mobile…) and the type of "target" (Major metropolitan areas or wireless complement of cable-type connection for rural areas) has to be taken into account.

This White paper will mainly focus on network planning in urban areas, answering two major questions :

- How to simulate according to the cartographic dataset available
- How to simulate according to the technology

1 What propagation model for what cartography ?

1.1 Cartographic data as a calculation basis for radio-planning

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.

1.1.1 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.

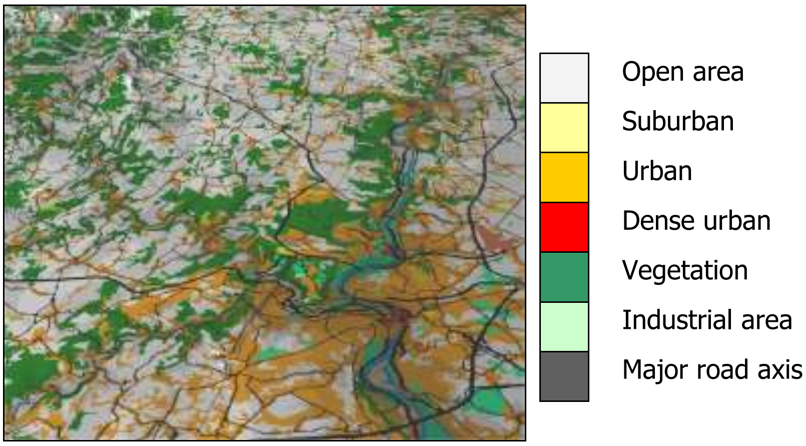
1.1.2 Medium resolution data

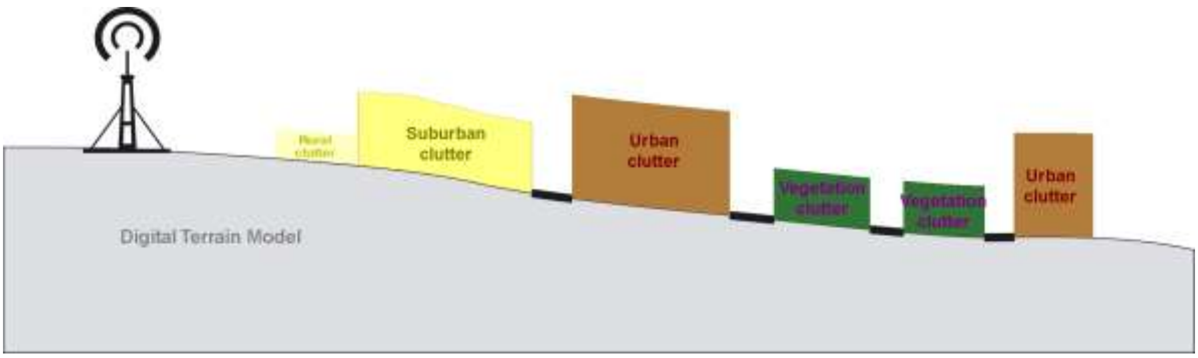
1.1.2.1 Rough description of MR data

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.





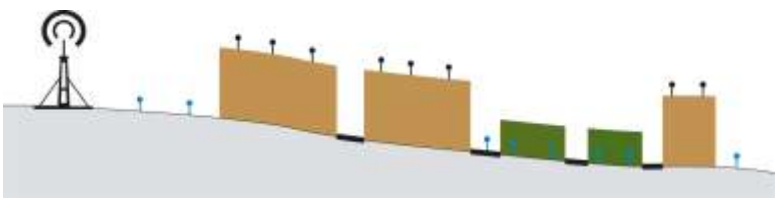
Using this kind of cartography, two kinds of propagation models can be used for network design purposes:

- Deterministic models
- Statistical models

1.1.2.2 Deterministic models and planning margins

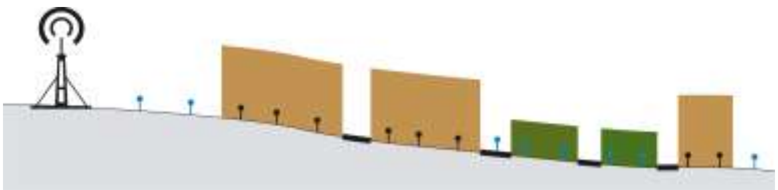
The deterministic models make use of the laws governing electromagnetic wave propagation to determine the received signal power at a particular location. They require a 3-D map of the propagation environment: the more compatible the accuracy of the cartography with a certain technology to simulate, the 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 as we will see in § 2.2)…

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



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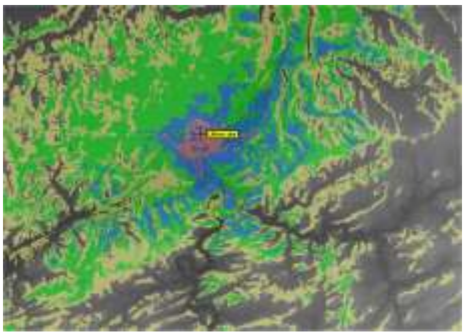
7	Major road axis	0.0	0	☑ rx ground

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

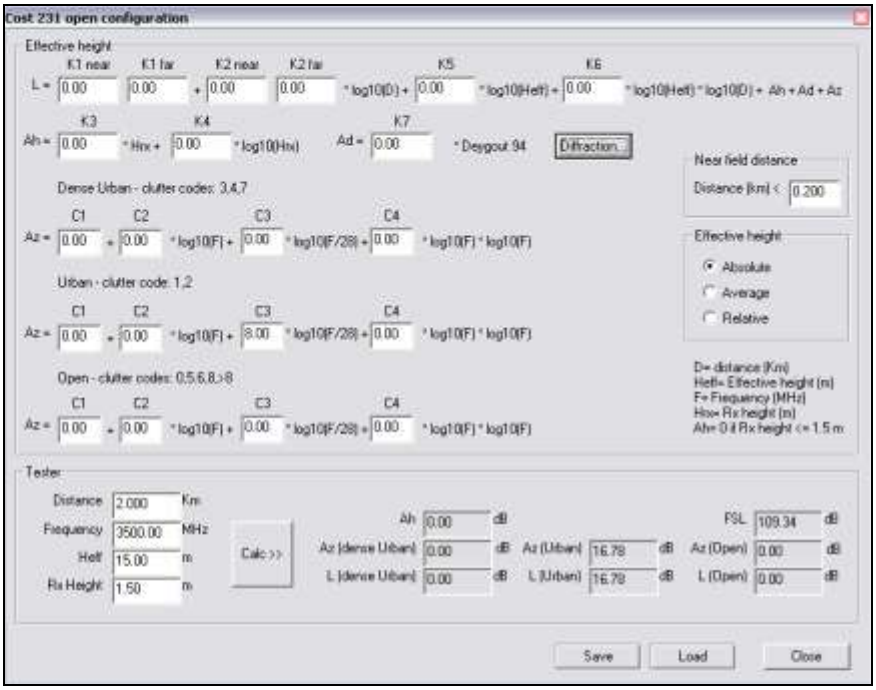
As we have seen earlier, Medium Resolution cartography does not describe the "real" height of each building, but a statistical ground occupancy. It means that a fully deterministic propagation model might be limited for technologies using high frequencies, where each above the ground feature can become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



1.1.2.3 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.



Example of empirical model to tune in ICS Telecom

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.

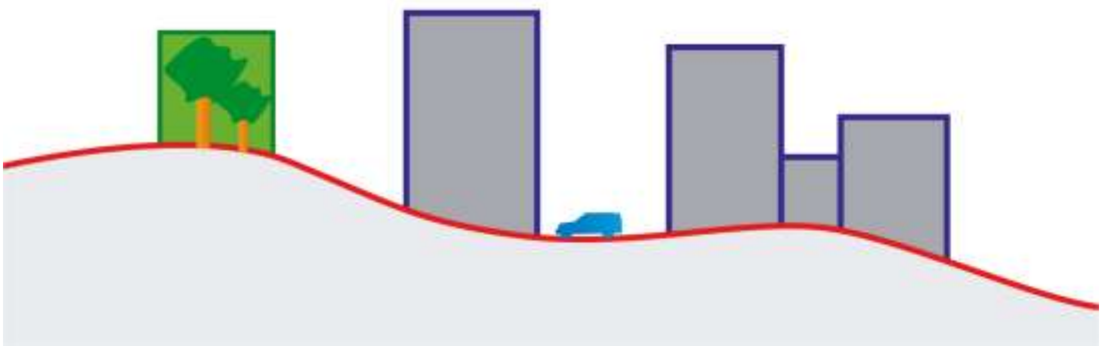
1.1.3 High resolution data

1.1.3.1 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.

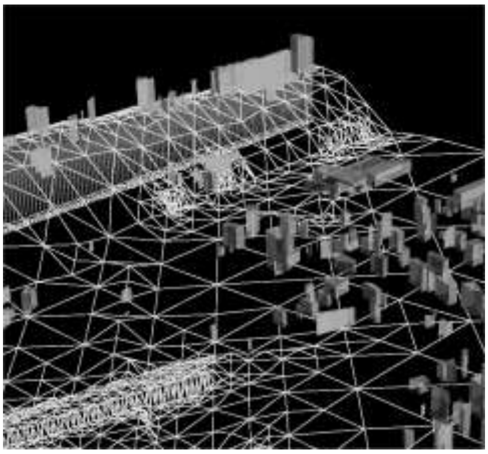
Different HR datasets can be outlined:

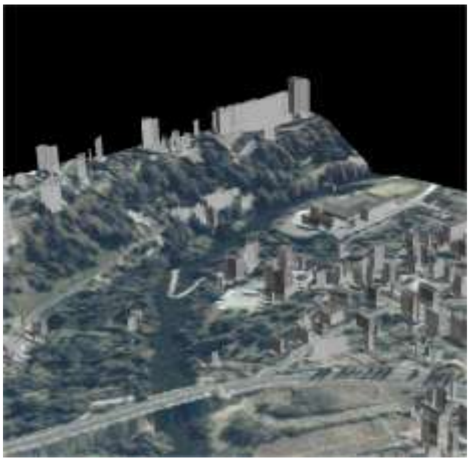
- DTM, building and clutter files



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.

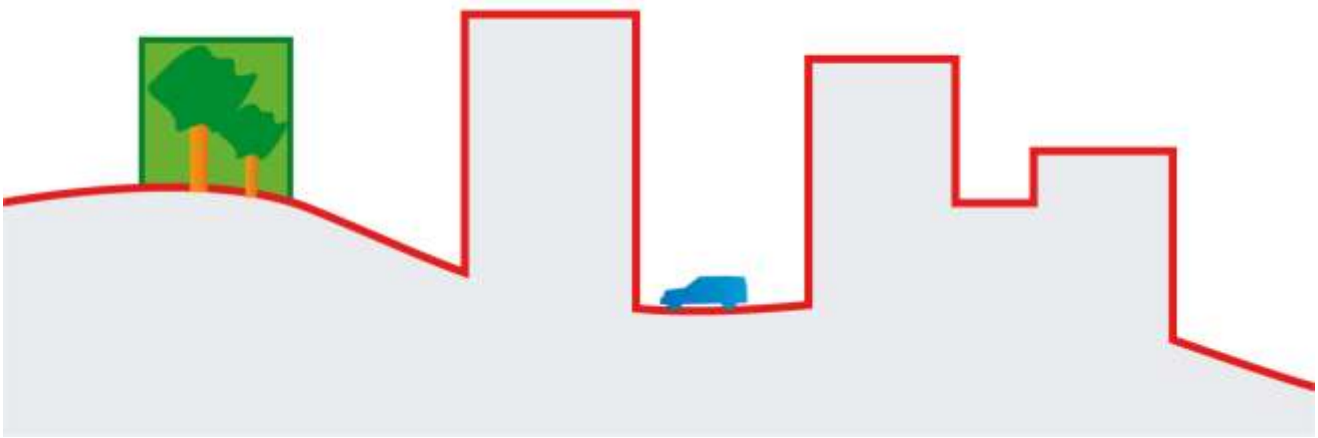




DTM in Wire frame and true-orthophoto with the blg file on top of it in ICS Telecom nG

- 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.

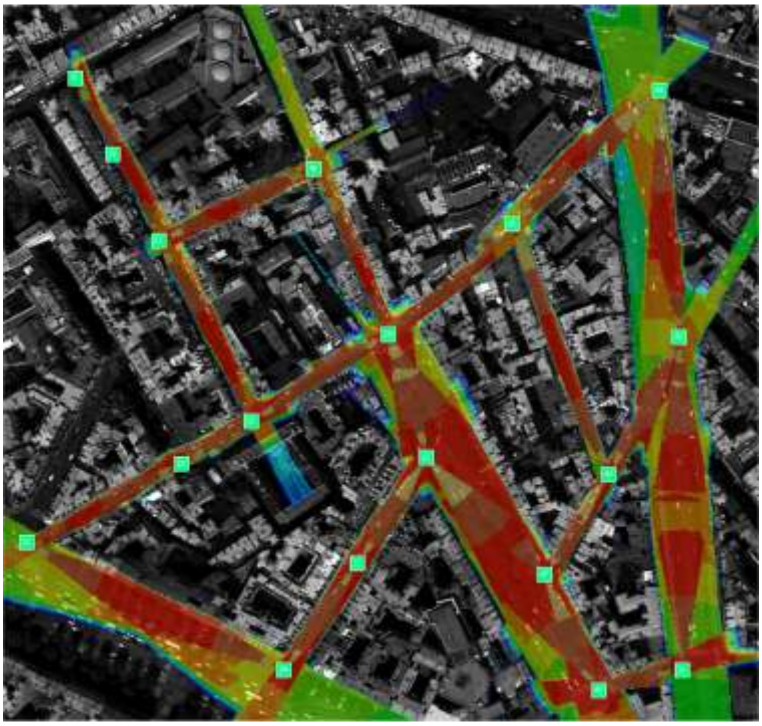


- DSM

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.

1.1.3.2 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.

1.1.3.3 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.

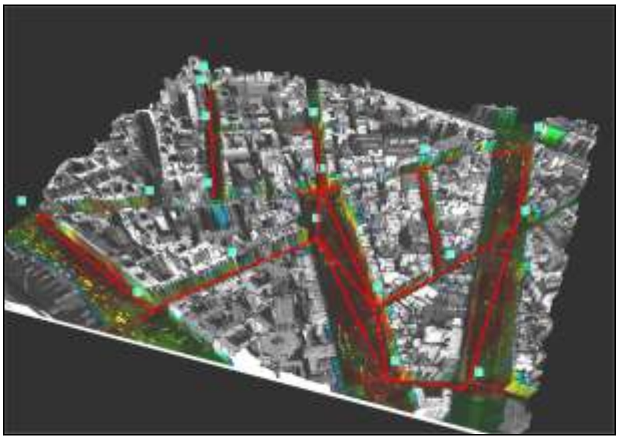
2 What propagation model for what technology ?

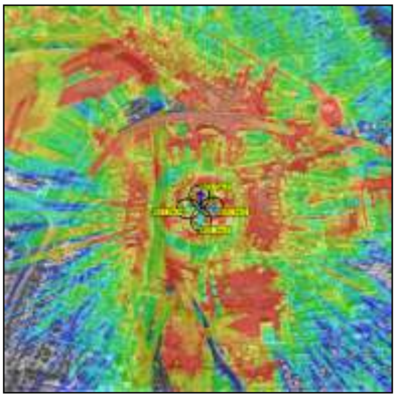
As we have seen in the previous section, the cartographic dataset, upon which the urban radio planning will be performed does influence the choice of the propagation model. But the most important is the technology to simulate in this urban environment: depending its the technical characteristics, different engineering methodologies have to applied: fixed-type, mobile-type, using OFDM or not…

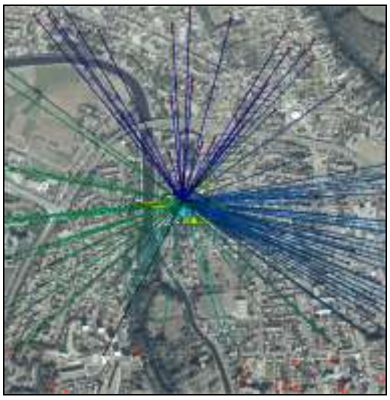
2.1 A wide range of wireless technologies for urban areas

Additions or complements to the now mature 3G and WLL technologies can be for instance outlined:

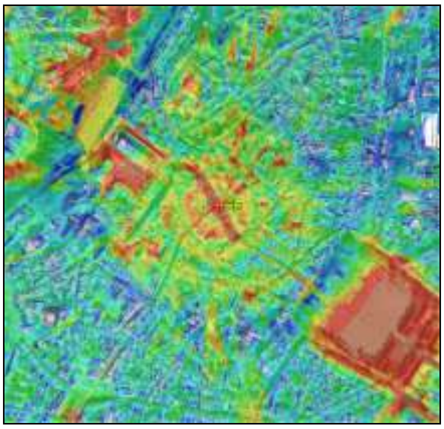
Mesh Networking in the US: After a first emerging in the year 2000 (ATDI was already a major player for simulating this kind of technology using switched beam antennas), Mesh networks seam experience a "revival", mainly based upon the 802.11 standard.



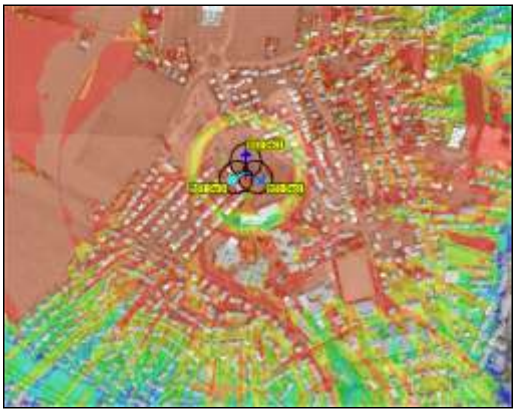




WiMAX technology has to be handled in two ways: FWA-Type of WiMAX, based upon the 802.16 2004 standard or Mobile-Type of WiMAX, that is still under development and validation. Thanks to its membership to the WiMAX forum and its relationship with major operators and equipment manufacturers, ATDI has been integrating WiMAX specific functions in ICS Telecom since late 2003.



DVB-H can be considered as the "mobile version" of Digital Video Broadcasting. Essentially targeting mobile video, data might also be carried in the downlink, whereas the uplink would be handled by alternative technologies (GPRS for instance).



WiBRO is an emerging technology, following a similar standard as the future mobile WiMAX. The WiBRO technology is actually being deployed in South Korea.

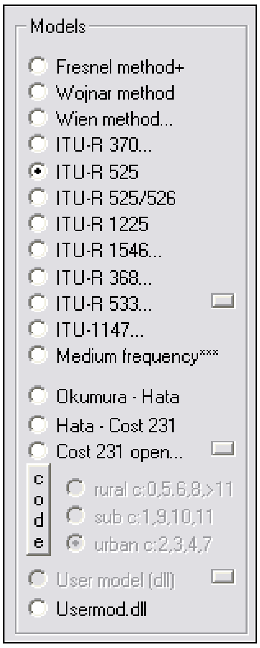
Other alternative technologies, such as Flash-OFDM© are also emerging.

Even though all of these are very different, the convergence of the content makes broadcasters, mobile radio-planners and fixed wireless operators become interested into the same technologies. The borders between each other's planning specialty are blurring: whatever the case, the goal be achieved is similar (ensuring not only a good coverage but also guaranteeing the data rate), even though each planning methodology to be used is different! Being multi-technology oriented, ICS Telecom is the planning tool that is flexible enough in order to simulate within the same platform several technologies using their corresponding engineering methods but targeting the same goal.

2.2 LOS, nonLOS: the use of the direct path

2.2.1 LOS propagation

A first approach is to consider the propagation in Line Of Sight, where the receiver is in direct visibility with the transmitter. In terms of radio planning: being in LOS means not only having visibility between the Tx and the Rx, but also having the cleared Fresnel zone all along the path.



If so, a deterministic formula such as the ITU-R 525 one can be applied in order to calculate the signal loss. In LOS environment, the only topographical characteristic used is the distance between the Tx and the Rx:

$$\mathbf{L_{fsd} = 20 * \log_{10}(d\ in\ km)}$$

Where: L_{fsd} : free space loss due to the topographic dataset

d : distance between the Tx and the Rx

This term is then introduced in the LOS calculation formula, that also depends on the frequency used :

$$\mathbf{L_{fsl} = 20 * Log_{10}\ (frequency\ in\ GHz) + L_{fsd} + 92.5}$$

2.2.2 The diffraction effect

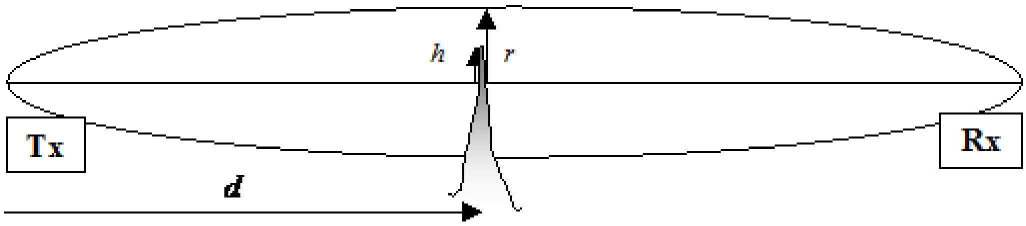
The diffraction effect is used in order to quantify the attenuation due to an obstruction of the direct path between the Tx and the Rx by one or several obstacles.

In the Fresnel theory, the attenuation due to one single knife-edge obstacle located in the free space path can be derived using Fresnel Integrals. As these integrals do not have any explicit solution, a good approximation of this knife-edge diffraction loss can be :

$$Ld = 6.9 + 20 \log\left[(\nu - 0.1) + \sqrt{1 + (\nu - 0.1)^2}\right]$$

where $\nu = \sqrt{\frac{h}{r}}$

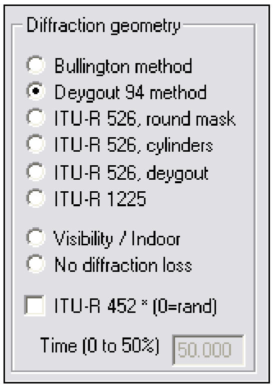
The fraction h/r, called the clearance ratio, is the ratio of the algebraic height (positive upward) of the edge above the line of sight over the radius of Fresnel ellipsoid at distance d from the Tx (see the drawing next page).



Different diffraction methods offer specific ways to evaluate one ν (single obstacle diffraction) or several ν (multiple obstacle diffraction) according to a path profile.

For example, Deygout proposed in 1966 a diffraction method that takes 2 obstacles into account: a primary obstacle (obtained from the maximum clearance ratio ν_1 according to the entire line of sight between Tx and Rx) and, if this primary obstacle exists ($\nu_1>0$), a secondary obstacle (obtained from the maximum clearance ratio ν_2 according to :

- the line of sight between the Tx and the primary obstacle
- The line of sight between the primary obstacle and Rx.

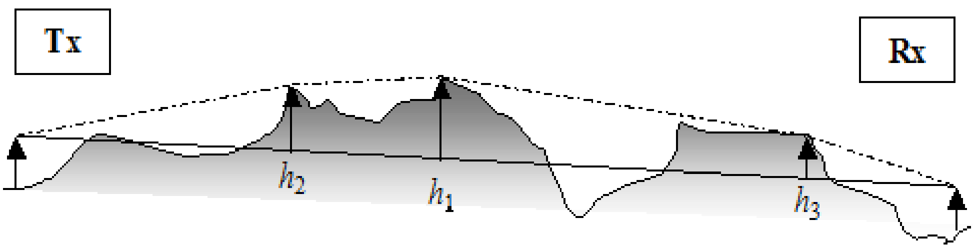


The global diffraction loss is then given by $L_d'=L_d(\nu_1)+L_d(\nu_2)$. This method provided better estimations than the diffraction method proposed by Bullington, but is still slightly optimistic.

In 1994, Deygout presented a generalized improvement of this method using a potentially infinite number of edges. The search for the edges is sequential : if the primary obstacle exists, two secondary obstacles (one between Tx and the obstacle and the other one between the obstacle and Rx) are searched .

Then, the same process is performed again on each side of the secondary obstacles possibly looking for tertiary obstacles. This process is reiterated recursively (the n+1 obstacles depend on the n obstacles) until no new obstacle is found. Then, the global diffraction loss is :

$$Ld=\sum_i Ld(\nu i)$$

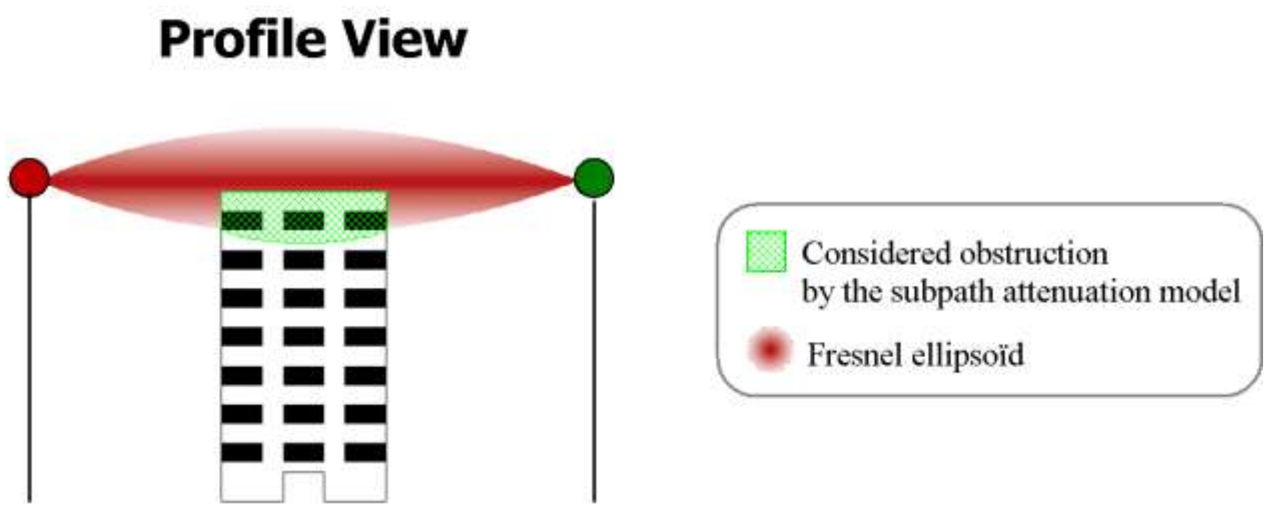


2.2.3 The sub-path attenuation effect

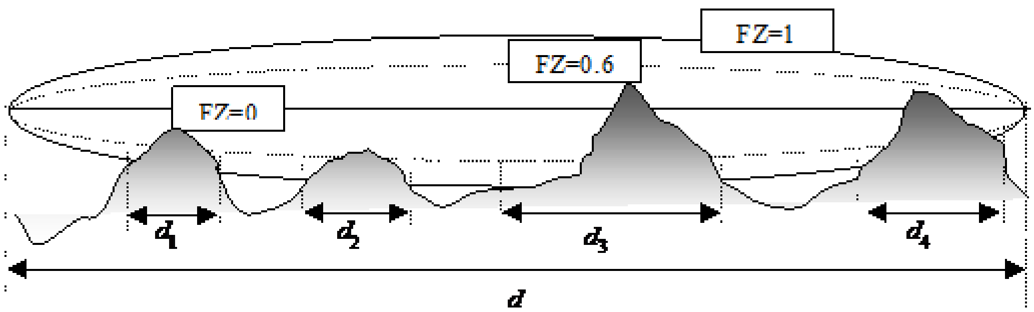
Selecting only a deterministic calculation method, corrected by a diffraction term generates a prediction that is too optimistic. For deterministic predictions, an additional term is introduced, called the sub-path attenuation effect. This correction term is directly derived from surface reflection modeling for low incident angles. It is also called ground reflection attenuation L_{gr}. It represents the attenuation due a partial obstruction of the Fresnel, whereas the Tx and the Rx are in visibility one with each other. It is representative of a first attenuation method in order to take into account ground/building multi-path effect, OFDM or not.

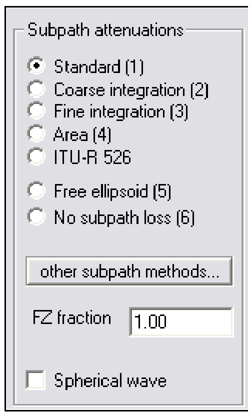
2.2.3.1 In the Z plane only

A first option can be defined in order to take into account the sub-path attenuation effect in the Z plane only.



Different methods can be selected in ICS Telecom, depending on the technology to simulate and the cartography available. All of them quantify the sub-path effect by multi-reflections according to an evaluation of the amount of terrain penetration into a fraction FZ of the Fresnel ellipsoid.

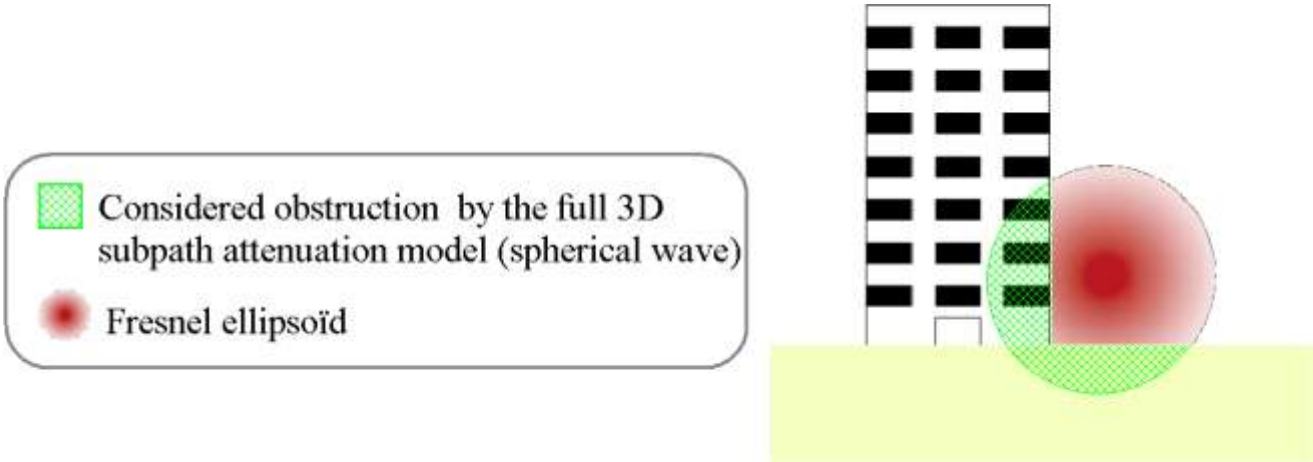


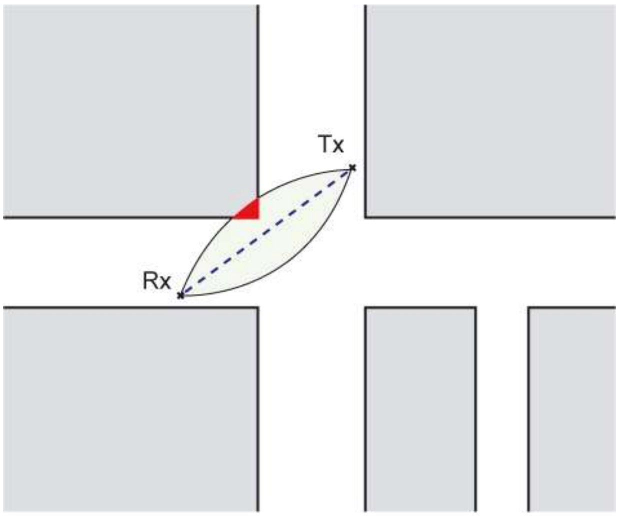


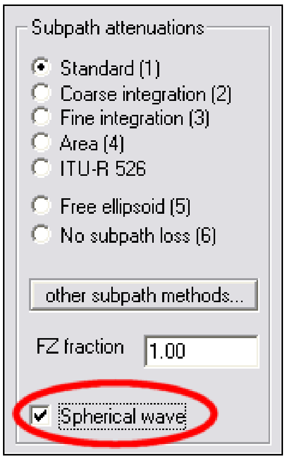
Such a calculation methodology is particularly suitable for fixed wireless type of technologies, where the receivers are usually placed on the rooftops. The main source of penetration of the Fresnel ellipsoid is then all the buildings located between the transmitter and the receiver.

2.2.3.2 Considering the Fresnel zone in 3D

However, this sub-path methodology might be too pessimistic for Rx placed within buildings that are taller than the one on which it is setup, or for mobile technologies, where is the receiver can be in the street.
In that case, the ICS Telecom user has the choice to consider the potential penetration of the Fresnel zone not only in the Z plane, but also in its "sides".







2.3 NearLOS: taking advantage of the canyon effect using OFDM

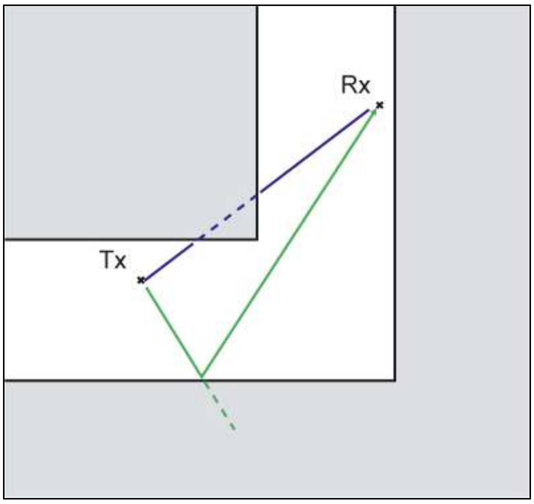
As defined previously, the canyon effect can be either :

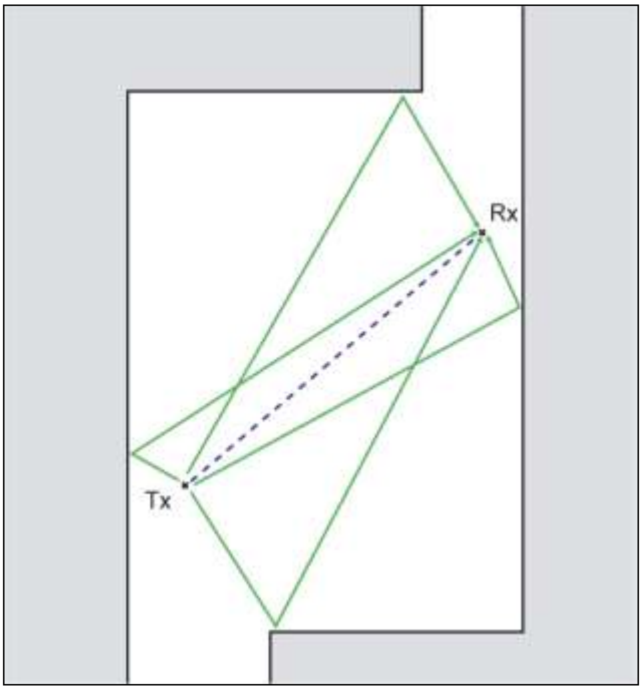
- A source of additional attenuation in the case of neighboring buildings within the Fresnel zone between the transmitter and the receiver. In that case, the standard sub-path attenuation method, using the spherical wave mode if required, helps to simulate such an attenuation effect.
- A source of additional coverage, when the building sides are used as reflectors for the signal propagation. The OFDM technology is an illustration of how the neighboring buildings can be used to improve, or even extend in same case the receivable signal.

2.3.1 OFDM ?

Orthogonal frequency division multiplexing (OFDM) technology provides operators with an efficient means to overcome the challenges of NLOS propagation. The WiMAX OFDM waveform offers the advantage of being able to operate with the larger delay spread of the NLOS environment. By virtue of the OFDM symbol time and use of a cyclic prefix, the OFDM waveform eliminates the inter-symbol interference (ISI) problems and the complexities of adaptive equalization. Because the OFDM waveform is composed of multiple narrowband orthogonal carriers, selective fading is localized to a subset of carriers that are relatively easy to equalize, as the use of several parallel sub-carriers in OFDM enables much longer symbol duration, which makes the signal more robust to multi-path time dispersion (see §2.3.3.2) (source : WiMAX forum).

As a practical illustration, an OFDM enabled receiver can consider as a received input signal all sub-carrier signals, whether they are direct or not, as soon as the time difference between them is not to long





OFDM propagation: the direct path (in blue) and the reflected paths (in green) not only do interfere one with each other (as soon as the difference in time of arrival is not too long…) but also combine each other in order to improve the reception.

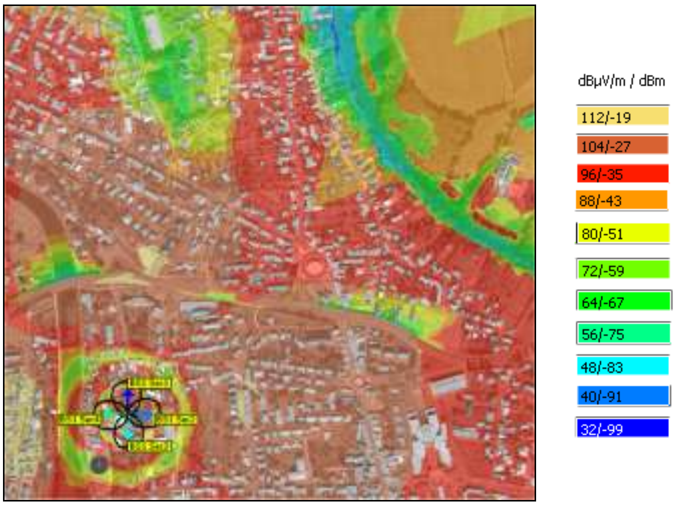
2.3.2 Necessity to use a deterministic approach using proper cartography for accurate simulation

The canyon effect, whether regarding its coverage limitative effect (standard propagation) or its coverage improvement effect (OFDM type of propagation) requires the planning tool to check the location of each building façade accurately. Such a process of "ray tracing" on building sides can only be achieved if the cartography is accurate enough to do so:

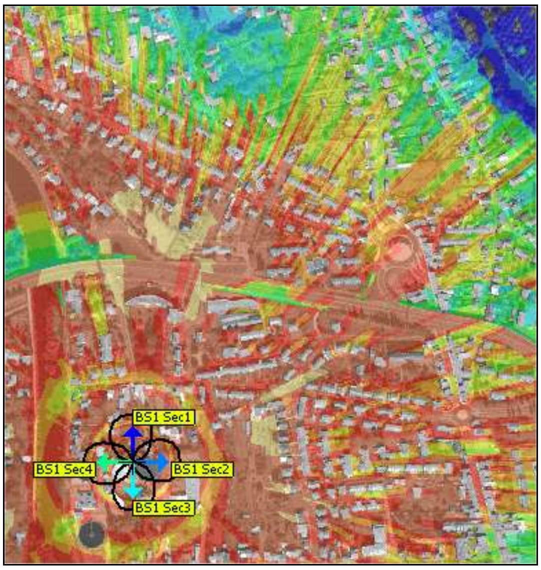
- Each building location and height is specified on the cartographic dataset
- Each street where the canyon effect could happen must be large enough. 2m accurate datasets are advised.

It means that the canyon effect can only be simulated:

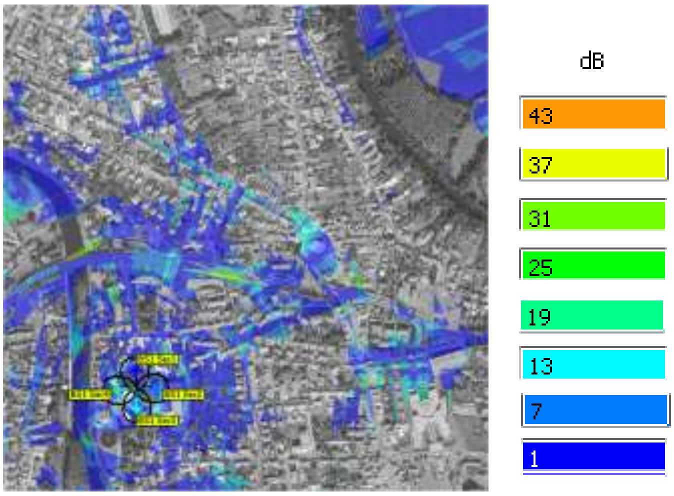
- Using High Resolution cartography, including all buildings locations and heights within the area of interest. Medium resolution datasets could only be used for OFDM-type simulation by applying an additional receiving average gain compared to a standard non-OFDM propagation.
- Using a deterministic propagation modeling approach



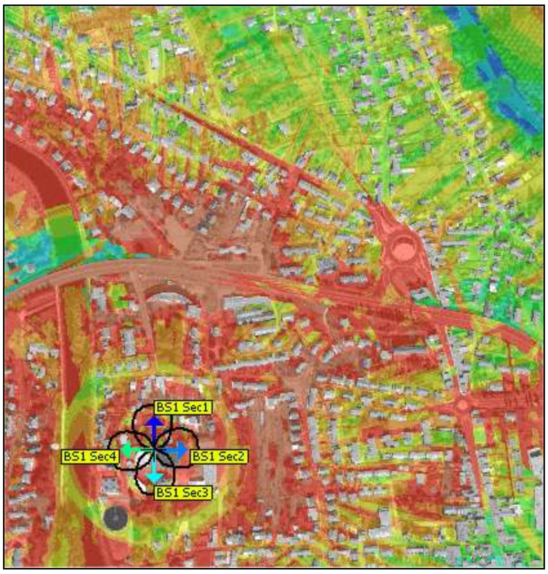
Step 1: Outdoor coverage prediction using Medium Resolution cartography. AS the building is not available on the cartographic dataset, it is not taken into account as a physical obstacle for the signal propagation. They have in that case to be taken into account separately, either using empirical models with its dedicated tuning, or deterministic models using margins.



Step 2: Deterministic simulation of the canyon effect using High Resolution data. Each building along the direct path becomes a physical obstacle to the signal propagation. No 3D reflections with ray tracing on building sides are taken into account.



Coverage difference using 3D ray tracing or not with HR data.



Step 3: deterministic simulation of the canyon effect using High Resolution data. Each building along the possible paths (direct or not) paths becomes a physical obstacle to the signal propagation. 3D reflections with ray tracing on building sides are taken into account.

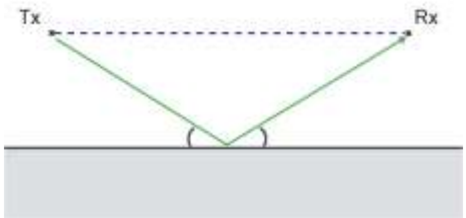
2.3.3 3D ray tracing modeling in ICS Telecom

In ICS Telecom, different ray tracing modes are available in order to take into account the 3D reflected paths along with the direct path.

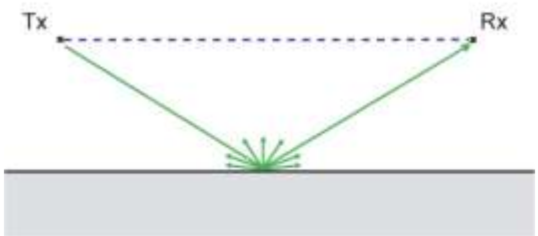
2.3.3.1 Reflection type

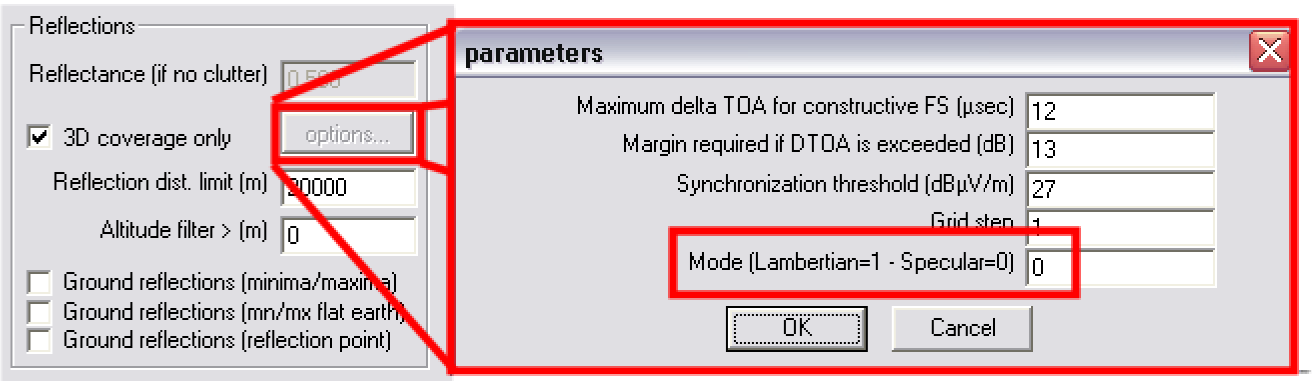
The radio-planner first selects what kind of reflected paths will have to be taken into account:

- The **Specular mode** takes into account the direct path, and all reflections on building sides. The reflected point radiates with the same incidence angle as its input signal.



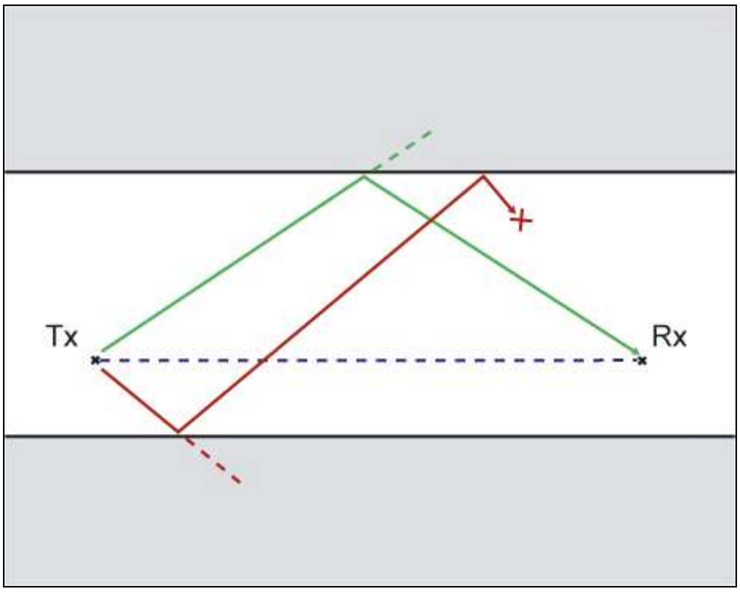
- The **Lambertian mode** takes into account the direct path, and all reflections on building sides. The reflected point radiates in all directions, in 3D. Due to the amount of calculations to perform, this mode is rather slow.





The number of reflection taken into account by the 3D ray-tracing engine of ICS Telecom is limited on purpose to **one reflection**. The reflection engine aims indeed to the following purposes:

- To be applicable to cartography that is commonly used by the radio planning community over entire cities. Full 3D vector datasets that have a real added value compared to standard raster 3D datasets (meaning containing more information) in terms of prices and availability over large areas are, for the moment, very rare. The main ways to produce large cartographic datasets for radio-planning purposes is indeed the same whether the delivery format is a raster, or a vector: 3D extraction from satellite/aerial imagery, LIDAR… Full 3D datasets require a local production (land surveying on each building façade) that is hardly applicable to large areas.
- To be fast enough in order to be applicable for a radio networks design over an entire city. Dozens of coverages might have to be calculated, each of them should take a reasonable time in order to able to apply severable scenarios.
- To give a reliable result, meaning a result that can be validated by measurement. A prediction tool such as ICS Telecom bases its result (connectivity, traffic offered, QoS…) on a field strength/power received. Even if the sub-carrier signals coming form secondary reflections could be isolated within all received sub-carriers, their contribution would be smaller than 1 dB, which is smaller than the accuracy of the measurement device and than the accuracy of the planning tool itself (modeling technical parameters of each radio entity, typical standard deviation of the propagation model used, accuracy of the cartographic environment…).



The ICS Telecom 3D ray-tracing engine is limited on purpose to paths reflecting one time on the building sides.

2.3.3.2 Multi-path interference

OFDM waveforms experience inter-symbol interference (ISI) and inter-channel interference (ICI) due to multi-path in the RF channel through which the signal is propagated. They can use a guard interval created by a cyclic prefix to mitigate the problem.

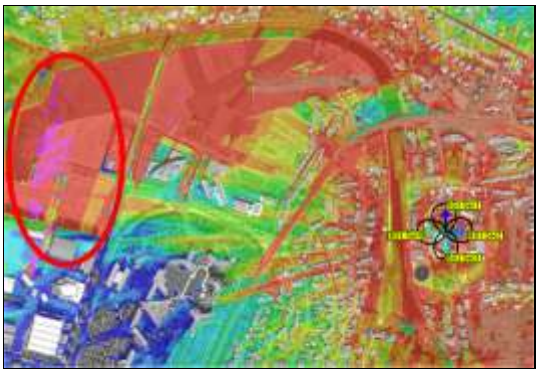
The cyclic prefix is made by replicating part of the OFDM time-domain waveform from the back to the front. The duration of the guard period is longer than the worst-case delay spread of the multi-path environment, so multi-path delayed up to the guard time will not cause ISI and the sub-carriers will remain orthogonal for multi-path delays up to the guard time, which eliminates ICI.

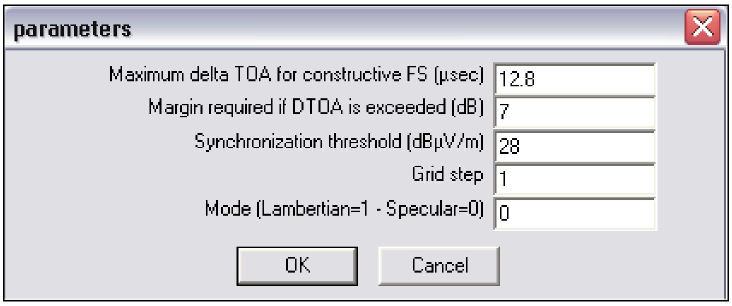
2.3.3.2.1 Modeling Inter Symbol Interference (ISI)

Inter Symbol Interference for OFDM-type of receivers can be highlighted during the coverage calculation:

The radio-planner specifies the guard interval of the equipment simulated, in μs. It represents the maximum difference of time between the arrival of the direct path and the arrival of a reflected path in order to have **constructive field strengths**.

If the difference in Time Of arrival is exceeded for given reflected rays, ICS Telecom will compare their signals with the direct signal received. If the direct one is higher than a specified margin in dB, the reflected signal will still be considered as constructive, if not it will be considered as destructive. If the receiving location is subject to **destructive field strength,** it will be highlighted with the pink color on the coverage map.





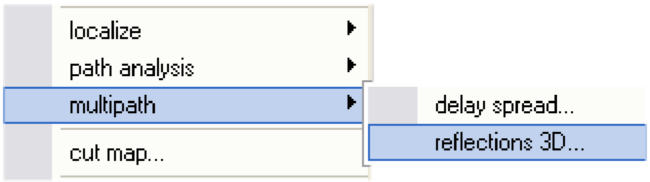
The synchronization threshold is the minimum field strength received by the direct path in order to take into account the ISI effect.

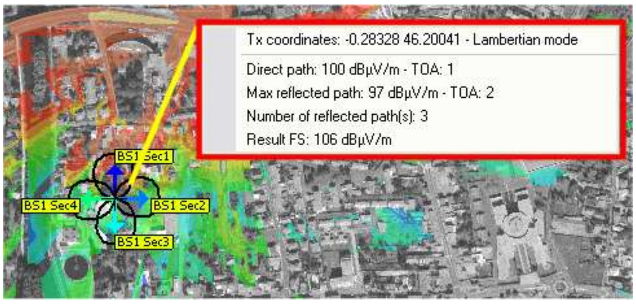
For example:

- for a given equipment threshold of 32 dBu,
- the minimum receiving signal from the direct path must be 22 dBu,
- the improvement of the coverage of this location due to constructive reflected paths is 14 dB.

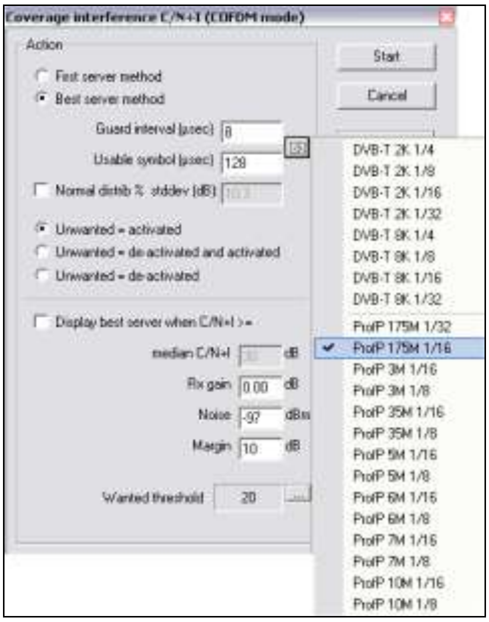
If the direct signal received is 26 dBu, the location will considered as covered at 26 + 14 = 40 dBu, it is a case of coverage extension. If the direct signal received is 20 dBu, the location will not be considered as covered, even though the signal sum is 34 >32 dBu, because the direct signal is not strong enough.

For a given receiving location specified by the user, ICS Telecom can highlight the direct path part, and the reflected paths part:





2.3.3.2.2 Modeling Inter-Channel Interference (ICI)



ICS telecom nG also features a dedicated OFDM interference calculation engine. The analysis in time of arrival can be divided in 3 different cases:

Case 1: if delta TOA between the wanted signal and the unwanted signal is positive and smaller than the Guard interval then the unwanted field strength will not be considered as being an interferer.

Case 2: if delta TOA between the wanted signal and the unwanted signal is higher than the Guard interval, but below the addition of the Guard interval and the Usable symbol time, the effective unwanted power becomes I=Pb*(1-T), where Pb is the maximum unwanted power, and $T=\left(\frac{Ts-Ti}{Tw}\right)^2$

Where Ts=Guard interval + Usable symbol

Ti=delta TOA

Tw=Usable symbol

Case 3: Delta TOA<0 and Usable symbol<abs(Delta TOA), the effective unwanted power is I=Pb*(1-T) with $T=\left(\frac{Tw+Ti}{Tw}\right)^2$

A **Normal distribution** expressed in percent can also be calculated displaying a probability of service.

2.3.3.3 The power delay spread

The power delay spread is based on multiple interferers, rather than on two-source approximations.

One way to achieve this is to view the received signal as a single transmission undergoing multi-path delay spread. The relative signal strengths and delays then correspond to the so-called power delay profile of the aggregate signal.

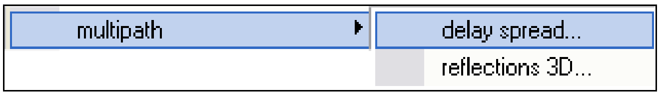
Studies show that for delays limited to a fraction of the symbol time, the amount of signal degradation depends not only on the actual delay profile, but also on the rms value of the delay, weighted by their respective power levels.

So the multi-path spread for N simulcasting signals is given by:

$$T_m = 2\sqrt{\frac{\sum_{i=1}^{N} P_i d_i^2}{\sum_{i=1}^{N} P_i} - \frac{(\sum_{i=1}^{N} P_i d_i)^2}{(\sum_{i=1}^{N} P_i)^2}}$$

Where ***Pi*** and ***di*** are the power and delay of the i-th signal, respectively.

In ICS Telecom, the power delay spread can be calculated either for each selected CPE (FWA type), or on any location on the map.

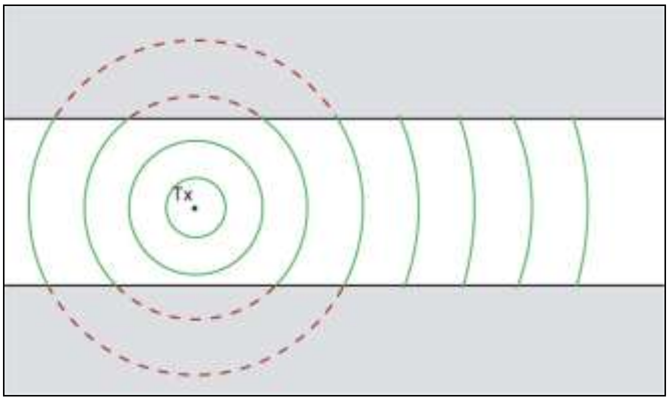


Dedicated documentation has been written by the technical department of ATDI.

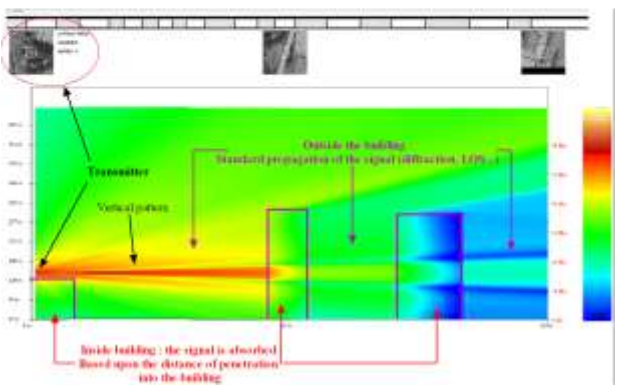
2.4 From the Outdoor to the Indoor : the diffusion and penetration effects

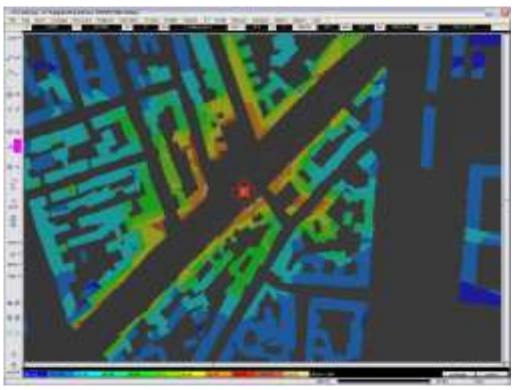
ICS Telecom nG features a unique engine in order to calculate both outdoor propagation (whether it is LOS, nLOS or NLOS) and indoor propagation. Two major effects can be highlighted for indoor propagation from an outdoor transmitter :

- A penetration loss, due to the outdoor to indoor penetration, through walls or glass
- A diffusion loss, due to the propagation of the signal inside the building.



A white paper concerning this aspect is available.





Losses due to the indoor absorption of the outdoor signal in ICS telecom nG

Conclusion :

Urban propagation modeling depends in ICS Telecom on:

- The type of cartographic dataset used, and how the streets, the buildings locations and heights are outlined
- The type of propagation model chosen (empirical or deterministic). Deterministic models are advised for coverage calculations using High Resolution datasets.
- The type of technology to simulate

The table here below can summarize the different cases for coverage prediction in urban environment:

	Low resolution data	Medium resolution data	High resolution data
Typical content	DTM at 200m	. DTM at 30m . Clutter file giving different urban heights as aggregates . Topographic map	. DTM at 2m . BLG file at 2m . Clutter file at 2m . True-orthophoto
Applicable propagation model	Not advised	. Empirical models (with appropriate tuning) . Deterministic models (with appropriate margins)	. Deterministic models . 3D ray tracing if needed
Predictable effects	Not advised because of the lack of accuracy of the cartography	Standard field strength/power received simulation, above or into the urban clutter	. Field strength/Power received simulation . Canyon effect with constructive/destructive signals . Diffusion effect . Multi-path effect . Power delay spread

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