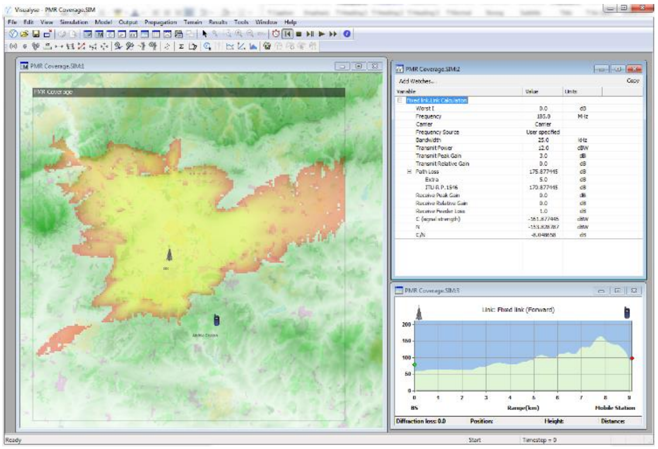
Propagation Modelling White Paper

Abstract: One of the key determinants of a radio link's received signal strength, whether wanted or interfering, is how the radio waves propagate. In order to predict the wanted or interfering signal, experts within the ITU-R have developed a number of propagation models for a range of scenarios and environments. These are continually being updated as new data becomes available – for example the model in Rec. ITU-R P.452 has just been revised to release 15. This White Paper looks at the differences between the main propagation models and their most recent releases.

Propagation Fundamentals

Radio waves are governed by the four Maxwell Equations, discovered by the Scottish physicist of that name and published between 1861 and 1862. Despite being the foundation of our understanding of electromagnetics and optics, they are not often used directly in the prediction of radio waves due to the computation complexity involved.

Hence it is usually necessary to make some simplifying assumptions or try to develop models that fit measured behaviour for specific conditions and scenarios. This allows them to be tuned and improved as more information is gathered.



Variable	Value	Units
Fixed link.Link Calculation		
Worst I	0.0	dB
Frequency	185.0	MHz
Carrier	Carrier	
Frequency Source	User specified	
Bandwidth	25.0	kHz
Transmit Power	12.0	dBW
Transmit Peak Gain	3.0	dB
Transmit Relative Gain	0.0	dB
Path Loss	175.877445	dB
Extra	5.0	dB
ITU-R P.1546	170.877445	dB
Receive Peak Gain	0.0	dB
Receive Relative Gain	0.0	dB
Receive Feeder Loss	1.0	dB
C (signal strength)	-161.877445	dBW
N	-153.828787	dBW
C/N	-8.048658	dB

So the propagation model to use will vary depending upon factors such as:

- What is the path geometry? In particular is the path:
  - Between the Earth and space?
  - Along the surface of the Earth?
  - Between ground and air?
- Are we considering the wanted signal (so might we worried about fading) or the interfering signal (so we might be worried about enhancements)?
- Are we analysing a specific location or is this a general sharing study aimed at deriving generic conclusions?
- What frequency bands are we considering?

The propagation effects are likely to be different depending upon the answers to these questions and hence it is more convenient (and in theory more accurate) for experts to create a model targeted at a sub-set of conditions.

The Key Propagation Models

From our experience in doing studies for the ITU-R, the main propagation models we encounter are those in the following ITU-R Recommendations:

- P.452: to model interfering signals for point to point terrestrial paths
- P.525: Free space path loss, typically combined with other propagation models
- P.526: Diffraction over terrain, either combined with P.525 or contained within one of the terrestrial propagation models
- P.528: Air to ground propagation models for VHF / UHF / SHF bands
- P.530: multi-path and rain fading for terrestrial paths
- P.618: rain model used for satellite links
- P.676: gaseous absorption for satellite or terrestrial paths
- P.1546: propagation model for point to area terrestrial services in VHF and UHF bands
- P.1812: more detailed propagation model for point to area terrestrial services in VHF and UHF bands
- P.2001: propagation model for Monte Carlo analysis for terrestrial services

There are also some propagation models that come from national or regional organisations. Two commonly used ones are:

- Longley-Rice: a propagation model for terrestrial services
- Hata / COST231: a median loss propagation model for terrestrial applications

Finally there are the generic two slope or three slope propagation models.

So what are the differences and how do you decide which to use?

Selection of Propagation Model

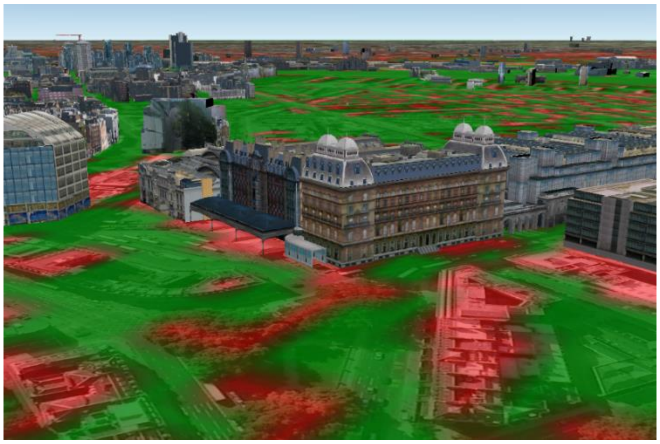
In some cases it is relatively simple to select the propagation model.

- If you are in deep space, with no atmosphere or terrain to consider, then communication between satellites is simply modelled using free space path loss, P.525
- If you are communicating with an aircraft sufficiently high above terrain that you can ignore it, then use P.528
- If you are analysing a satellite link between Earth and space, then you could use a combination of P.525 (free space), P.676 (gaseous attenuation) and possibly P.618 (rain)

For these satellite links you might want to consider what would happen if your wanted signal was faded due to rain but the interferer was unfaded, so there are cases where you'd use or not include rain fade. Furthermore some analysis – such as whether power flux density (PFD) limits are met – is based upon free space path loss only.

Terrestrial paths have a wider range of propagation models, including P.452, P.525, P.526, P.530, P.1546, P.1812, P.2001 and Hata / COST231.

So how do you decide which of these to use?



Terrestrial Propagation Models

These can be classified by factors such as:

- Are they modelling point to point paths or point to area?
- Are they designed for wanted paths, interfering paths or a combination of the two?
- Related to the above, do they have the ability to select a percentage of time or is it fixed?
- Do they have the ability to take into account terrain and clutter and if so how?
- What is the frequency range over which they have been tested and approved?

So let's consider each of the main terrestrial propagation models using these classifications.

Recommendation ITU-R P.452

Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz

This, as it says in the title, is designed to analyse interference paths, and allows a percentage of time to be entered in the range 50% to 0.001%, so it can be used to model the median wanted signal and enhanced interfering signals.

It is intended for point to point paths, and if terrain data and clutter data is available it can be used. It includes free space path loss and diffraction, i.e. both P.525 and P.526.

Example usage: calculation of interference between fixed stations, such as point to point fixed links and satellite earth stations.

Recommendations ITU-R P.525 and P.526

P.525: Calculation of free space attenuation

P.526: Propagation by diffraction

These two models can be combined together to produce a basic terrestrial propagation model that takes account of attenuation and diffraction. While it does not include the other propagation modes (e.g. ducting and diffraction as modelled by P.452) it can operate at lower frequencies, potentially down to 10 MHz. There isn't an associated percentage of time so it should be considered a median model. It can handle either smooth Earth or with terrain if a database is available.

Example usage: calculation of interference for systems operating below 100 MHz

Recommendations ITU-R P.525 and P.530

P.525: Calculation of free space attenuation

P.526: Propagation data and prediction methods required for the design of terrestrial line-of-sight systems

These two models can be combined together to produce a terrestrial propagation model that takes account of attenuation and fading. The fading can be either due to multi-path or due to rain loss. The fade depth has an associated percentage of time which varies from 50% to very small values such as 10-5, and there could also be an enhancement.

Example usage: calculation of faded and unfaded signals for terrestrial point to point fixed links

Recommendation ITU-R P.1546

Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3 000 MHz

As the title says, this is a point to area model, so it calculates the signal strength over a pixel, with an additional parameters of "percentage of locations" within that pixel. By setting this to 50% you could use this as a point to point model.

This model has a long history, being based upon the prediction curves from Rec. ITU-R P.370, with adjustments for clutter loss and horizon elevation angles. It therefore takes a limited account of terrain, not to the level of detail of P.452, P.1812 and P.2001.

The percentage of time can vary from 1% to 50% so it can be used to model the median wanted signal and enhanced interfering signals.

It is what is called a high-to-low propagation model, in that the transmit station is assumed to be above the local clutter and should not be used for cases when both stations are below the height of the local clutter.

Example usage: planning of broadcasting networks or private mobile radio (PMR).

Recommendation ITU-R P.1812

A path-specific propagation prediction method for point-to-area terrestrial services in the VHF and UHF bands

The objective of this model was to take the best aspects of the propagation models in P.452 and P.1546 to be a next generation point to area model. So it uses the terrain analysis methodology from P.452 (and hence P.526) combined with the clutter model and point to area techniques of P.1546.

Note there are differences in how the terrain path profile is extracted compared to P.452 in that it includes clutter as described further below.

The frequency range of validity and percentages of time and location are the same as for P.1546.

Example usage: more detailed planning of broadcasting networks or private mobile radio (PMR).

Recommendation ITU-R P.2001

A general purpose wide-range terrestrial propagation model in the frequency range 30 MHz to 50 GHz

The propagation models above tended to have be constrained in the percentages of time that they considered. For example P.452 was limited to 50% of time as it was designed to model interference and so the enhancement aspects were not included.

This is acceptable when undertaking static analysis such as minimum coupling loss (MCL) or area analysis, but when using Monte Carlo methodology it is necessary to be able to consider the whole range of percentages from 0 to 100% so that the convolution of random elements does not introduce any bias.

The objective of P.2001 is therefore to extend the methodology in P.452 (and by implication P.1812) to a generic case to handle the widest possible range of frequencies and percentages of time. While in theory handling all percentages from 0% to 100% there are internal constraints that limit it to 0.00001% to 99.99999%.

As with P.452 and P.1546 there are sub-models for line of sight (P.525), diffraction, ducting (P.526) and troposcatter. There is also a Sporadic-E model for low frequencies.

Example usage: Monte Carlo analysis of scenarios involving terrestrial networks or coverage predictions that take fading into account

Hata / COST231

This is a simplified model that matches measurements of the median loss for various environments such as:

- Urban
- Suburban
- Rural / open

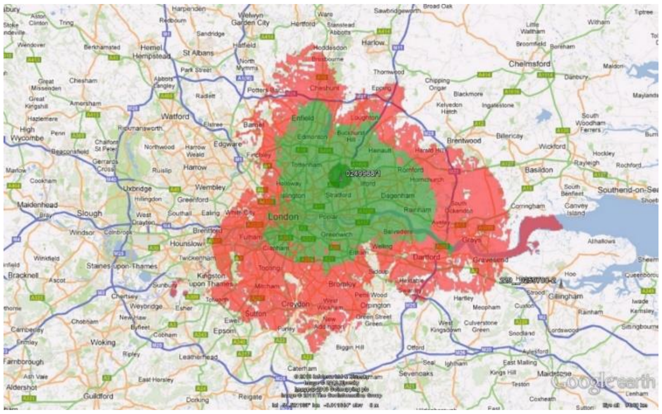
As it is a median loss model it does not include a percentage of time and so cannot be used for many interference scenarios that have an associated percentage of time other than 50%.

It doesn't have the ability to handle terrain data so the results are by definition generic and not site specific.

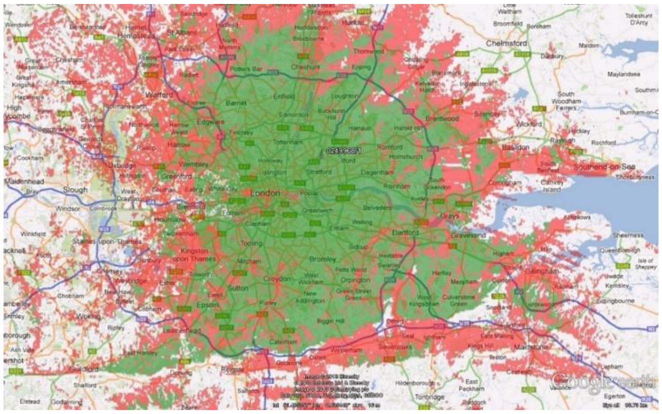
Example usage: Wanted signal calculations for a generic mobile or broadcasting network for sharing studies

How big a difference can it make?

The propagation model can be the dominating factor in some scenarios, causing wanted or interfering signal to vary by tens of dB. For example consider the two coverage plots below:



TX antenna above clutter using P.1546 at VHF



TX antenna above clutter using P.1812 at VHF

The motivation for P.1546 and P.1812 are similar but as can be seen here they can give very different results with the same inputs.

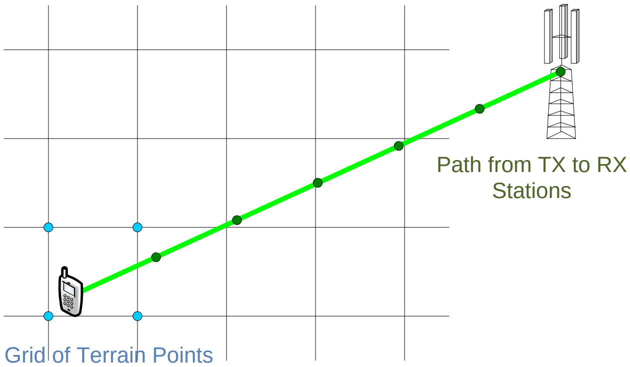
The key difference here is that P.1546 only makes partial use of the terrain data while P.1812 goes into greater detail.

How propagation models take account of terrain – and clutter data – is a key distinguisher, as described in the following section.

Terrain, Clutter & Surface Databases

When a terrain database is available it can be used to create a path profile.

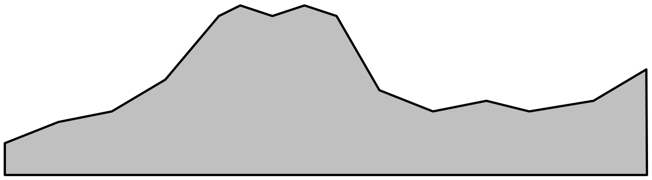
The usual approach is to create a great circle line from the transmitter to the receiver, then calculate the height at fixed distances between them as in the figure below.



Extraction of Path Profile

The spot height calculation takes account of the terrain database's surrounding four points using methods such as linear interpolation.

The resulting path profile will look something like this:



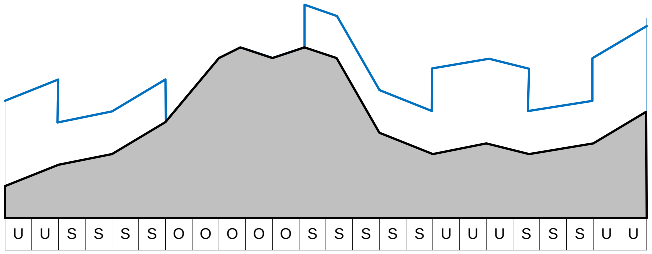
Extracted Terrain Path Profile

In addition to terrain data there can also be land use databases. These tend to have a code for each location pixel that is mapped onto environment types such as:

- Dense urban
- Urban
- Suburban
- Sea
- Wood

The land use codes are used to calculate the clutter loss at the transmit and receive station (P.452, P.1812 and P.2001) or just the receive station (P.1546).

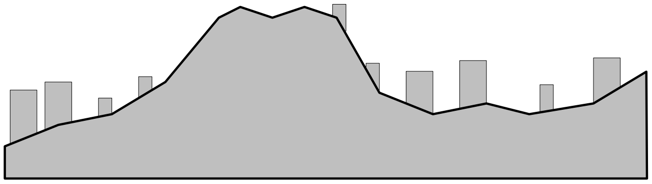
However P.1812 also uses the clutter code to adjust the path profile by adding the height of the clutter to the path profile as in the figure below.



P.1812 Path Profile with Clutter Adjustment

It could be argued that other similar propagation models (e.g. P.2001) should handle clutter in a similar way.

Finally, there have recently become available high resolution surface databases that include building data on top of terrain. These could be used instead of clutter and the path profile would then be highly representative of the actual radio path:



Extracted Surface Path Profile

An example of a surface database for London is shown in the figure below.

Example Surface Database for Central London

Not all surface databases are sufficiently high resolution to identify individual buildings. For example the ASTER and SRTM databases are both surface but 30m and 90m resolution respectively, and so it is not possible to identify structures smaller than (say) city blocks.

These lower resolution surface databases could be considered to include the terrain + surface path profiles used by P.1812 (as described above) but not the terminal clutter which it could be argued should continue to be added.

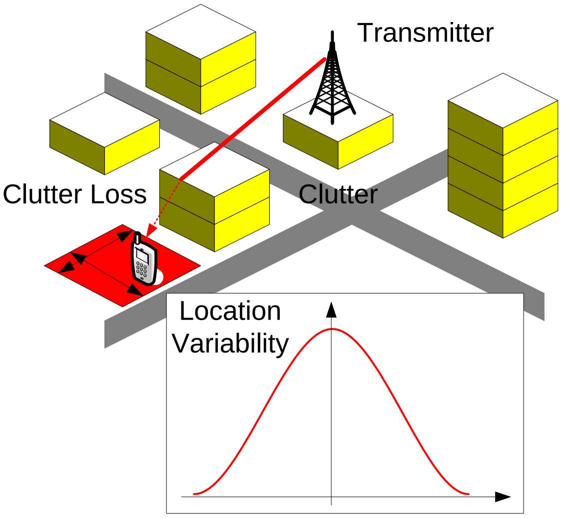
In contrast, the higher resolution 3m surface database could be considered to model both the terrain + surface path profile and terminal clutter.

However there are two additional problems to consider:

- It is necessary to know the locations of stations (latitude, longitude and height) to a much higher level of detail when using high resolution surface databases
- For area coverage it becomes significant which specific pixels to cover – is it roads + outdoors, or buildings + inside, or an average over typical user locations?

Terminal Clutter and Location Variability

Many of the propagation models also include the concept of terminal clutter adjustment and some also include location variability, as shown in the figure below:



Terminal Clutter and Location Variability

Here a transmitter is located in an environment with clutter (buildings) that reduce the signal received by the handset. The last term in the propagation model is usually therefore the loss due to the final obstruction or clutter, which reduces the signal received.

This clutter loss is present in most of the terrestrial propagation models including P.452, P.1546 and P.1812. It could in theory also be used with P.2001 though it isn’t specified.

Note that the clutter models in P.1546 and P.1812 are the same and different from the one in P.452.

The P.1546 and P.1812 propagation models are defined as point to area, so that the receiver is assumed to be located not at a fixed point but somewhere within a pixel.

The signal within this pixel is then assumed to vary – typically using a normal distribution with mean zero standard deviation that could depend upon frequency, land use or signal type. In addition, the variability is likely to be reduced for small pixels compared to larger pixels.

In P.1812, the location variability also could vary by height of the receiver compared to the surrounding clutter, reducing when they are similar.

Location Variability and Surface Databases

The location variability describes how the signal received would vary across a pixel. However with very high resolution surface databases (such as those generated by LIDAR) it could be feasible to identify how the signal varies directly without use of a separate location variability term.

This is likely to be more pixelated, as shown in the figure below:

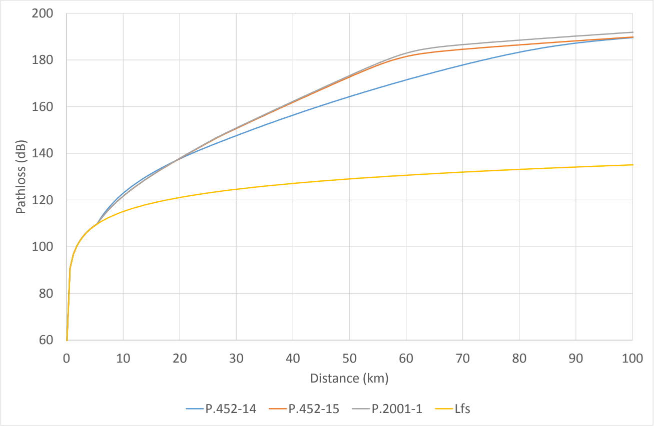
Recommendation Updates

The propagation models in ITU-R Recommendations are continually being updated as more information becomes available.

A major update in recent years has been the replacement of the Deygout diffraction model with the Bullington model.

The diffraction is defined in P.526 but also used in other of the core models, in particular P.452, P.1812 and P.2001. Hence there had to be consequential changes to the propagation models, such as for P.452 to be updated to version 15.

These changes can create results which are significantly different from previous versions. For example the plot below shows the difference between P.452-14, P.452-15, P.2001 and free space path loss for a smooth Earth path in the UK:



Propagation loss for 50% of the time

Conclusions

Selecting the right propagation model is one of the key tasks of any radio simulation study. This will depend upon the locations of the stations – whether land, sea, air or in space – and also the type of study, frequency band, service etc.

It is therefore very important to know which propagation model is right for each situation.

When using a propagation model that uses terrain, surface or clutter data there are additional issues to address, some of which were raised in this White Paper.

There are also continuous updates to the existing propagation models and new ones being developed.

How we can help

We can help operators and spectrum managers analyse propagation related issues including:

Visualyse Professional

Our desktop study tool Visualyse Professional can be used to analyse radio systems including link planning, coverage and interference analysis.

This can analyse almost all types of radio system including mobile, fixed, broadcasting plus other services that might have to share spectrum such as satellite earth stations.

Visualyse Professional contains all the propagation models described in this White Paper.

Consultancy Work

Our consultants can assist you by undertaking:

- Studies of compatibility and methodologies, including interference analysis using Monte Carlo models
- Studies into propagation models and the impact on coverage
- Conversion and use of terrain, surface and land use data
- Analysis of network coverage (e.g. mobile or broadcasting) to meet regulatory obligations
- Link design and radio spectrum planning

Regulatory Support

- We can provide a range of services to support regulatory activities including licensing and representation at international and regional meetings (e.g. ITU and CEPT).
- We have experience in developing and revising ITU-R Recommendations

Contact us

If you have any questions or comments about this White Paper or would like more information please do not hesitate to contact us at:

Email: info@transfinite.com