Accurate Coverage prediction and optimization

— for digital broadcasting

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Digital broadcasting services (e.g. DVB-T and DAB) require higher prediction accuracy than traditional analogue networks, because digital services are planned with tighter margins on the signal strength and interference. This article describes new prediction models, created by the authors, that offer higher accuracy and which can be used to optimize digital broadcasting networks.

Digital terrestrial broadcasting services, both for television and radio, are proving a big success in Europe, as improved service quality, low set-up costs and increased content offered by the broadcasters attracts more viewers and listeners to these new platforms.

But in order to reach their target subscriber levels before a hypothetical analogue switch-off, digital operators not only face the challenge of making their content attractive, but they also need to know more accurately the quality of terrestrial coverage they can provide to their potential customers. This will help to create a credible service to encourage digital switchover and act as an aid to maximizing the coverage and service quality.

The transition period currently in place in several European countries means that digital and analogue transmissions will co-exist for several more years. Until then, this cohabitation period puts an additional constraint on Digital Terrestrial Television (DTT) networks, as operators of digital channels must ensure that their transmissions do not cause problems to viewers of existing analogue channels. It also means, in many cases, that new transmitters cannot be deployed, as making changes to elaborate frequency plans already in place does not particularly appeal to operators and regulators alike. Acting as a stumbling block of equal importance are the difficulties experienced by the likes of mobile phone operators in gaining planning permissions for deploying new transmitter sites. These issues make the careful planning of DTT transmitters, and their predicted coverage, all the more critical.

Digital broadcasting services (DTT and DAB) require higher prediction accuracy than traditional analogue networks because digital services are planned with tighter margins on the signal strength and interference. Given this need, broadcasters nevertheless need to plan and optimize their new digital networks in order to provide:

- accurate modelling of the impact of new digital services on analogue availability;
- prediction of the coverage that can be provided by a new digital network;
- selection of channels to best accommodate digital services;
- creation of efficient and cost-effective network plans to achieve migration from analogue;
- optimization of digital networks to maximize the number of customers.

This article describes the authors' experiences in creating higher accuracy models, and using these models to optimize digital networks. The experience embodied in these models has been arrived at through a variety of projects with several broadcasters, including the BBC via the DigiPlan project [1], the former commercial UK DTT operator OnDigital (latterly itvDigital) and, more recently, new European DTT operators who are faced with creating new networks in bands already heavily congested with analogue interferers.

Need for better predictions

The constraints currently imposed on DTT operators – resulting from the co-existence with analogue, and the difficulty of planning a nationwide network under these conditions – all contribute to put extra burden on operators. It has therefore become crucial for the operators to make the best use of their available assets. One area that has long been overlooked has been the prediction tools used to evaluate network coverage. Operators have generally relied on coverage predictions obtained from tools used to predict coverage for the analogue networks. Although the mechanisms underlying the propagation of analogue and digital signals do not vary fundamentally, there is larger tolerance for the signal to drop below the set threshold levels in analogue transmissions, resulting in a picture of average quality. In digital transmissions, however, picture quality fails precipitously over a very small range of signal levels, making accurate predictions of availability more critical.

There are two main classes of models used for propagation prediction:

1) **Semi-empirical models**

   These models provide a prediction for 50% of locations and are based on measurement data conducted in regions representative of the general terrain characteristics found in the area of interest. The models described in the ITU Rec. P.370 belong to this category. These models will generally have a set of correction factors such as an end-of-path correction to take into account the clutter-type or the terrain characteristics surrounding the receiver point, the effective height of the transmitter and other parameters.

   These models have the benefit of being easy to use, requiring very little initial set-up and can provide predictions quickly and easily. However, these only provide limited accuracy and, as such, are rarely used for domestic coverage prediction. Instead, they are generally used for predicting the field strengths from remote interfering transmitters.

   In order to make semi-empirical models adequate for domestic coverage prediction, it is common to add a site-specific correction to account for diffraction losses over terrain. The most commonly encountered examples of such models make use of variants of the Deygout diffraction correction to account for propagation over geographic features such as hills. In its simple form, the Deygout model identifies an equivalent single diffracting edge between the transmitter and the receiver as being at the intersection between the clearance angle lines at both ends of the path [2]. The Deygout model shows however some fundamental limitations in cases where, for instance, the clearance angle is large resulting in the diffraction loss being significantly overestimated. In order to overcome this problem, Causebrook [3] introduced a semi-empirical correction factor to the Deygout model. Although the resolution of the data used in such models is improving in many applications down to about 50m, the models are tuned to give good accuracy only with terrain, and no specific account is taken of clutter such as trees and buildings.

2) **Fully deterministic models**

   These models are based on electromagnetic wave propagation theory and encompass the various propagation mechanisms experienced by the signal between the transmitter and the receiver. This includes the reflection, scattering and diffraction of the wave over obstacles and surfaces along its path. These models are heavily dependent on the quality of data representing the 3D terrain and building morphology of the area of interest. In general, these models do not rely on adjustable parameters – provided the electromagnetic characteristics of the surfaces interacting with the propagating waves are known. These models require very high accuracy, high resolution data sets. Such planning data has become increasingly affordable and available over major cities, since the explosion of mobile communications and their requirement for this type of data. However, the sheer size of the data and the complexity of solving the propagation path require sophisticated data-handling and management database software. As a result, this considerably increases the computation time, with the accuracy of the prediction remaining highly dependent on the quality of the input.

High-accuracy coverage prediction

The authors have developed models for digital broadcast coverage prediction that provide higher accuracy than semi-empirical models, yet can be computed in a reasonable timescale with a lower requirement on data accuracy than full 3D deterministic solvers.

These models rely on three important elements:

- they use a combination of high-resolution data, representing the locations and heights of terrain and buildings in built-up areas, and medium-resolution data for more open, rural areas;
- they incorporate recent advances in propagation prediction algorithms to account for the improved data;
- they make use of increases in computing speed and resources, allowing the increased complexity to be accounted for in reasonable computing times.

High-resolution data

There is a wide range of high-resolution data now available from various data providers. There are two main sources which are currently practical:

- ***Stereo aerial photography***, where pairs of photographs taken from offset locations can be used to infer the heights of terrain and buildings. The data extraction process is still largely manual, but the quality of the data produced can be very good if provided by reputable suppliers.
- ***Laser interferometry***, which measures the return time for scattering a laser pulse from an airborne platform, such as a light aircraft or helicopter. In essence the system directly "scans" the ground in swathes which are tens or hundreds of metres in width. The quality of the resulting data depends on the type of laser, the processing methods and the height of the airborne collection. Data can have an accuracy of the order of tens of centimetres and can provide a resolution on the ground of around 1 m.

Satellite collection is also possible, and provides a way of gathering data quickly over very large areas, although commercial sources are currently limited in accuracy and resolution.

For the modelling of digital broadcasting systems, we have found that a data resolution of around 5 m on the ground is adequate. Our models require only a raster of terrain heights, avoiding the need to process the data

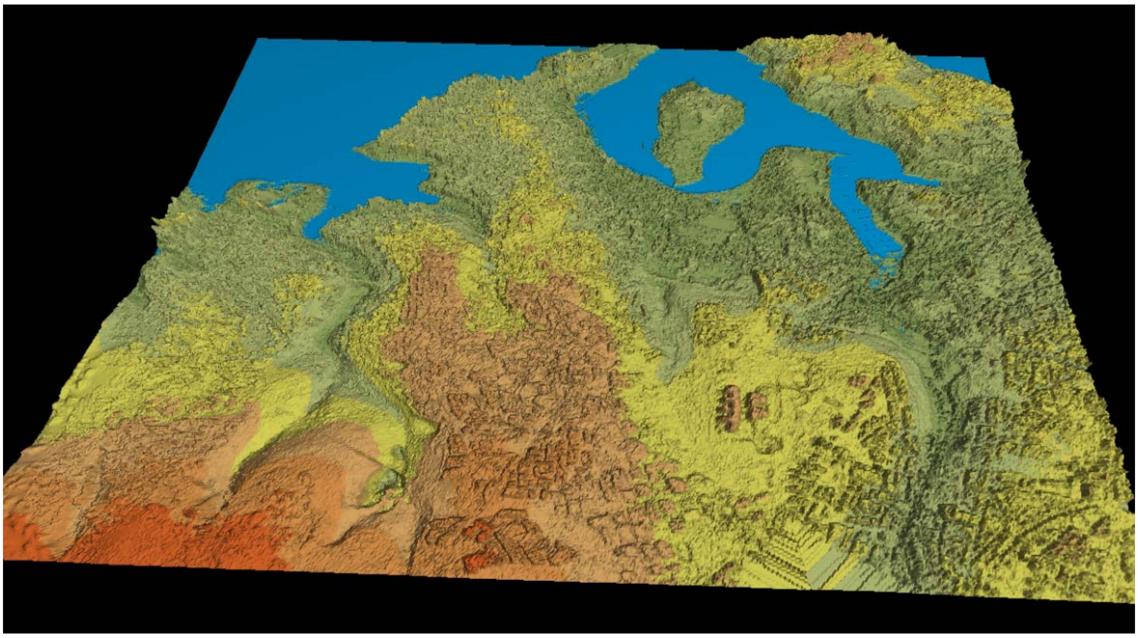

Figure 1
Example of terrain and building data from aerial photography at 5 m resolution. Colours show height contours, increasing from blue (sea level) to red

into a vector form that represents the full geometry of the buildings. An example of such data, collected using aerial photography, is shown in *Fig. 1*. Individual buildings are clearly discernible.

The model

The main mechanism for predicting the attenuation of signals across obstructions such as buildings and hills is *multiple diffraction*. This problem is numerically complex, and has been studied for many years. Recently, a technique known as ***slope diffraction***, inspired by an advanced form of the ray-tracing techniques common in computing graphics, has been found to produce solutions that are as accurate as much more complex techniques in short run-times. In contrast to many other traditional techniques, it is capable of accounting for diffraction over a large number of obstructions, with arbitrary locations and heights. Traditional techniques only work properly for a small number of obstructions and tend to fail when obstructions are nearly in-line with each other, and with the transmitter or with the receiver. One recent form of this technique was created jointly by one of the present authors [4].

The multiple diffraction technique will only produce accurate results, however, if radiowave propagation occurs over a clearly-defined path (the great-circle path) between the transmitter and receiver. In practice, particularly for buildings, it is necessary to account for the finite width of buildings and the possibility of off-path propagation around building edges. Doing this in a rigorous fashion increases complexity unacceptably, however. These effects have instead been incorporated via a correction to the basic method which accounts for the specifics of the path geometry, particularly in areas close to the receiver where such effects are most significant.

The optimized model has to be implemented efficiently in order to make the most of available computing resources. The diffraction model is, however, only one part of the data processing sequence, which also includes:

- the extraction of suitable path profiles to suit the requirements of the model;
- post processing of the prediction results to include the effects of antenna radiation patterns;
- computation of the availability, based on the relevant planning margins.

By considering all of these steps together, we have created an efficient platform for accurate prediction of a wide range of planning scenarios.

Example predictions

On behalf of a digital broadcaster, Cellular Design Services (CDS) conducted a series of detailed measurements in a residential suburban area. The measurements covered a large area consisting of 6 km^2, served by a transmitter approximately 30 km away. Field-strength measurements on four channels were made at a height of 10 m using a vehicle equipped with a pump-up mast. An average of 20 measurements per square kilometre were made, resulting in a total set of 468 measurements.

Table 2
Results of the prediction error

Channel	25		28		29		34	
No. of Pts	117		115		117		116	
Model	Causebrook	CDS	Causebrook	CDS	Causebrook	CDS	Causebrook	CDS
Mean err. [a]	–9.47	–3.41	–5.85	–0.37	–8.99	–3.88	–12.32	–6.25
STD [b]	8.23	5.72	8.89	5.79	7.97	6.02	7.69	6.16
Correl. [c]	0.39	0.62	0.43	0.60	0.34	0.59	0.34	0.60

a. Mean error (in dB);

b. Standard deviation (in dB);

c. Correlation coefficient.

Field-strength predictions for the received locations were also available from a tool which is based on an enhanced version of a Causebrook-type model, using 250 m resolution terrain data.

Table 1 gives the results of the prediction error analysis between the Causebrook and the CDS models compared to the measured levels.

Improvements in the mean error, of the order of 5 - 6 dB, can be seen across the set of measured channels. However, most importantly is the observed improvement in the standard deviation when the high-accuracy prediction model is used. A low standard deviation expresses the ability of the model to track local changes in the field strength due mainly to shadowing effects. It is a critical parameter for network planning, as a low standard deviation model would generally require a small fade margin to be accounted for in the system's link budget. Over the four measured channels, the standard deviation was improved by between 1.5 and 3 dB.

There was also a considerable increase in the correlation coefficient, seen to increase by an average of about 50% compared to the performance of the Causebrook model prediction.

Although these results show that improvements were made on a macroscopic scale, it is also worth noting how the new model predictions have contributed to a better description of the field strength at local level. For this, we have used the concept of hit rates [5], which expresses the percentage of locations whose availability state is correctly predicted by the model at a given field strength threshold.

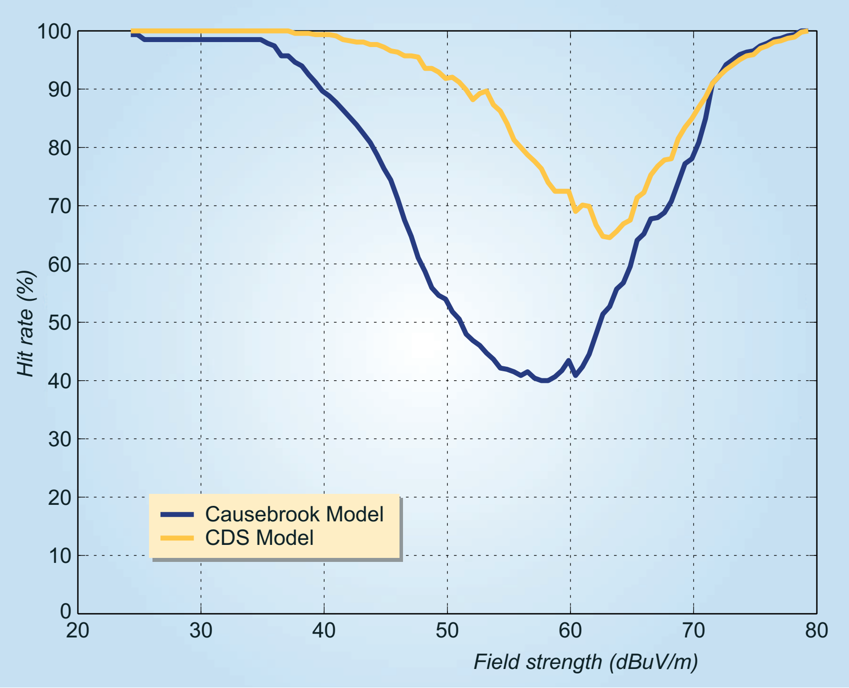

Figure 2
Results of the hit rate analysis

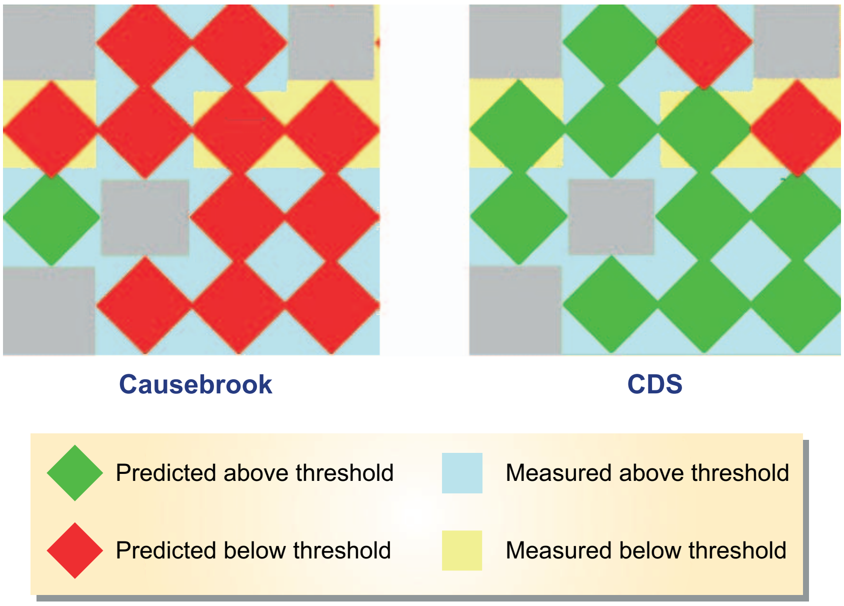

Figure 3
Comparison between the performances of the prediction models in a 1 km² tile

Results of the hit rates analysis are shown in *Fig. 2*. The measured field strength levels varied from about 25 to 80 dBμV/m. The blue curve shows the score of the Causebrook model prediction over this range, and the yellow curve that of the CDS model predictions. The CDS model predictions are significantly better across a wide range of measured levels. In the medium part of the range (50 - 60 dBμV/m) corresponding to the edge of the coverage area the CDS predictions produced a hit rate some 30 to 40% higher than the Causebrook predictions.

Fig. 3 illustrates the impact of the improved hit rate over a 1 km^2 tile. In this figure, the left tile shows

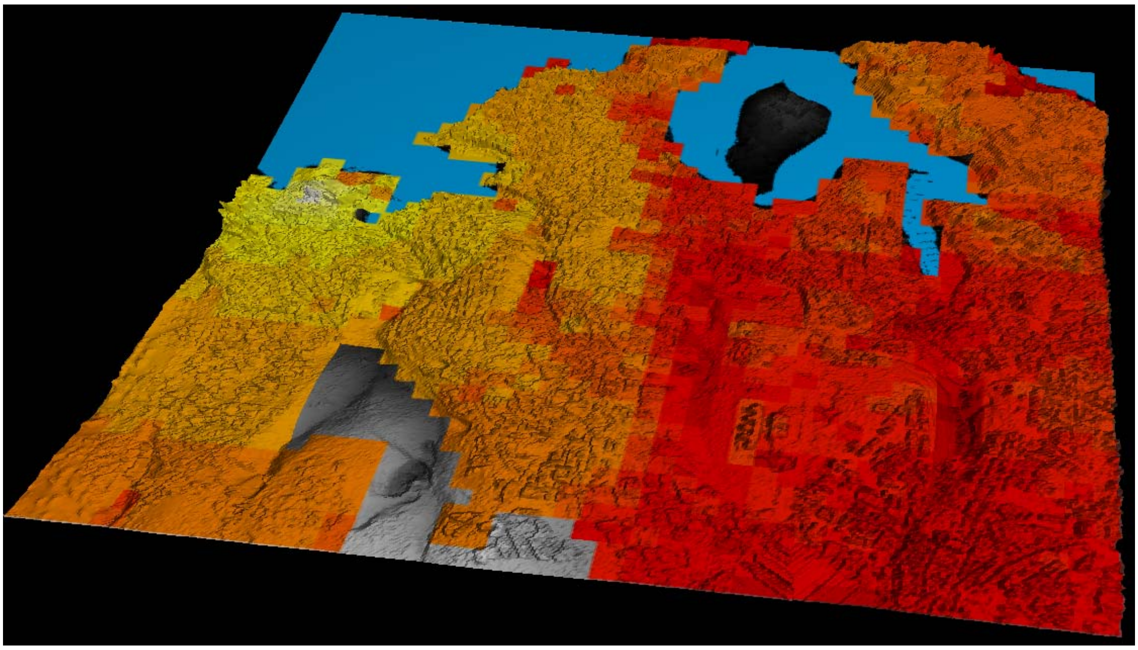

Figure 4
Field strength prediction from the CDS model. The colour scale ranges between 40 dBµV/m for the dark red colours, to 100 dBµV/m for the bright yellow. The transmitter site is indicated by an arrow. Although the underlying data has 5m resolution, predictions are made at 100m squares, selecting a representative location in each to reflect the requirements of the broadcaster. Grey areas are out of town.

the performance of the Causebrook model and that of the CDS model is on the right. The tile has been subdivided into 16 pixels of size 250 x 250 m each, with each pixel showing the available measured field strengths in the background and the predicted field strengths in diamonds. The field strengths are shown relative to a threshold level of 55 dBμV/m so that the measured levels appear in blue when they exceed the threshold, and in yellow otherwise. For the prediction, the colour code is green when they are above the threshold and red when they are below. In an ideal situation where the hit rate is 100% accurate, the red diamonds would line up with the yellow background and the green diamonds with the blue background. Note that some pixels did not have measurements performed on them and are shown in grey. The Causebrook results show that four pixels are correctly matched, compared to nine from the CDS prediction model.

This result is very significant as it shows that more than twice as many locations were correctly predicted by the CDS model. This is particularly significant given that these gains were made at the fringes of the coverage area, a region generally prone to interference from neighbouring transmitters. This area is particularly important for planning purposes and translates into a more focused use of the RF resources available to the broadcaster through the use of a lower fade margin to account for this inaccuracy. Other benefits include a more efficient use of their marketing efforts to attract new customers.

Fig. 4, for example, shows a CDS coverage prediction obtained over the area presented in *Fig. 1*. The plot clearly shows detailed local variability in the field strength, resulting not only from terrain but also from building obstructions.

Network performance optimization

Accurate coverage predictions from a transmitter are only one part of creating an improved network. It is necessary also to make decisions regarding how best to optimize the network to deliver the best possible coverage. Examples of parameters to optimize include:

- selection of site locations;
- antenna heights;
- antenna types and orientations;
- channel selection.

Selecting the best possible combination of these parameters is a complex and time-consuming task, which can also make it difficult to verify that the end result is the best possible outcome.

In order to assist with this process, the authors have developed a unique automated network planning and optimization service, known as *SmartPlan*, and have used it successfully in real networks. Results show that significant cost savings, profit increases and quality enhancements can be achieved, as well as large reductions in planning timescales compared to manual planning methods. Digital TV, 2G, TETRA and 3G networks can all be handled.

The process optimizes key performance indicators (KPIs) specified by the broadcaster such as profit, cost, coverage and capacity.

SmartPlan utilises predictions from an existing planning tool or from CDS's high-resolution prediction techniques, ensuring that the plans derived satisfy the KPI criteria when evaluated in the tool. Additionally *SmartPlan* can use measured data to account for actual in-service network performance using a measurement-based prediction process.

SmartPlan uses an efficient evolutionary process to generate a network by gradually iterating the network configuration, *SmartPlan* typically considers many thousands of intelligently chosen network configurations and associated costs, including far more possibilities than would be possible using a manual process.

The relative importance of network KPIs can be adjusted as required so that, for example, the cost/coverage trade-off can be determined. The typical output is a set of alternative network plans, giving the broadcaster a number of options from which to choose the plan that best satisfies his requirements.

SmartPlan has two modes of operation. Firstly, in *Rollout* mode the tool is free to choose any sites from a large list of potential sites, as well as any antenna parameters. Thus plans can always be produced using real, known sites, minimizing the risks and timescales involved in the site acquisition process and maximizing the opportunities for using known available portfolios of sites. This is ideal for initial network planning and rollout.

Alternatively, in *Optimization* mode, the tool starts from an existing plan or network, and iterates antenna parameters, also adding or removing sites if appropriate. This mode is appropriate for post-build optimization, where improvements to network quality or capacity and/or cutting the costs may be required. Measurement information is often included at this stage.

In either case, as the planning inputs change, for example due to requirements for increased capacity, SmartPlan can recalculate the optimum plan using the latest information.

An example of the results produced from *SmartPlan* is shown in *Fig. 5*. Each point represents the coverage performance of a variety of networks versus the associated cost in sites and site hardware such as antennas. Network D1 was selected as optimal in this case as it represents the best balance between cost and performance. In arriving at these results, many thousands of alternative network configurations were evaluated against a wide range of performance criteria.

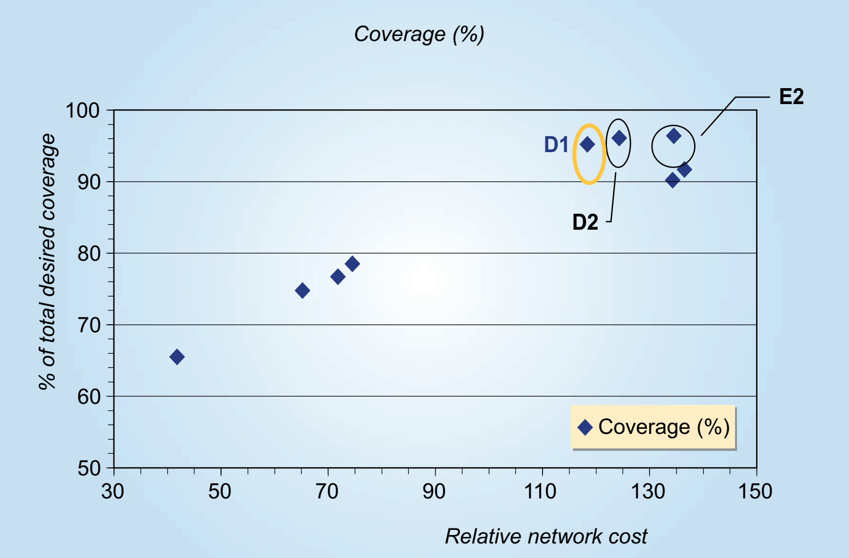

Figure 5
Cost/benefit trade-off for a network coverage problem. Each point represents a complete network configuration, and the points shown are the best to emerge form the automated evolution process in each cost range.

Benefits and Conclusions

It is clear from the example predictions given here that significant accuracy gains can be produced using the models described. It is necessary, however, to translate these gains into benefits for the broadcaster.

As Chief Technology Officer at Cellular Design Services, **Professor Simon Saunders** provides technical direction and leads the technical consultancy and R&D activities. The services provided span a wide range of technical issues in cellular, Wireless LAN, private mobile, broadcasting and fixed wireless systems. Several innovative products are offered to assist in the efficient design and optimization of wireless networks to complement these services.

Simon Saunders is the author of over 100 papers in learned journals and at international conferences and wrote a successful book entitled "Antennas and Propagation for Wireless Communication Systems", published by John Wiley & Sons in April 1999. He is the inventor of some 15 patents spanning a wide range of wireless technologies. He has specialised in mobile communication systems throughout his career, working for leading mobile companies such as Philips, Ascom and Motorola. He is a Visiting Professor at the University of Surrey, England.

Dr Belloul joined Cellular Design Services in a radio-planning managerial role, working as a consultant on various projects in mobile communications and broadcasting, and developing innovative methods and solutions for improving propagation prediction for macro-cellular and in-building networks. During this time, he has been responsible for the invention of patented techniques incorporated into CDS tools.

Bachir Belloul obtained a PhD from the University of Paris in 1996. He has had considerable experience spanning over ten years, working closely with a number of major actors from the wireless industry. While he was at the National Centre for Scientific Research (CNRS) in France, he worked on a novel satellite-to-satellite radio occultation technique for mapping the atmosphere as part of the European Space Agency's *Earth Observation* project.

Prior to joining CDS, Dr Belloul was at the Centre for Communication Systems Research at University of Surrey, England. His interests included microwave satellite links and cellular radiowave propagation.

The following assumptions were used to derive the benefits to be gained from this increased accuracy:

- 80% of the households were predicted to be covered nationally, of which 8% were deemed as marginal;
- 40% of the households offered a service required an antenna re-fit due to inaccurate predictions.

The results from the hit rate analysis presented in *Fig. 2* were used as the basis for extending the findings to a national maximum of 25 million households. The extrapolated results showed that an estimated 1.3 million extra households could be included in the service area: using the standard model, these households were predicted to be unserved.

Furthermore, the new model predicted that there were in excess of 390,000 households that could not be provided with digital services due to poor coverage – despite the fact that these households were predicted to be in the service area when using the conventional model. This improved accuracy prevented unnecessary marketing resources from being used in these areas.

A model for accurately predicting field strength in DTT networks has been presented together with results comparing the performance of the model with measurements in marginal coverage areas where accurate predictions are particularly valuable.

This model has consistently performed well and has proved to be very effective in (i) reducing the standard deviation of the prediction error and (ii) significantly increasing the hit rate. It has already been used in real situations, either to address optimization issues in existing networks or for choosing the optimum parameters for a new network. In this context, the automated network optimization capability provided by *SmartPlan* provides an excellent basis for decision-making.

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