THE QUEEN'S AWARDS FOR ENTERPRISE 2001

R&D White Paper

WHP 047

September 2002

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Research & Development
BRITISH BROADCASTING CORPORATION

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Abstract

Transmitter network design for digital broadcast services must balance the conflicting requirements of providing high-quality service to the users and maintaining good spectral efficiency, whilst minimising the costs for realising the network and achieving a rapid roll-out towards the required coverage. This places far greater requirements on the accuracy of coverage prediction tools than previously.

The main aim of the DigiPlan project was to develop new path loss prediction algorithms that can be used to plan and maintain digital broadcast networks with an accuracy commensurate with the requirements of these new services.

This paper outlines the context for the DigiPlan project and then describes the key aims and objectives. A new approach has been developed, based on diffraction methods, that yields higher accuracy for a given computation time than previous rigorous theoretical methods. The paper outlines the development and implementation of the new method. Measurement campaigns were conducted to collect additional measurements for validation of the model. Comparisons of the measured and predicted path losses are presented..

This document was originally published in the Conference Publication of the International Broadcasting Convention (IBC 2002) Amsterdam, 12-17 September 2002.

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THE DIGIPLAN PROJECT: COVERAGE PREDICTION FOR DIGITAL BROADCAST SERVICES

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ABSTRACT

Transmitter network design for digital broadcast services must balance the conflicting requirements of providing high-quality service to the users and maintaining good spectral efficiency, whilst minimising the costs for realising the network and achieving a rapid roll-out towards the required coverage. This places far greater requirements on the accuracy of coverage prediction tools than previously.

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This paper outlines the context for the DigiPlan project and then describes the key aims and objectives. A new approach has been developed, based on diffraction methods, that yields higher accuracy for a given computation time than previous rigorous theoretical methods. The paper outlines the development and implementation of the new method. Measurement campaigns were conducted to collect additional measurements for validation of the model. Comparisons of the measured and predicted path losses are presented.

INTRODUCTION

Transmitter network design for digital broadcast services must balance the conflicting requirements of providing high-quality service to the users and maintaining good spectral efficiency, whilst minimising the costs for realising the network and achieving a rapid roll-out towards the required coverage. The DigiPlan project was launched in the context of considerable uncertainty regarding the suitability of standard analogue network planning approaches for digital TV and radio broadcasting. The expectation was that the digital systems would place far greater requirements on the accuracy of coverage prediction tools than previously. In an analogue network, the soft degradation in performance allowed a considerable tolerance to differences between predicted and actual signal strengths, whilst still maintaining acceptable service quality. In the digital system the same margin of error may lead to no service at all.

The DigiPlan project was funded under the UK Department of Trade and Industry (DTI) LINK Broadcast Technology Programme, and involved a collaboration between the BBC R&D Spectrum Planning Group (BBC), Cellular Design Services Ltd. (CDS) and the Centre for Communication Systems Research (CCSR) at the University of Surrey. The main aim of the project was to develop new path loss prediction algorithms that can be used to plan and maintain digital broadcast networks with an accuracy commensurate with the requirements of these new services.

PROJECT AIMS & OBJECTIVES

DigiPlan's approach was founded on an intention to make use of three key developments. Firstly, new developments in numerical electromagnetics, which permit the effects of large numbers of significant obstacles, such as buildings, terrain and trees, to be accurately predicted. Secondly, the availability of high accuracy, high resolution terrain and clutter mapping data at reasonable cost, from satellite and aerial photography; and lastly, the availability of relatively cheap, high-performance computing power.

The project objectives, following slight modifications made during the project, were as follows:

- To identify the prediction accuracy and key service parameters required for DVB-T and T-DAB services and the impact of prediction inaccuracies on coverage area, spectral efficiency and quality of service.
- To implement and characterise standard prediction methods of coverage prediction as a benchmark. Such methods are based on empirical or heuristic extensions of basic theory and tend to fail in unpredictable fashions in some situations.
- To develop, implement and optimise new prediction methods based on multiple diffraction over and around canonical objects such as edges, cylinders and arbitrary piecewise-linear edges. New approaches, partially already developed by CCSR, allow predictions to be made with a user-specified trade-off between prediction accuracy and computation time.
- To create a database of benchmark measurements against which the effectiveness of prediction techniques can be tested.
- To examine optimal methods for extracting arrangements of canonical objects from a range of terrain and clutter data formats.
- To determine the explicit trade-off between data resolution, computation time and prediction accuracy, leading to optimal approaches for practical broadcast network design.
- To create and develop efficient methods for including statistical effects such as time or location variability and correlated shadowing, following a hybrid physical/statistical approach.
- To apply parallel computing and advanced mathematical techniques to permit very fast prediction of propagation over large numbers of path profiles, yielding complete area coverage predictions.
- To interface the best of the resulting software with existing and enhanced user interfaces and data structures to create a practical advanced prediction tool.
- To communicate the results of the project to other broadcasting organisations, international standards bodies and to the scientific community.

KEY ADVANCES

The project objectives were substantially achieved and a number of specific advances of technical and practical worth were produced, including particularly those highlighted below.

Assessment of Existing Algorithms

A detailed comparative assessment was made of existing algorithms for the prediction of attenuation due to multiple diffraction. This assessment used a database of some 20,000 measurements and terrain path profile information supplied by the UK Radiocommunications Agency, and showed that there are considerable differences in both the mean and standard deviation of the prediction accuracy arising from the different methods. The results were reported in Tzaras and Saunders 2000 (1).

New Diffraction Models

Three new diffraction models were developed during the course of the Project: the fast Vogler model, an accurate multiple cylinder model and a new slope-UTD model. Two of these are briefly described below.

The Fast Vogler model

The representation of real obstacles by infinite knife-edges has been found appropriate for built-up areas (Saunders and Bonar (2), Walfisch and Bertoni (3)) with the Vogler solution (Vogler (4)) representing the ultimate in accuracy compared with other approximate deterministic models. However, the Vogler solution has been found impractical when a large number of edges (say >5) is included in the path since it either fails or the computational requirements are prohibitive. Although Vogler's solution can become more efficient by considering the significant knife-edges only (for example those which lie inside the first Fresnel zone), such an approach removes the sensitivity of the method in arbitrary path profiles and also introduces unreliability since the performance of the method becomes unpredictable.

A new approach was developed for selecting diffracting obstacles and for computing the accurate multiple knife-edge diffraction attenuation function. The new approach allows stable results to be obtained from the function for a larger number of diffracting obstacles than was previously the case, by using Babinet's principle recursively to transform a 'hard' arrangement of edges into a numerically stable arrangement. The approach also reduces the number of terms that have to be computed and thereby reduces the computation time. This method is described further in Tzaras and Saunders 1999 (5).

The Slope-UTD model

The Uniform Geometrical Theory of Diffraction (UTD) has been applied by many researchers to predicting field strengths resulting from complicated geometries, such as those encountered in 3D urban propagation. However, UTD in its basic form does not correctly predict the field arising from multiple obstructions illuminated within the transition region close to the shadow boundary, and this is an important practical case.

A new model of multiple diffraction prediction was developed, which produces results virtually as accurate as the Vogler model, but in computing times of around an order of magnitude less than even the rapid approach reported in (5). This technique was inspired by previous work (Andersen (6)) on computing the slope diffraction term in UTD (slope-UTD) but accounted for phase terms and distance parameters in a more exact fashion and therefore produced accurate results even for very large numbers of obstructions. Another advantage of the new model is that it applies equally to diffraction over wedges and other canonical structures as well as simple knife-edges, permitting the detailed structure of terrain and buildings to be modelled more exactly. The new model is described further in Tzaras and Saunders 2001 (7).

Comparison tests

In addition, extensive comparison tests were conducted with the most commonly used diffraction models, using the database of some 20,000 measurements and terrain path profile information supplied by the UK Radiocommunications Agency. Statistics for these comparisons are presented in Table 1.

Method	Mean error (dB)	Standard deviation of error (dB)
Deygout	6.4	9.17
Giovaneli	9.54	8.43
Causebrook	-3.02	8.01
Vogler	-1.79	7.53
UTD	-2.03	7.51

Table 1 - Comparative results for five knife edges

The results show that the UTD and the Vogler solutions perform better for all sites. These solutions also exhibit greater consistency and reliability. Increasing the number of edges considered produces better performance for the UTD and the Vogler solution whereas the other models produce the same or worse predictions, suggesting that only UTD and Vogler provide an accurate representation of the underlying propagation mechanisms.

Hit Rate Metrics

The accuracy of prediction models has, historically, been assessed almost entirely on the basis of first-order statistics such as the mean and standard deviation of the error and, occasionally, the correlation coefficient between measurements and predictions. First order statistics give a global perspective, but are not always appropriate to the needs of final system design.

To complement first-order statistics, new metrics were developed (‘hit rates’) for evaluating the performance of propagation models compared with measurements. Hit-rates are more sensitive to changes in model accuracy than the standard deviation, and correlate more closely with the expected performance of the models in predicting system coverage in particular areas, since they include a measure of the model’s spatial correlation with measurements.

Hit rate metrics are obtained by assessing both predicted and measured values at each point along a route against a field strength or path loss threshold. If the measured path loss is less than or equal to a given path loss threshold, then at those particular points along the route, ‘coverage’ is achieved for the experimental result. Otherwise, ‘outage’ is achieved for the experimental result. The same test is applied to the set of predicted path loss data. Various hit-rate metrics can then be defined in terms of combinations of the probabilities, from measurement and prediction within the set of points, that coverage is or is not achieved. The hit-rate metrics are defined and their performance analysed in Owadally et al (8).

Data Integration

Software tools were created to import high-resolution building elevation and ground height data, integrate it with low-resolution terrain and ground cover data, derive path profiles and run the new model. The results could be automatically compared with measurement results at corresponding locations. The new model was tested in part using detailed building and terrain height data supplied by the UK Environment Agency. This data had a ground resolution of 2m and was derived from airborne laser scanning techniques (LIDAR). An example area, showing the part of the Docklands area of East London and the Millennium

Dome, is shown in Figure 1. A second sample LIDAR data area, for part of the city of Cardiff, was also used in the course of the Project.

Statistical City Models

A statistical approach to the generation of buildings data sets was developed, with the aim of reducing the costs of buildings data which would be required to apply the new models to coverage prediction over a wide area. This approach uses three simple parameters relating to the spatial statistics of building heights in any given area, and algorithms were implemented to regenerate a statistically accurate arrangement of buildings using these parameters. The prediction models could then be applied to the statistical data, yielding an accurate representation of the fraction of the area covered. This fitted the requirements of the BBC well, since their requirements are often more concerned with ensuring a sufficiently large proportion of the public receives service, rather than determining precisely which individuals are served or unserved.

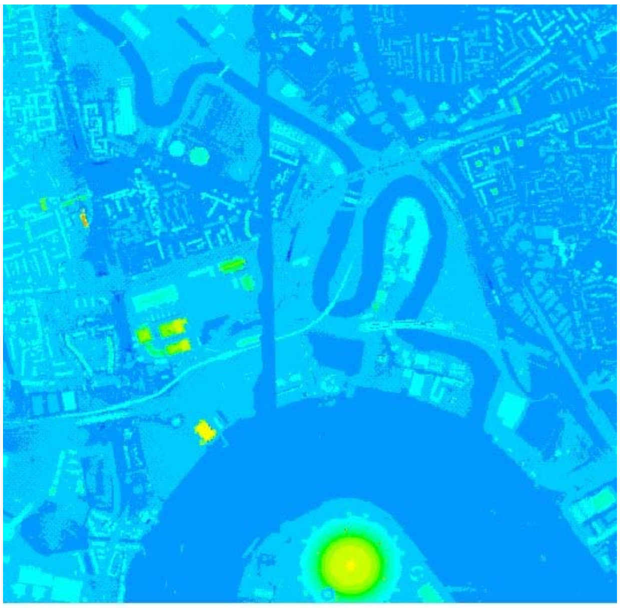


Figure 1 - Example high-resolution building height data for East London. Supplied by the Environment Agency

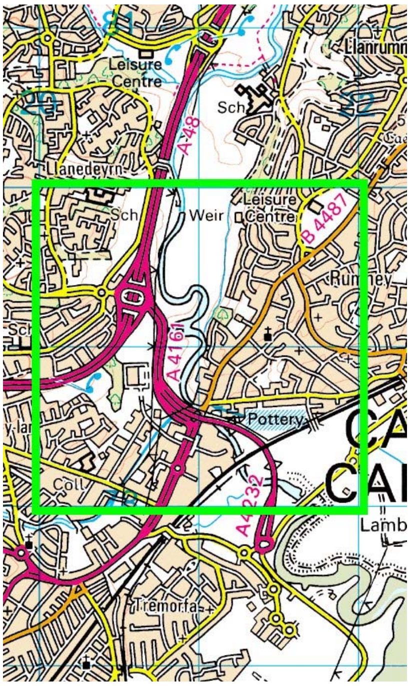
COLLECTION OF NEW MEASUREMENTS DATA SETS

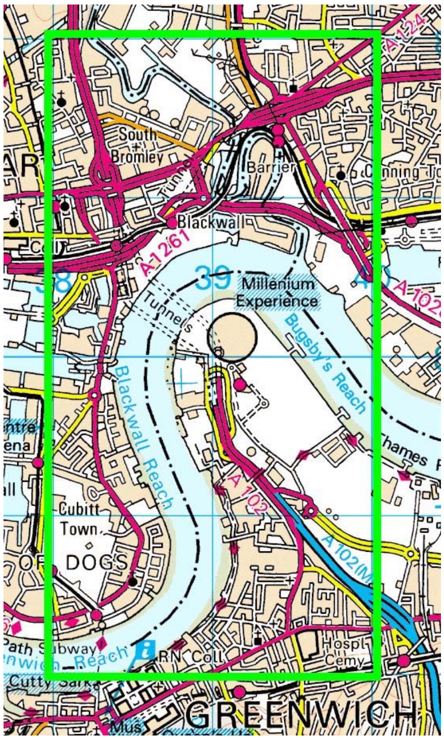
In order to evaluate the accuracy of the new prediction methods identified and implemented within the DigiPlan project, measurements were made within the specified LIDAR data areas and the results compared with the predicted path loss values. These measurements were made by CDS in two phases using various test scenarios. These test scenarios included measurements of existing DVB and DAB transmissions and also measurements of specific test transmitters (‘candidate’ tests), the objective being to evaluate the prediction tool using measurements collected within the relevant frequency bands and with varying path profiles.

Phase 1 was carried out in May and June 2000, and involved collecting data in both Cardiff and East London test areas. These test areas were defined by the availability of LIDAR terrain data and are as shown in Figure 2. The testing during Phase 1 was concerned with collecting field strength data from both existing transmissions and test transmitters at both DAB and DVB frequencies.

DAB tests were made in a dynamic environment where the test equipment was mounted within a test vehicle and recorded data collected along a specific test route. Measurements in this case were linked to geographical position using a GPS-based navigation system. Tests were carried out using both ‘candidate’ test transmitter sites and existing DAB transmissions in the Cardiff area, whilst tests carried out in the East London area were limited to existing DAB transmissions only.

DVB tests were made in static conditions, with measurements made at specific test locations. Once again tests were carried out using both ‘candidate’ test transmitter sites and existing DAB transmissions in the Cardiff area, whilst tests carried out in the East London area were limited to existing DVB transmissions only.





CARDIFF EAST LONDON

Figure 2 - Test areas, showing the extents of the sample LIDAR data

Phase 2 testing was carried out in September 2001, and was concerned with collecting existing DVB transmission data within the Cardiff test area only.

The above tests enabled the new prediction techniques to be evaluated, particularly for the candidate and existing transmission static DVB measurements made within the targetted test areas. Unfortunately the timescales provided by the project did not allow for evaluation of the dynamic DAB measurements, or the analysis of Phase 2 data.

Looking to the future, a more extensive evaluation of the prediction methods resulting from this project can be carried out by utilising further measurements within a wider range of test frequencies and environments. For example tests at 1.5GHz, using longer propagation paths, or receiving locations within severe multipath environments.

COMPARISON WITH MEASUREMENTS

The modified UTD model was used to predict the path loss in two specific urban environments: London and Cardiff. The predictions were compared against the measurement sets provided by CDS. In order to assess the accuracy of the modified UTD model, the predictions were analysed using first-order statistics and hit rate metrics.

Results are presented here for measurements made in Cardiff, for the transmitters located at Wenvoe (about 11 km south-west of the measurement area) and Mendip (about 47 km south-east of the area). Fifteen receiving locations were used, located within the area covered by the LIDAR sample data. At each location, measurements were made at 6, 8 and 10 metres above ground level. Predictions were obtained using the 50 metre resolution terrain and ground cover data and the 2 metre resolution LIDAR data. Table 2 shows the statistics for the measurements vs. predictions for the two transmitters.

Transmitter	Mendip			Wenvoe		
Rx height (m)	6	8	10	6	8	10
Mean error (dB)	-5.37527	-4.6470	-6.8597	3.8425	3.0033	1.9715
Standard deviation of error (dB)	6.70106	8.7525	6.3286	6.3142	4.1355	5.4742
Correlation coefficient	0.86096	0.8780	0.8155	0.7478	0.9051	0.8442

Table 2 - Statistics for the 15 receiving locations in Cardiff

The comparison graphs and the statistical analysis revealed that the modified UTD model produces good results, in terms of the correlation of the measured and predicted field strength variations. There are, however, some discrepancies, particularly in the mean differences between predictions and measurements, which are sometimes excessively large. It has been verified, by examining paths that are mostly unobstructed, that these discrepancies do not arise from the diffraction calculations. Additionally, comparisons have been made against existing BBC in-house tools and the DigiPlan predictions generally show less deviation from the measurements. The origins of the unexpectedly large discrepancies are still being investigated.

RESEARCH IMPACT AND BENEFITS TO SOCIETY

The work of the DigiPlan project has been disseminated in a range of ways. Firstly, through journal publications ((1), (2) and (6)) and also at two international conferences ((8) and Saunders and Tzaras 1999 (9)). Dr. Saunders was invited to present at the XXVIth General Assembly of the International Union of Radio Science and presented an overview of the DigiPlan models. A presentation was also given at the DTI's workshop on the LINK Broadcast Technology programme. More recently, interest in the results of DigiPlan has been expressed by digital broadcasters around Europe. Other publications are planned.

As well as providing important and useful new models for the broadcasting community, the project has helped the other project partners to progress their commercial activities. CDS have expanded their commercial activities into the broadcasting arena, previously having worked only on cellular mobile systems. BBC R&D is applying the knowledge gained within DigiPlan to help specify a new suite of high-resolution prediction techniques within the UK digital broadcasting community. CCSR, meanwhile, have continued their work on broadcasting through the LINK 'COMBINE' project within the Mobile Virtual Centre of Excellence (Tuttlebee (10)).

During the period of the project, digital terrestrial broadcasting in the UK has become firmly established, both through the free-to-air services provided by the BBC and others, and through subscription services. The knowledge created by DigiPlan will help those networks to provide high service quality to a maximum proportion of the public in the target service areas, with high spectral efficiency. It will also help to enable the UK to maintain its lead in digital broadcasting technology.

CONCLUSIONS

The main aim of the DigiPlan project was to develop new path loss prediction algorithms that can be used to plan and maintain digital broadcast networks with an accuracy commensurate with the requirements of these new services. DigiPlan's approach was founded on an intention to make use of three key developments. Firstly, new developments in numerical electromagnetics, which permit the effects of large numbers of significant obstacles, to be accurately predicted. Secondly, the availability of high accuracy, high resolution terrain and clutter mapping data at reasonable cost, from satellite and aerial photography; and lastly, the availability of relatively cheap, high-performance computing power.

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ACKNOWLEDGEMENTS

The authors wish to thank the UK Department of Trade and Industry and the Engineering and Physical Science Research Council for funding provided through the LINK Broadcast Technology Programme. Thanks are also due to the BBC for their permission to publish this paper.