PROPAGATION STUDIES FOR ENHANCED BROADBAND WIRELESS ACCESS

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ABSTRACT

Propagation results from the EU Fifth Framework project EMBRACE are reported. These relate to broadband wireless access systems operating at millimetre wave frequencies. A planning tool has been developed for network optimisation, combining an efficient ray tracing propagation engine and mathematical optimisation algorithms. Optimisation can be applied to financial criteria, as well as to the more common area coverage. Significant enhancements in availability and performance can be obtained by the application of server and space diversity to overcome degradations caused by rain and tree blockage, respectively. These techniques have been experimentally validated.

INTRODUCTION

The potential of millimetre-wave radio (particularly at 28GHz and 40GHz) as a delivery system for broadband services is recognised. The goal is to deliver a flexible mix of telecommunication and interactive broadcasting services at a cost most people can afford. However, providing universal coverage is a major challenge due to the propagation impairments experienced at these frequencies.

Under the European Commission Fourth Framework programme the ACTS project CRABS (Cellular Radio Access for Broadband Services) performed systems studies and experimental trials at 40GHz. The study of propagation was one of the main activities in the project. A number of new modelling and measurement results for coverage and availability predictions were obtained, and aspects of performance were studied [1,2]. These results form the basis of Recommendation P.1410 of the International Telecommunication Union on propagation information for terrestrial broadband radio access systems operating in the frequency range 20 to 50 GHz [3].

The CRABS results showed the viability of providing broadband wireless access (BWA) by means of millimetre-wave cellular systems. However the effects of building and terrain blockage, attenuation due to rain, and the static and dynamic effects of vegetation, on the propagation path between the base station and the user impose limitations on the coverage, availability and performance of the service offered.

Propagation studies at 40GHz to overcome some of these limitations are continuing within the European Commission Fifth Framework project EMBRACE (Efficient Millimetre Broadband Radio Access for Convergence and Evolution). The main object of this project is to develop a low-cost, efficient, broadband wireless access system and services. The purpose of the propagation studies is to develop planning tools for the efficient (optimised) design of the cellular networks, and countermeasures against the propagation impairments in order to enhance the availability and performance of the system.

NETWORK OPTIMISATION

A planning tool has been developed for network optimisation, combining an efficient ray tracing propagation engine and mathematical optimisation algorithms [4]. In an area to be covered by a BWA network, the path loss from all potential base station locations to all potential receiver locations is calculated using a ray trace engine that takes account of free space propagation, diffraction, gaseous absorption and rain attenuation. The three-dimensional geographical data required include terrain, buildings and vegetation, obtained from airborne stereographic images or lidar surveys; an example is shown in Figure 1. Efficient algorithms have been developed to enable realistically large areas (tens of thousands of buildings), representative of a BWA franchise area, to be modelled. Indeed, each building can be assigned several receiver test points (Figure 2), allowing the optimiser to find automatically the “best” building location for a BWA antenna.

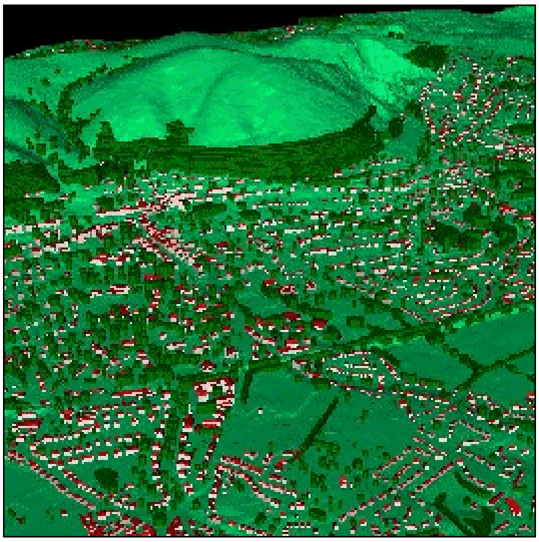

Figure 1: Example of large building database used in planning tool

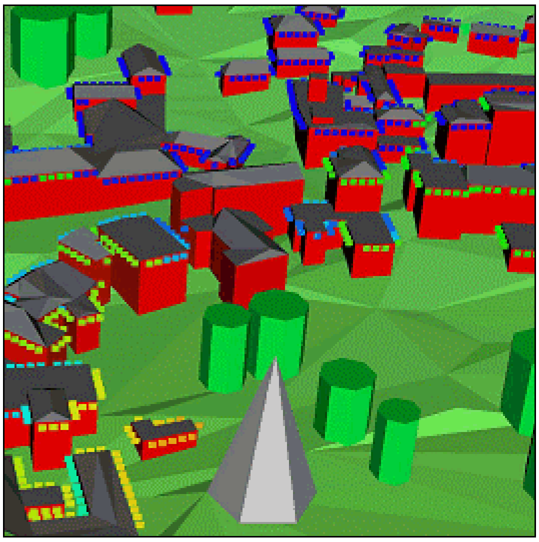

Figure 2: Detail of building data showing receiver test points

The propagation information is used by mathematical optimisation methods (such as hill-climbing with simulated annealing or tabu search meta-heuristic algorithms) to design an optimum (or at least near-optimum) network configuration subject to suitable constraints and optimisation criteria. Variables include base station locations (normally selected from a set of pre-selected potential sites), base station antenna sectorisation and tilt, and transmitter power. Constraints include capacity limits at the base station, and quality of service requirements for a given user/traffic type (which will in general be different, for example, for domestic and business users). The simplest optimisation criterion is the number of users covered. However in a network with a heterogeneous mix of user types and traffic, coverage is not necessarily the best indicator of an optimum network. Consequently a simple financial revenue model has been developed that can optimise the design, for example, for maximum revenue or minimum network cost per user.

Figure 3 shows a network solution for the town in Figure 1. The optimiser has selected two base stations (the coloured squares) from a set of 21 potential sites as the best locations to satisfy the input coverage and capacity constraints. The blue base station has been assigned two sectored antennas (blue and green) while the red base station has a single sector. Figure 4 shows an alternative solution where three base stations have been selected by the optimiser to provide somewhat higher coverage, at the cost of a slight reduction in revenue.

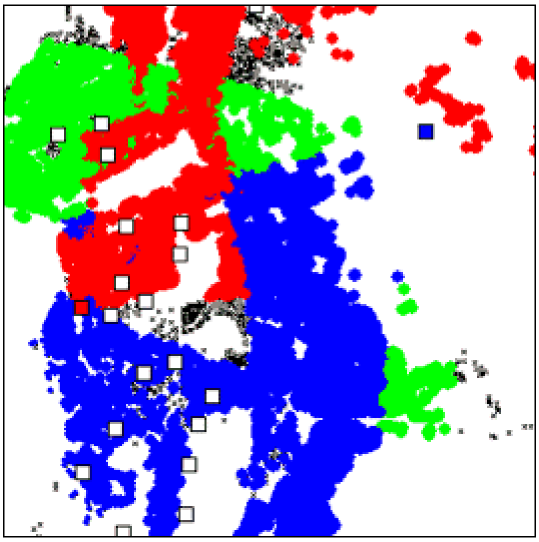

Figure 3: Optimised network using 2 base stations

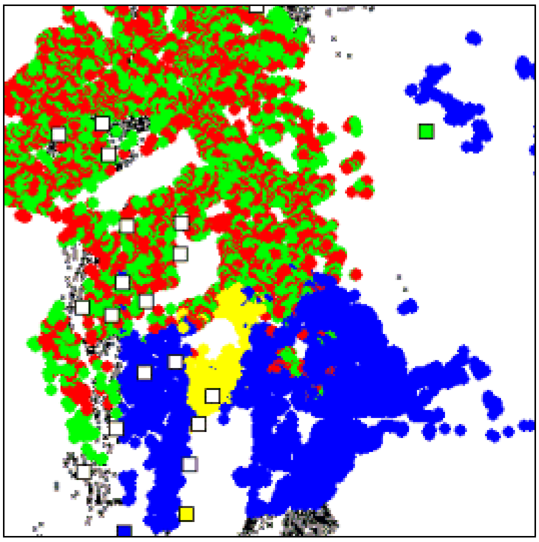

Figure 4: Optimised network using 3 base stations

AVAILABILITY ENHANCEMENT

Rain (and other hydrometeors such as snow) severely limits the size of a cell for a required level of system availability, bandwidth and system margin. For example, the rain attenuation on a 4 km path at 41GHz in northern Europe is 3, 10 and 25dB respectively at availabilities of 99, 99.9 and 99.99%. Providing the higher availability levels over path lengths of a few kilometres is very costly in terms of transmitter power. While many users may find a lower availability (for example 99.7%) acceptable, a relatively low cost solution to providing users with higher availability is desirable.

Noting that during non-rainy conditions, many users are likely to have line-of-sight to more than one base station, base station diversity has been investigated, and is being implemented, within the EMBRACE project. (Results from the optimiser have shown that a network can be designed to provide a high proportion of users with a diversity option, without significantly increasing the cost of the network.) Server diversity allows the system to exploit the inhomogeneity of intense rain cells—intense cores are generally spatially limited, and the deepest signal fades will tend to occur on only one of the paths at any given time. Much of the work has related to the switching and network requirements needed to support diversity, but new propagation results have also been obtained.

A general model for rain diversity (gain and improvement) has been developed using area rain attenuation results derived from a rain radar database. The model takes account of the path lengths (L_{ref} and L_{div} for the reference and diversity paths, respectively) and asymmetry, availability (*%*) and path angle separation (θ). The formulae separate into three terms, representing the symmetric path diversity gain or improvement, a path asymmetry reduction factor, and the path angle separation. For example, diversity gain G is given by:

$$G(L_{ref}, L_{div}, \%, \theta) = G_{symmetric}(L_{ref}, \%) \times h(L_{\max} / L_{\min}) \times S(\theta, L_{\max} / L_{\min})$$

L_{max} and L_{min} are the maximum and minimum, respectively, of L_{ref} and L_{div}. The diversity gain is illustrated in Figure 5 for symmetric paths of various lengths at an availability of 99.7%. The diversity gains increase rapidly with required availability, being twice the values shown in Figure 5 at 99.9% and six times at 99.99% availability.

Measurements from a 42GHz star network in Norway comprising four links with path lengths ranging from 2.4 to 5.6km and path diversity angles from 6 to 65° have been made, and used to test the diversity model. Studies of rain dynamics have also been made in order to develop algorithms for network switching. Maintaining active diversity paths all the time would be wasteful of network capacity; instead a "rain predictor" based on the signal dynamics is used to allocate the network capacity for diversity as and when it is required. Figure 6 shows the fade rate distributions at various threshold levels measured on a 4.9km path from which the switching algorithm has been derived.

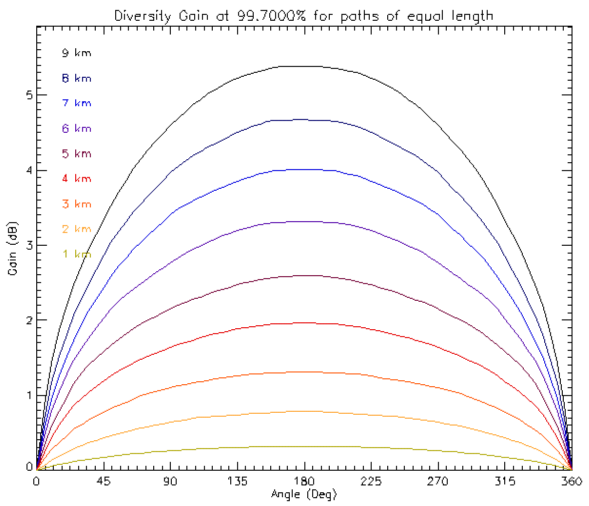

Figure 5: Diversity gain with path angle separation

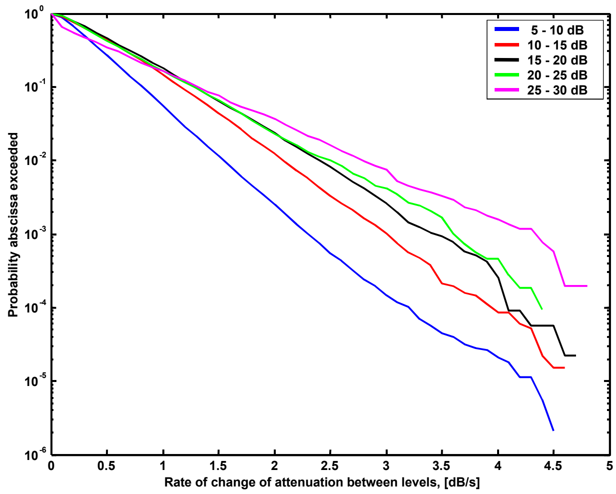

Figure 6: Probability distribution of rain fade rate

PERFORMANCE ENHANCEMENT

The partial obstruction of the propagation path by trees causes rapid fading due to multipath, which has been shown to have a wide correlation bandwidth [2]. Extensive measurements have been made at 40GHz behind trees with various path geometries. In particular, the benefit obtained by using space diversity (two parallel paths separated in space) has been quantified. Figure 7 shows in-leaf tree-fade distributions obtained by averaging 13 sets of measurements with varying diversity antenna separation (29-195 cm). Comparing the single antenna and diversity distributions, it is clear that significant diversity gain is obtainable, particularly at the smaller time percentages (higher availabilites).

In order to confirm these results, a practical demonstration was carried out using antenna diversity and a maximum power combiner. A digital television signal was transmitted during the tests, and the decoded video displayed separately from the two diversity legs, and the combined signal. Figure 8 shows the large variability on the signals from each of the two legs (channels 1 and 2), and the much reduced variability from the combiner. Another measure of the benefit of diversity was given by graphs of diversity improvement. These showed that outage time in the diversity channel was up to 70 times less than in the unprotected channels. The most impressive confirmation of the success of this demonstration however, came from observing the video monitors. Whereas the unprotected systems experienced frequent blackouts from vegetation fades, the protected channel was almost 100% error free.

CONCLUSIONS

The propagation results from the EMBRACE project have shown that, with good design tools and enhancement techniques for overcoming the principal propagation impairments inherent at millimetre-wave frequencies, millimetre-wave wireless access is a viable method for the delivery of broadband services.

ACKNOWLEDGEMENTS

The authors wish to thank many colleagues who contributed to the work reported in this paper, in particular: S. Allen, P. Lindhom, W.D. Miners, A. Paulsen, R. Taplin, I. Usman and M.J. Willis.

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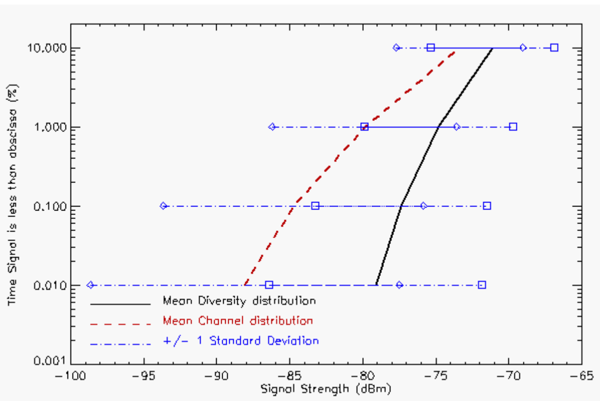

Figure 7: Tree fade distributions from single (red) and diversity (black) antennas

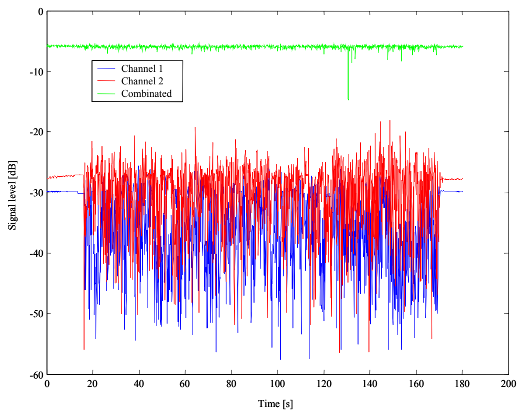

Figure 8: Signal variation in single channels and from diversity combiner (offset)