# IMPROVING PREDICTED COVERAGE ACCURACY IN MACROCELLS BY USE OF MEASUREMENT-BASED PREDICTIONS

**B. Belloul and S. R. Saunders**

**Cellular Design Services Ltd, UK**

**E-mail: B.Belloul@cdseurope.com**

## INTRODUCTION

Measurement-based Prediction (or MbP) is a unique radio propagation process, which increases the accuracy of conventional propagation model predictions by making use of measured data to improve the model predictions around sites. The process accounts for the first and second order statistics of the survey data by including the specific propagation features of terrain, buildings and trees revealed within the data, and encompasses the electromagnetic effects specified by the model. MbP extracts the main features of the slow fading characteristics of the propagation from the measurements and applies these to predict the shadowing across a wider area. The results are used to provide improved predictions for the surveyed site, regardless of which antenna configurations are subsequently used. All cells associated with the site can share the same survey data.

This paper presents the results of an investigation into the performance of MbP compared to a conventional model prediction.

## THE MbP METHODOLOGY

Conventional coverage prediction for mobile radio networks is based on the use of path loss models, such as those described in (1) which are tuned empirically against measurement data at a set of representative sites. Most efforts to improve the accuracy of such models to date have relied on the use of high-resolution data to describe clutter data with greater precision and analysis techniques based on deterministic physical models. While such approaches can yield very good accuracy, the cost of the data and the computing power involved has lead to very little usage of such methods for practical network planning.

The measurement-based prediction approach replaces the use of clutter data with site-specific measurement data, which is often collected anyway in the process of selecting or subsequently optimising the site. MbP thus combines the relative simplicity of conventional empirical or semi-empirical methods in terms of simplicity of use and required computing resources with the added assurance of local measurements in producing predictions as close as possible to reality. This combination allows a more accurate prediction of the path loss in and around an experimental site prior to its deployment and provides network planners with higher confidence in the performance of a particular site or group of sites.

The overall MbP scheme is illustrated in Figure 1. In the first phase of the MbP scheme, measured data, which include accurate measurement locations and signal strength levels, are carefully calibrated and filtered to produce a locally optimised model. The slow fading component of the signal variability is then extracted and its statistical spatial signature is processed in order to map its main features over the whole desired prediction area. By combining the slow fading features of the measured signal, together with the optimised model output and the site information (location, height, transmit power, antenna type, orientation and tilt), it is then possible to generate a very accurate prediction of the complete site coverage. A more detailed description of the MbP process can be found in Belloul and Saunders (2). The application of MbP to in-building UMTS systems design has also been described in (3).

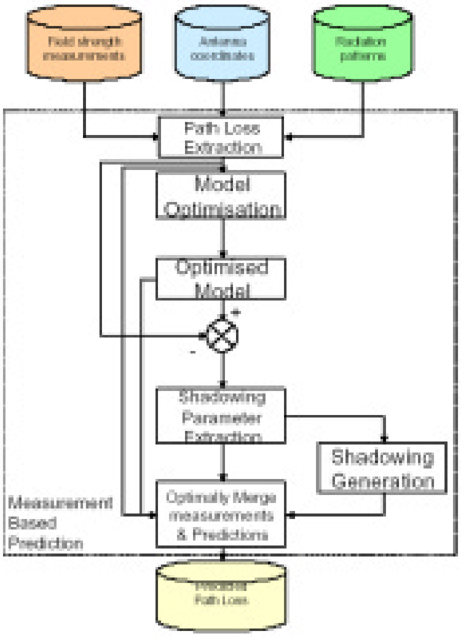

**Figure 1: Measurement-based prediction methodology**

The measurements require thorough processing to ensure their integrity. This processing will depend in detail on the collection system used, but will typically include:

- Removal of the fast fading effects
- Removal of points with very low signal strength where the receiver noise floor will limit accuracy

- Removal of points with high signal strength where the receiver may be operating in a strongly non-linear region
- Adjustment of the recorded power values to account for the accurate calibration of the signals reported by the receiver

The site measurement consists of the transmitter details such as location, height of the radiation centre, power and antenna pattern. In addition, the height of the terrain over the entire prediction area is assumed to be available. Typically, this height would be available at a number of discrete locations at a fixed interval dictated by the terrain data resolution. Greater accuracy may be produced if a classification of clutter into a number of discrete classes is available.

## ANALYSIS METHOD

The analysis was conducted using an extensive drive route data set from which one part was used for running the MbP process (the optimisation set) and the remaining data used for performing the accuracy analysis (the evaluation set). The drive route setting consisted mainly of suburban clutter category set in hilly rural surroundings and hence presented a challenging environment for the analysis.

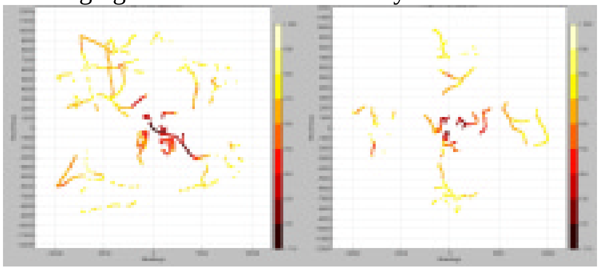
(i) (ii)

**Figure 2 Measurement drive route: (i) is the tuning set and (ii) is the evaluation set. The site is located at the origin and coordinates are in metres**

The approach used to split the data ensured that distinct sets were used for the optimisation and for the evaluation of the prediction accuracy. This approach also meant that no further errors were introduced in the analysis process since the data were collected using the same equipment (transmit and receive) and that these were collected on the same day. Entire contiguous areas, located to the north, east, south and west of the site, were removed from the main drive data, as illustrated in Figure 2. This method of splitting the data set ensured that any potential bias linked to the direction of propagation would be eliminated. Approximately 69% of the drive route was used for the MbP process and the remaining 31% used for the accuracy evaluation. The dynamic range of the measured path loss values in the evaluation was of the same order as the range of the tuning set and ranged between about 110dB and 200dB.

## RESULTS

A local propagation model, based on an empirical COST231 – Hata model, ($^4$) was first tuned using the full data set. Having a locally tuned model is highly optimistic for conventional modelling and would never usually be available in practice. The resulting path losses were then compared with the measured path loss and with the path loss predicted from the local model alone (no MbP).

Figure 3 shows the coverage map when MbP was not applied, and Figure 4 shows the coverage plots resulting from applying MbP to the propagation model.

A similar colour scheme was used for the plots of Figure 3 and Figure 4 in order to illustrate the difference in coverage between the predictions.
This comparison reveals visually the fundamental difference between the conventional model and the MbP optimised prediction. The MbP coverage reveals a variety of effects that were extracted from the measurements which the conventional model could not predict. This is apparent in the centre, to the south and the east of the site, where the clutter type is suburban everywhere so the conventional model is unable to distinguish local clutter effects and thus returns almost circular contour levels.

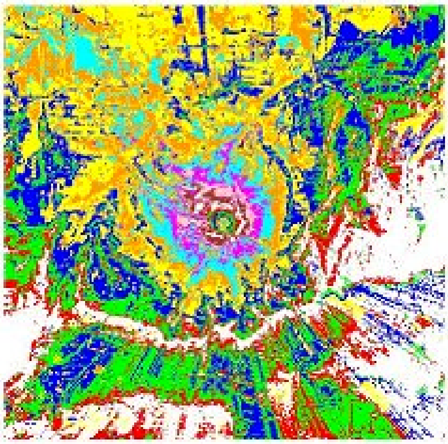

**Figure 3 Coverage prediction obtained without using locally-tuned COST231-Hata model . The area is 20km x 20km wide.**

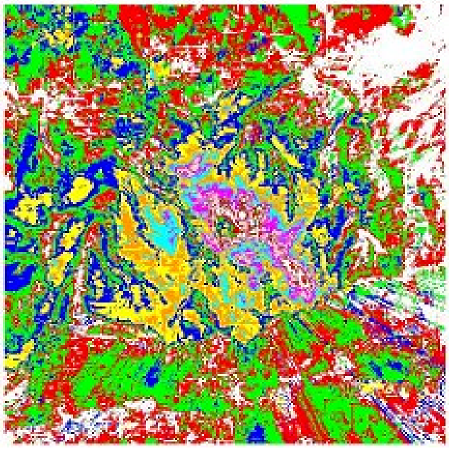

**Figure 4 Coverage plot obtained using Measurement-based Prediction**

## ACCURACY ANALYSIS

When the full data set was used for the evaluation and the tuning (i.e. the analysis is performed on the same measurements used to run MbP), a standard deviation of 3.5 to 4dB for the prediction error is achieved, with a high correlation coefficient (>0.95) between measured and MbP-predicted path losses. This is to be expected, since the MbP predictions use the same data, but this nevertheless illustrates how well the measurements are integrated into the prediction process.

When the evaluation and the optimisation measurement sets are distinct, there is a consistent improvement of the MbP predictions over the conventional model predictions. A first order statistical analysis, consisting of standard deviation, correlation coefficient and mean error, was performed and the corresponding results presented in Table 1.

| | **Results** | |
|---|---|---|
| | *Locally tuned COST 231* | *MbP* |
| **Mean error** | -0.02 dB | -1.16 dB |
| **Standard deviation** | 11.5dB | 7.0dB |
| **Correlation coefficient** | 0.68 | 0.88 |

**Table 1 Results of accuracy evaluation**

This case is representative of the general improvement that MbP brings about to the predicted path loss and by no means represents an isolated case. Even though the original model did not provide a high accuracy initially (11.5dB STD) due to the large variability in the measurements, the MbP process has succeeded in improving the standard deviation by 4.5dB, bringing it down to 7dB, while the correlation coefficient increased from 0.68 to 0.88.

However, these improvements only give a general overview of the gains to be made by using MbP. In order to get a more detailed account of the impact of the improved accuracy on the prediction results, a hit-rate analysis ([5]) of the measured area was performed. The hit rate shows the percentage of locations for which the coverage state at a given path loss level is correctly predicted within the evaluation data set. Results of this investigation are shown in Figure 5. The comparison made is between the MbP prediction and the conventional model tuned for each particular site, both of which are compared against measured values.

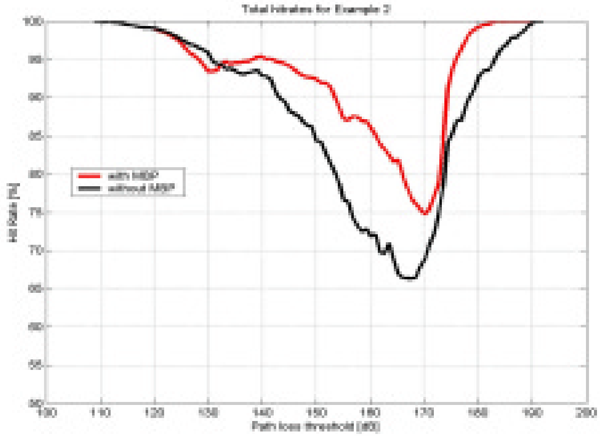

**Figure 5 Total hit rate for predictions made with and without using MbP**

The results show a significant gain made by MbP predictions across the range of measured path loss levels. For some levels (e.g. at 160dB in Figure 5) MbP correctly predicts some 15% more locations than the conventional model, and is correct for over 87% of locations at all threshold levels compared to 73% for the conventional model.

It should be noted that the improvement in hit rate occurs mainly in the 140dB-170dB path loss range. This region would generally correspond to the cell's boundary limits of service and hence the most common region for handover. From a cell planning point of view, it is therefore a critical region in terms of the importance of accurately predicting path losses.

## BENEFITS FROM INCREASED PREDICTION ACCURACY

To illustrate the benefits gained from an increased prediction accuracy of path loss from a network planning perspective, we have examined the challenges of interference management in 3rd Generation systems such as UMTS. Figure 6, for example, shows the theoretical variation of signal strength to interference ratios resulting from two adjacent sites operating on the same frequency channel. In contrast to a simple coverage-limited case, both increases and decreases in path loss from both sites are of importance in determining the system availability, since both affect the carrier-to-interference ratio (or equivalently, the Eb/Io). The fade margin, which must be included in network plans to account for this, is not a simple function, since it depends on, amongst others elements:

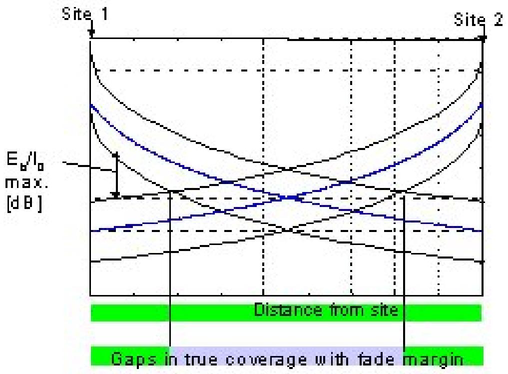

**Figure 6 Variation in Eb/Io resulting from two co-channel sites**

- The correlation of the path loss prediction errors between the two sites, which is in turn affected by the specific terrain and clutter environment around the sites
- The application and settings for soft handover
- The resource management techniques applied in the network
- The distribution of users and services in the area

Nevertheless, the required fade margin increases with the prediction error of the model. For uncorrelated errors between two sites[1] and using the accuracy results shown in Table 1, assuming a prediction standard deviation of 11.5 dB for both sites, the effective variability of the C/I, and consequently the fade margin, in the overlap region would be 16.3 dB (i.e. $11.5 \times 2^{1/2}$) for a 50% confidence network. This figure would increase to 26 dB (1.6 × 16.3 dB) for a 95% confidence network. If this level of margin is simply tolerated by allowing for it in the link budget, a very inefficient, low capacity network design will result.

Taking the same example for illustration, but with an MbP prediction this time, the fade margin, for a 95% confidence network, would drop to 15.8 dB, an overall saving of more than 10 dB over the conventional model prediction.

## CONCLUSION

Results of an investigation into a novel path loss prediction method that utilises measurements at the core of the process shows that the accuracy of the predictions is greatly improved. In addition, the inclusion of a site-specific element in the prediction enhances the confidence in the prediction levels. Observed improvements in the standard deviation are shown to be as high as 4.5dB as illustrated in the example provided and the correlation coefficient showed a significant improvement (0.86, up from 0.68). These improvements are coupled with a noticeable increase in the hit rate across the whole range of measured path loss levels. These improvements have a substantial impact on the confidence with which interference-limited networks, such as UMTS, can be planned, and provide a viable alternative to high-resolution physical models, with reduced data and computing costs.

## REFERENCES

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[1] This is likely to be the case at many locations close to overlap areas between the sites where the paths to the sites are widely separated in angle.