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Making wireless networks deliver

The introduction of third generation mobile telephone systems is resulting in new demands on mobile networks and novel techniques are being developed to improve the efficiency of network planning. After summarising the issues involved, the authors describe here one approach to network planning, using measurement-based prediction.

Introduction

At a time when radio spectrum is a highly valued commodity and where environmental issues are high on the agenda of local planning authorities, it has become vital for network planners to determine the optimum network design to satisfy these demands. Accurately predicting propagation in highly cluttered environments, where local effects are dominant, is not a simple task. Using a measurement-based approach to predict the all-important signal strengths in different locations puts a little 'reality' back into the radio planning process, and provides the planners with more confidence in taking complex effects into account.

Wireless networks in general, and cellular mobile networks in particular, require accurate planning and design in order to use efficiently the allocated radio spectrum. An optimised design also has a positive impact on the environment by minimising the number of sites needed to support the network.

There are two principal difficulties in accurate network design – the ability to predict the exact behaviour of radio signals in the complex local environment (buildings, trees, hills, valleys) and the uncertainty in the way signals travel because of multipath fluctuations (so-called 'fading'). In the early stages of a network design, predictions of the coverage area of each base station are made with the help of a planning tool. This software system has two main components:

- a propagation model, which predicts the loss of power, or path loss, between the base station and the mobile or portable handset
- a system simulator, which uses the path-loss predictions, together with a knowledge of system parameters such as transmit powers and antenna patterns, to predict the received signals and the resulting system performance.

The propagation models applied for macrocell mobile systems are generally empirical[1]. They have a built-in error (generally of the order of 7–10 dB standard deviation – a factor of ten in signal power), accounted for during the network design through a margin added to the overall signal strength calculations to take account of the natural signal fading phenomenon. Any reduction that can be achieved in this error will have a direct and significant impact on the size and performance of the network and hence in both the economics and customer satisfaction of the service.

The challenges of third generation (3G) mobile systems

3G systems, of which the first in Europe entered service in the Isle of Man recently, are based on the wideband code division multiple access (W-CDMA) air interface, known more generally as UMTS (universal mobile telephony system), and make different demands on radio planning to their second-generation (2G) predecessors. They achieve high levels of capacity via intense reuse of the limited spectral resource, with typically only one to three frequency carriers available to a given operator. In such an environment, the quality of the network is profoundly determined by the operator's ability to manage the use and reuse of the spectrum, so interference management is key. Although 2G systems are also interference-limited in high capacity areas, they have an essentially hard constraint on the carrier-to-interference (C/I) ratio which must be achieved, and this can be satisfied by careful frequency planning, with no significant benefit in exceeding the C/I threshold. By contrast, a 1 dB increase in the noise-plus-interference floor in a UMTS system produces a reduction in capacity of around 25% at 50% loading of the call capacity. A greater reduction occurs as loading increases[2]. In the very early stages of UMTS rollout, when loading is low, this will not be so apparent, but will be vital in order to support large numbers of users, or even small numbers of users demanding the high bit-rate services (such as pictorial information – maps, video clips, games screens) which will be essential if UMTS is to provide any benefit over 2G systems.

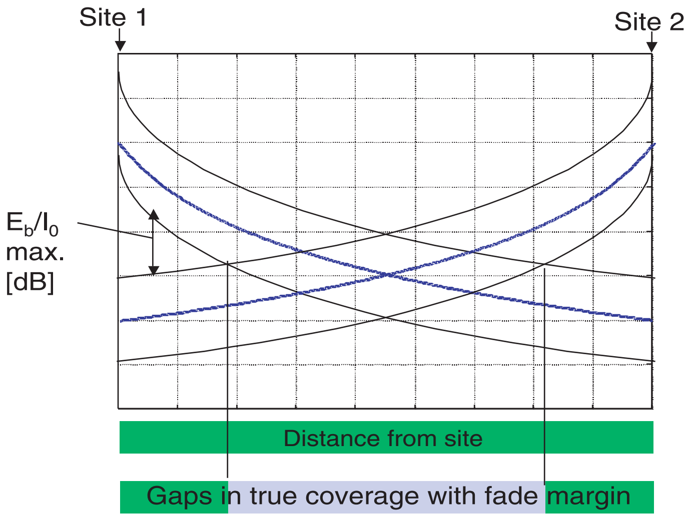

Figure 1: Variation in carrier to interference ratio resulting from two co-channel sites

To illustrate the challenges of interference management, Figure 1 shows the variation of signal strengths resulting from two adjacent sites operating on the same frequency channel. In contrast to a simple coverage-limited case, 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 (C/I). The fade margin, which must be included in network plans to account for this, is not a simple function, since it depends on, amongst other elements:

- 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 a handover from site to site as the customer moves and which is imperceptible to the customer
- the management techniques applied in the network to handle the density and variability of calls
- the distribution of users and services in the area.

The required fade margin increases with the prediction error of the model. For uncorrelated errors between two sites and a prediction standard deviation of 7.8 dB for both sites, the effective variability of C/I, and consequently the fade margin, in the overlap region is 11.0 dB (i.e. 7 × √2) for a 50% confidence network. This figure increases to 17.6 dB (1.6 x 11.0 dB) for a 95% confidence network. Thus, the fade margin for 95% confidence in a given carrier/interference level in this case is 1.6 x 11.0 = 17.6 dB. 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. Network planning techniques thus have to evolve to provide greater planning confidence.

One solution is to use high-resolution geometrical information to describe the environment (buildings, terrain, trees, etc.). This information is then used as input to an electromagnetic simulator which makes direct physical predictions of signal strengths. This approach can yield good accuracy, but requires considerable expenditure on the basic data and on run-time computation. Often, measurements are still needed to verify and 'tune' the results, since electrical parameters of the environment (e.g. the amount of metal in structures, dampness of trees) are rarely known.

An alternative approach to predicting system performance, based directly on extensive measurements (measurement-based prediction or MbP for short) and yielding higher accuracy and reliability than those available using conventional approaches, has been designed by CDS Ltd and its results are described here.

Measurement-based prediction (MbP)

The MbP approach combines the relative simplicity of the semi-empirical methods commonly used in current planning tools 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 2.

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 any fast fading effects – these are generally not important to the signal strength for planning
- 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 antenna, 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. Such data are now widely available from a variety of sources. Greater accuracy may be produced if a classification of clutter into a number of discrete classes is available.

Slow fading

The measured signal levels, the site and terrain information and the antenna radiation pattern are processed to yield measurements of path loss against location. This loss is made up of two components: a distance dependent component, resulting from the bulk characteristics of the propagation medium, and a component which depends on the characteristics of the nearby propagation environment (local clutter). Subtracting the distance dependent part from the total loss yields the latter component, known as shadowing or slow fading.

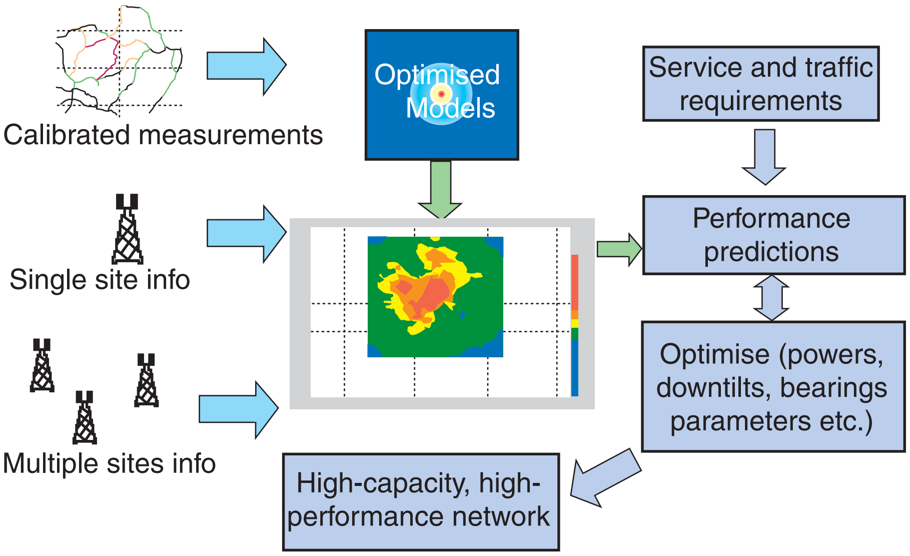

Figure 2: Measurement-based prediction methodology

First- (mean, standard deviation, probability density function ...) and second-order (auto-correlation and cross-correlation) statistics of the shadowing are analysed to yield representative parameters of the test area. Depending on the density of the measurement available for each clutter category within the test area, the shadowing parameters can be estimated for the whole area, or per clutter class.

The derived shadowing parameters are used to generate a set of shadowing predictions for the whole area of interest, and the result is added to the distance- and diffraction-dependant path loss predictions produced by the propagation model for the area. The result then has very similar characteristics to measurements which would have been produced not only at the measurement route but over the whole prediction area. Using a local distance-dependant prediction model also guarantees the output to have zero mean error and a minimised standard deviation, in contrast to a conventional prediction which relies on the physical similarity of the prediction area to the system which was originally used to derive the model.

Finally, the total path-loss predictions (including shadowing) are merged with the original measurements. If the measurements include multiple base stations, the predictions are performed for all of them individually. The joint statistics of the shadowing for all pairs of base stations are extracted, and these are used to ensure that the statistics of the predictions conform to them.

The final output is a set of high-confidence path-loss predictions for every base station site with available measurements. Additional sites can also be added, but these will be subject to similar (but still reduced) errors as using conventional predictions.

Typical results

Measurements of signal strength were obtained around a suburban site. The

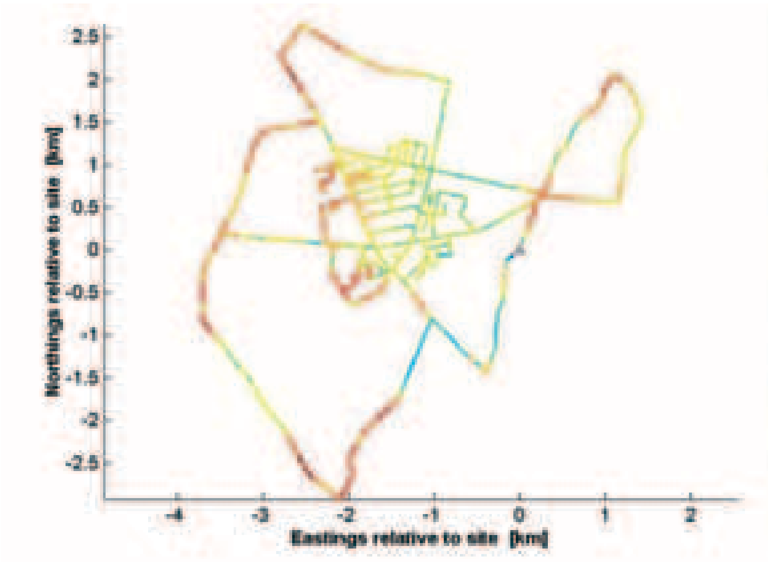

Figure 3: Example showing measured path loss in decibels along a drive route. Colours represent path loss in decibels, and coordinates are in kilometres relative to the site location. The decibel scale is the same as for Figure 4.

corresponding path-loss values were derived from the measurements and the result is shown in Figure 3. The path-loss map, reconstructed from the measurement-based prediction method described above, is shown in Figure 4. The agreement between the measured and predicted path loss, at and around the measurement locations along the drive route gives a very good indication of the accuracy of the results.

A quantitative analysis of the accuracy of the predictions is performed on a subset of the measurement data not used in the MbP process. Very good agreement is obtained between the measurements and the measurement-based predictions as demonstrated by these results. A standard deviation of 5.7 dB was obtained for the MbP prediction. This is better than can be obtained by any standard model (which produced 8.6 dB in this instance). The correlation coefficient between measured and predicted values (a measure of how well the predictions track the variations in measurements over the full dynamic range of the data) has also improved from 0.85 to 0.94. This again is a clear indication of how well MbP can track the smallest variations in path loss, no matter at what distance the receiver is from the base station.

The impact of this accuracy on prediction results is shown in Figure 5, which shows the total hit rate obtained for the measured area. The hit rate[3] shows the percentage of locations for which the state of coverage is correctly predicted. The comparison made in Figure 5 is between the measurement-based prediction technique and a conventional empirical model. The empirical model was tuned for this particular site, which is highly optimistic and would never usually be available in practice. The result is that MbP is correct for over 90% of locations at all threshold levels.

Optimisation

Once the measurement-based prediction of path loss has been created, it can be used at the heart of the optimisation of the system performance. The proposed site parameters are used together with the measurement-based predictions to predict signal strengths over the prediction area. Although the site location (and preferably the antenna heights) should be the same, the other parameters need bear no relationship to the original measurement parameters. An initial measurement using an omni-directional antenna can be used to represent a 3-sector arrangement with any powers, bearings and downtilts without affecting the quality of the predicted path loss.

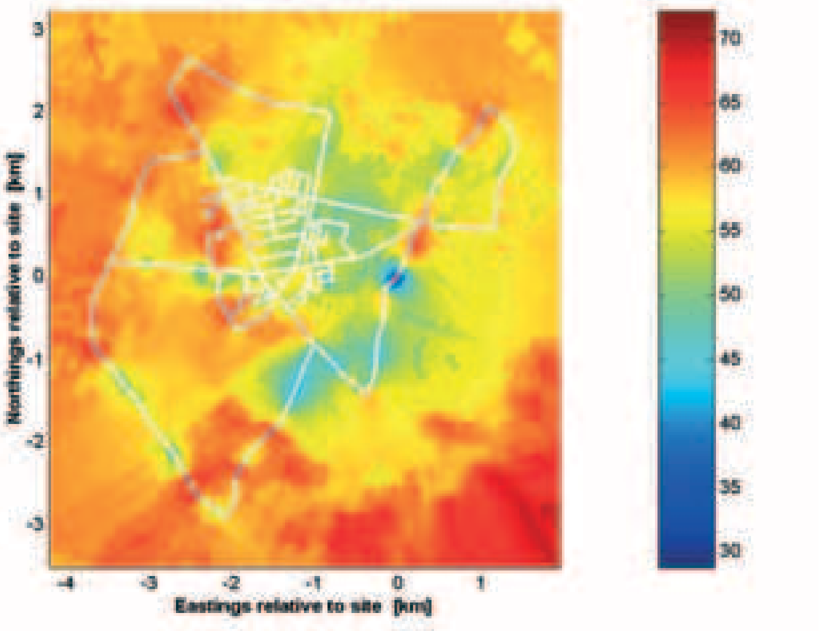

Figure 4: Path-loss map around a suburban site constructed using measurement-based predictions. The outline of the measurement route is shown in white.

The derived signal strengths are used to simulate the system performance, by computing intermediate parameters, such as handover boundaries, carrier-to-interference ratios and coverage probabilities. In sophisticated planning systems, the dynamics of mobile users and of algorithms such as power control and resource management are included in the simulation. If the resulting performance is unacceptable, the site parameters can be modified and used to re-simulate, with no need to recalculate the initial path-loss predictions. This process continues until acceptable system performance is obtained.

The simulation and optimisation process is essentially the same as that used with conventional predictions, except that the MbP provides far greater confidence in the results.

Conclusion

MbP is a major advance with very significant impact for radio network design. The accuracy will of course greatly depend on how many measurements are available. In the extreme case of measurements being available everywhere, MbP can be regarded as identical to reality. If no measurements are available, MbP should be at least as good as the conventional planning process.

The MbP technique has been illustrated with reference to macrocell models, but any model having tuneable parameters can equally be applied. For indoor applications, for example, the model could be a wall and floor factor model, with the parameters to be tuned being the loss per floor and per wall and the path-loss exponent, and the clutter classes being represented by the types of walls and floors penetrated by the direct path. This is particularly important for the emerging environment of wireless local area networks (WLAN) in airports, shopping centres, and buildings. ■

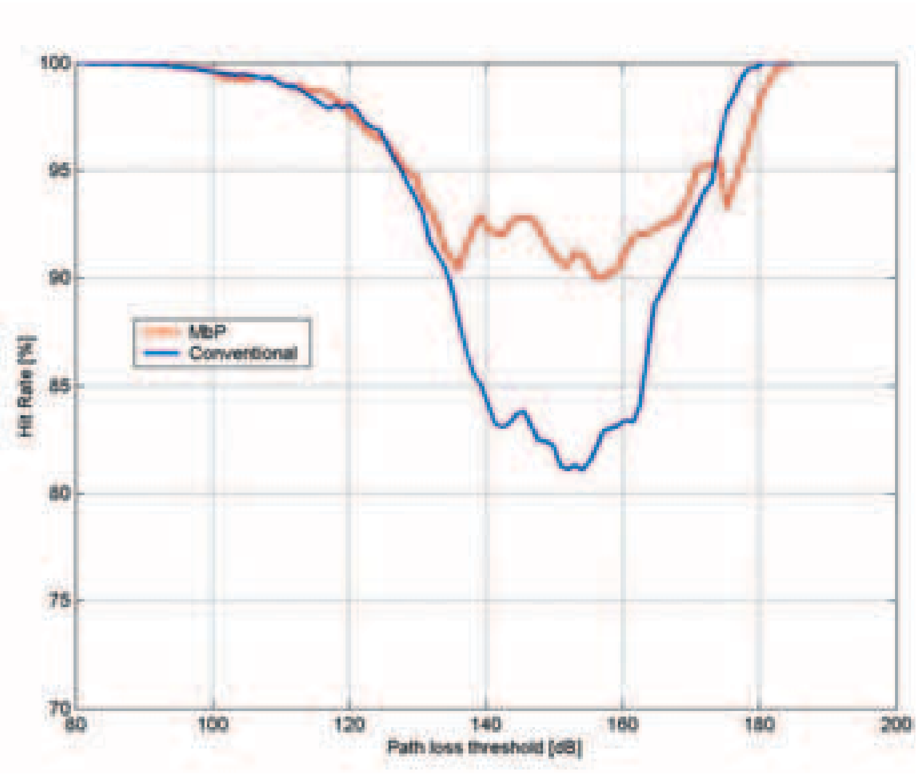

Figure 5: Total hit rates: performance of conventional (blue) v MbP predictions (red)

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