Dynamic W-CDMA Network Planning using Mobile Location

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Abstract: *Location assisted dynamic network planning enables an operator to obtain geographic specific performance estimates and automatically redistribute radio resources. Statistical data is gathered in a database and refreshed periodically to create a dynamic distributed planning tool. Since mobile terminals now measure the actual path loss to each location, the uncertainties associated with propagation modelling and geographic databases are removed.*

Dynamic coverage maps enable basestations to increase (or decrease) their coverage and capacity in areas regularly (or not regularly) visited by subscribers. The basestations also make provision for the additional resources required by high data rate users, possibly through the process of intelligent handover. The concept can be viewed as a fusion of location techniques and network planning. The network subsequently has a powerful self-learning capability and adapts over time to slow variations in the propagation environment or traffic loading conditions.

In this contribution the performance of a number of location techniques is studied and the required location accuracy for dynamic W-CDMA planning determined.

1 Introduction

Telecommunication companies face growing competition and must efficiently deploy and manage a vast array of complex network infrastructure. With the introduction of W-CDMA, there is a strong demand for ubiquitous coverage, with customers wanting services anywhere, anytime. If the radio network is not efficiently designed then the infrastructure cost can rise significantly. The need for new radio network planning techniques that maximise the use of network infrastructure is crucial for successful competition. Also, with the advent of value added service providers, there is a need to develop tools that will enable rapid service deployment. Self-organising techniques are a recent alternative to the more traditional fixed planning approach. These new methods have the ability to organise future wireless networks, making them more efficient, more flexible and more adaptive [1].

Recently, interest has grown in the use of mobile location technologies and support for location based services. This has been driven by the high bandwidth availability in UMTS and obligations laid down by regulators such as the FCC (Federal Communications Committee) and the European Commission. These require the reporting of location from all mobile handset originated emergency calls to an accuracy of 50m [2].

The improvements made in handset technology now offer the operators the potential to develop a huge distributed network-monitoring system. The ability exists to collect and report back location based channel estimates for network optimisation purposes. This leads to the possibility of adapting coverage as a function of change in the network environment or load profile. For example, such methods enable the detection and automatic rectification of coverage problems in the network. As such if a basestation sector was to fail then the radio resource can be automatically reallocated through the use of a lighthouse beam [3]. For subscribers, this is expected to significantly increase their perceived QoS. Financially, optimising the allocation of radio resources will maximise the revenue generated by the operator. In [4] the possibility of using a Situation Aware algorithm to reconfigure network coverage in response to temporal variations in the environment was explored. The Genetic Algorithm (GA) was used to enable network adaption. Indirect estimates of the QoS perceived by mobile users were supplied together with propagation data from a deterministic microcellular propagation prediction tool, Citrus™. The work demonstrated that Situation Awareness (SA) could sustain a near constant outage probability over time, thereby avoiding the expensive cost of manual replanning and re-optimising. The concept is simple and cost-effective, requiring only a server for processing purposes. As a consequence, the basestation transmit powers can be suitably adjusted during off peak hours in order to update the coverage footprint.

In this paper the feasibility of reporting channel estimates (or received signal strength indicators) from mobile stations is explored to develop a distributed and dynamic network planning and optimisation tool. The performance of the chosen location technique is shown to be vital when creating dynamic coverage maps. The impact of positioning error on the field strength error distribution is determined by randomly deploying W-CDMA users in the city centre of Bristol. Error distribution curves are generated from location estimates derived from three positioning techniques. Using this data, the error in the associated dynamic field strength

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map is determined for each location algorithm. The paper is structured as follows: Section 2 provides descriptions of the generic positioning techniques. Each algorithm is then statistically evaluated in section 3. The paper ends by determining the mobile location accuracy required to achieve a given prediction accuracy.

2 Location techniques

The simplest method for locating mobile users is based on cell identification. The advantage of this method is that no calculation is required and accuracy is directly dependent on cell radius. Accuracy requirements are generally dictated by the nature of the location-based services. Generally, for billing services accurate estimates of up to 500m are sufficient. This can be achieved by analysis of signal strength at the basestation. Emergency services require a precision of 50m, which is often provided by GPS (global positioning system). Network based location systems are based on signal strength, angle of arrival (AOA) or time of arrival (ToA) measurements (or some combination).

2.1 Signal strength

Using signal strength measurements from the control channels of several BSs, the various distances between the MS and the BSs can be estimated. Assuming two-dimensional geometry, an omnidirectional BS antenna, and free-space propagation conditions, signal level contours around the BSs are circular. If signal levels from three different BSs are known then the location of the MS can be determined as the unique intersection point of the three circles [5].

Multipath fading and shadowing poses a problem for distance estimation based on signal level. The instantaneous narrowband signal level in GSM can vary by up to 40dB over a distance of only a fraction of the wavelength. In UMTS, signal strength measurements are expected to be more reliable due to the wide bandwidths involved. Signal strength methods can be implemented using mobile assisted or mobile-based methods.

2.2 Angle of arrival

The angle of arrival (AOA) of a signal transmitted by a mobile station and measured at several BSs using an antenna array can be used for positioning. In the absence of a LOS signal component, the antenna array can lock to a reflected signal that may not travel from the MS direction. However, even in the presence of a LOS component, multipath can still interfere with the angle measurement. The accuracy of this method diminishes with increasing distance between the MS and BS [6]. In 3G systems, AOA measurements may be available without the need for additional hardware if adaptive BS antennas (arrays) are widely deployed.

2.3 Time based systems

Signal time of arrival (TOA) measurements, performed either at the BSs or at the MS, can be used for positioning. If the BSs and the MS are fully synchronised, TOA measurements are directly related to the BS-MS distances and three measurements are needed for a unique location. Geometrically, this relates to the intersection of circles centred at the basestation. However, if the network is not synchronised, such as GSM and UMTS FDD networks, the ToA difference (TDoA) measurements are used. Since the hyperbola is a curve of constant time of difference between two basestations, the intersection between two such curves corresponds to the location of a mobile.

2.4 Simulated radio location techniques

AoA techniques require costly antenna arrays at each node and TDoA based systems have unacceptably high synchronisation requirements. However, both techniques are more accurate than signal strength based methods, which are highly sensitive to channel impairments. All three methods are considered in this simulation. The cellular study is performed over a one square kilometre region of central Bristol. The morphology of the area is dense urban, is it also characterised by considerable terrain variations and a high foliage density. A microcellular UMTS W-CDMA FDD network is simulated and the distribution of location errors is presented. A 3-D deterministic ray-tracing tool is used to obtain propagation data (angular and time of flight) for various BS/MS links.

2.4.1 Path-Gain Weighted Centroid (PGWC)

In the PGWC method the MS position is calculated as the average (centroid) of the positions of N visible basestations [7].

Multipath effects are assumed to be averaged out and are not considered in this study. A modification is brought to the original equation so that it can be applied to a deterministic propagation model:

$$(x', y') = \sum_{i=1}^{N} \frac{w_i}{w_T}(x_i, y_i) \qquad (1)$$

Where g_i represents the path gain between the MS and BS, $w_i = 1/g_i$ and $w_T = \sum w_i$. In the eventuality that the MS can track only one BS (N=1), the PGWC reduces to a cell ID.

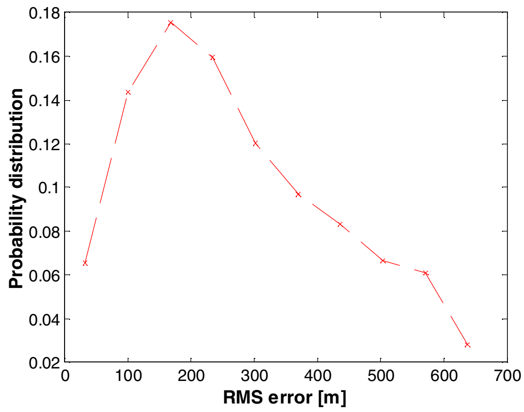

Figure 1. PDF curve for PGWC algorithm

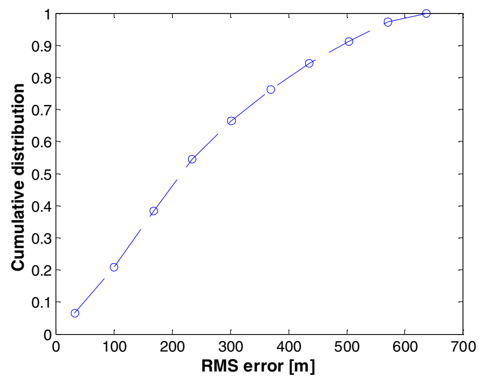

Figure 2. CDF curve for PGWC algorithm

The root mean square (RMS) is used as a measure of accuracy for the location algorithm:

$$RMS = \sqrt{(x-\hat{x})^2 + (y-\hat{y})^2} \qquad (2)$$

Where $\hat{x}, \hat{y}$ are the x and y estimated mobile co-ordinate. Figure 1 shows the error PDF for the PGWC algorithm, which appears to fit a Rayleigh distribution with a mean μ = 280m and a standard deviation σ = 160m.

2.4.2 TDoA static positioning algorithm

The forward link time difference of arrival (TDoA) method is implemented in this section [8].

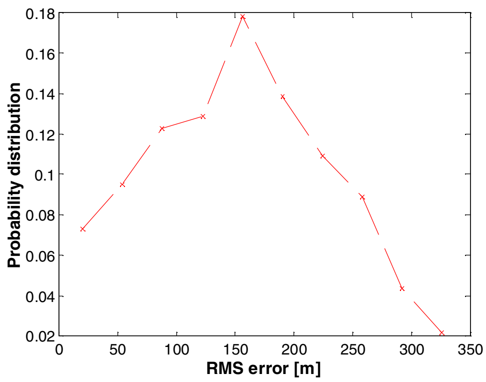

Figure 3. PDF curve for TDoA algorithm

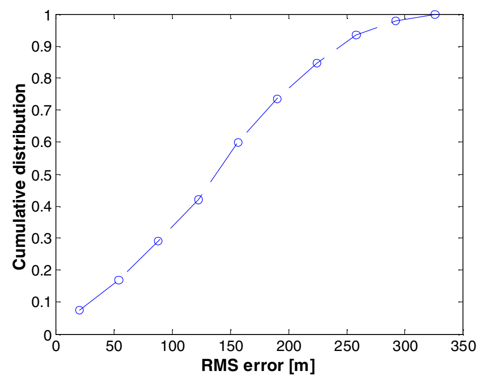

Figure 4. CDF curve for TDoA algorithm

The requirement for the mobile is to detect at least three pilots. The relative arrival times of signals from the basestations are then used to form hyperboloids. The hyperboloid equation is solved using a closed form of Fang's algorithm [9].The derived results do not take the synchronisation problem into account. NLOS measurements are however considered and they are seen to bias the true range substantially, causing inaccurate location estimates. Figure 3 illustrates the probability distribution function of the algorithm. The mean is estimated to be μ =154m and the standard deviation σ = 78m.

2.4.3 AoA static positioning algorithm

Assuming 2D geometry as illustrated in Figure 5 together with angle of arrival measurements from two basestations BS1, BS2 with co-ordinates (x_1,y_1) and (x_2,y_2), a unique location (x_0,y_0) can be estimated. The quadratic equation (3) is easily derived:

$$\left[1+\frac{1}{\tan^2\xi}\right]y_0^2+\left[\left(\frac{-2y_1}{\tan^2\xi}\right)-2y_1\right]y_0+\left[\left(\frac{y_1^2}{\tan^2\xi}\right)+y_1^2-\left(\frac{\sin^2(\beta')d_0}{\sin^2\phi}\right)\right]=0 \qquad (3)$$

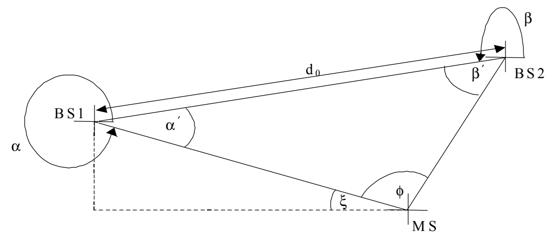

Figure 5. 2D geometry layout for location estimation

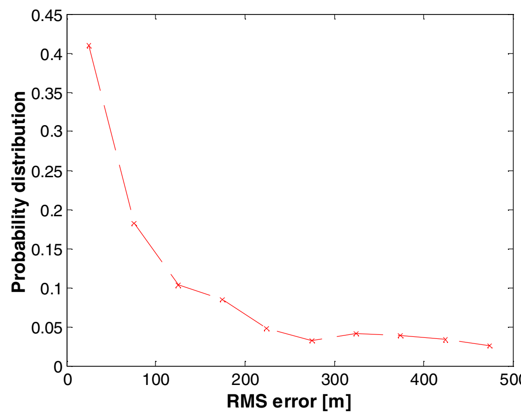

Figure 6. PDF curve for AoA algorithm

Figure 6 illustrates the probability distribution function of the algorithm. The mean error is evaluated to be μ =124m and the standard deviation σ = 129m.

3 Adaptive Planning

Location aided planning allows a Situation Awareness (SA) basestation to optimise radio resource allocation and augment the radio resource management (RRM) capability of the network. However, before developing algorithms that can exploit dynamic coverage maps, it is important to evaluate the impact of mobile location error on prediction accuracy.

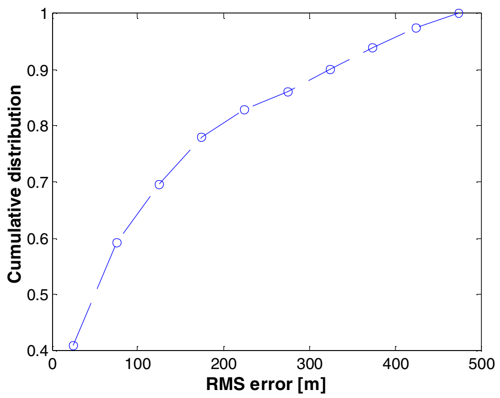

Figure 7. CDF curve for AoA algorithm

3.1 Propagation grid accuracy and terminal issues

The accuracy of propagation models varies greatly. Generally, the very best propagation models achieve a standard deviation of around 8-15dB. Significant errors and variations can arise just months after network rollout due to geographic variations. The propagation errors can rise significantly to a point where the original fixed plan is no longer appropriate. For dynamic mapping it is important that the standard deviation is at least comparable to that of fixed prediction methods.

Path loss can be derived from RSSI measurements, however this is not independent of the mobile terminal. Received field strength (Vm^{-1}) is a more reliable parameter. In order to normalise the path loss measurements derived from various mobile terminals (PDAs, mobile phones, etc.), it is important to consider the type of antennas involved. As such, in the context of Situation Awareness and dynamic planning, it is suggested that handset antenna parameters (such as effective area and gain) be transmitted to the basestation on a control channel. Alternatively, a unique database of antenna characteristics for each mobile could be stored by the operator.

3.2 Coverage grid

The selection of a location technique for location aided planning (LAP) can be based on two criteria, namely the predictive error bound and the spatial properties of the method. Errors in positioning estimates translate to a wrong estimation of the signal level at each pixel co-ordinate in the dynamic map. It is interesting to note that propagation models lead to correct locations but erroneous field predictions. Dynamic maps result in correct field predictions but erroneous locations. As a result, imprecise locations may prevent the valid use of dynamic maps.

3.2.1 Approach to estimating error bound of field strength prediction of dynamic maps

A Monte Carlo simulation approach is used to estimate the mean and standard deviation of the predictive error associated with each radiolocation technique. The probability distribution function of each method is used to generate positioning errors, r_0, which are associated with the exact location of randomly deployed mobiles. The field strength error is calculated as the difference between the field strength at the true location and that at a location displaced by r_0. The process is repeated many times until an error distribution curve is generated.

3.2.2 Dynamic maps based on different location techniques

Results from the PGWC algorithm suggest that this location technique is not well suited to an urban environment where path gain at a particular location varies considerably. The mean positioning error is more than 250m and the resulting spatial properties are poor, as illustrated in Figure 8. It can be observed with the PGWC algorithm that there is a clustering of estimates around the basestations.

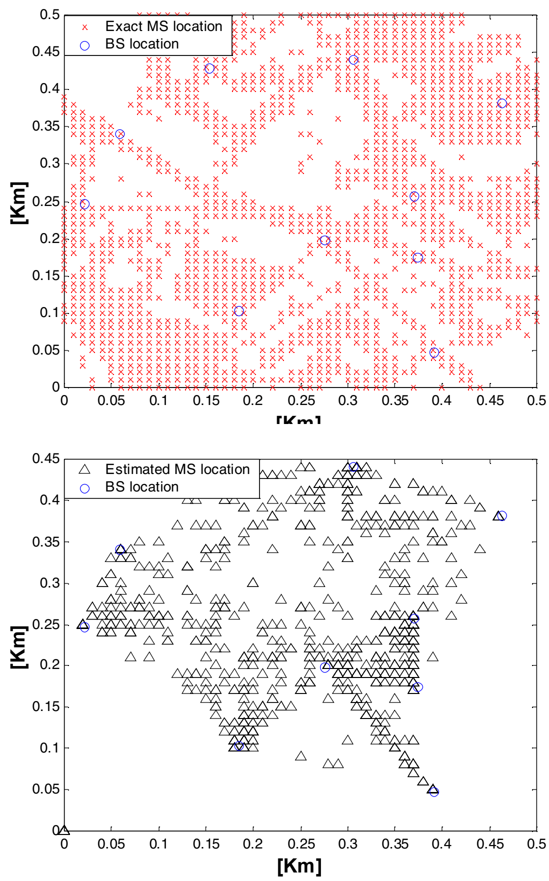

Figure 8: Total spread of possible outdoor mobile locations in study area and estimated fixes using PGWC

The mean field strength prediction error μ and standard deviation σ for each technique is summarised in table 1. As a means of comparison, location errors were also simulated using a Gaussian distribution with μ=10m and σ =10m. Based on simulation results, error statistics (Figure 12) for any position error is generated. From Figure 12 it can be deduced that in order to achieve a standard deviation better than 15dB in field strength prediction, a positioning accuracy better than 100m is required. Given a 50m accuracy (emergency services specification), the standard deviation in the test environment is 7dB.

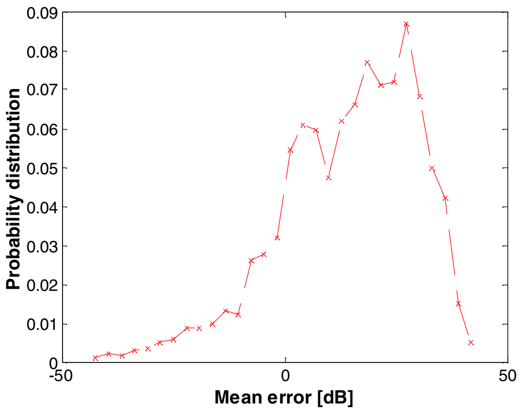

Figure 9: PDF of field strength error with PGWC

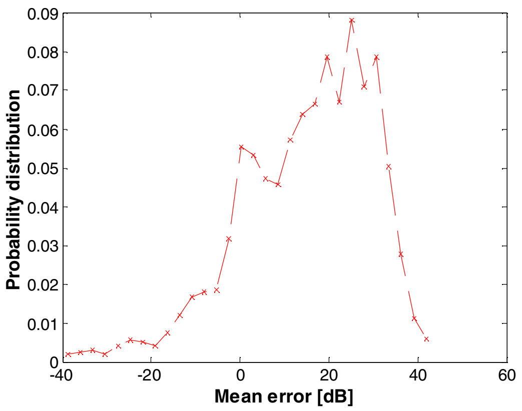

Figure 10: PDF of field strength error with TDoA

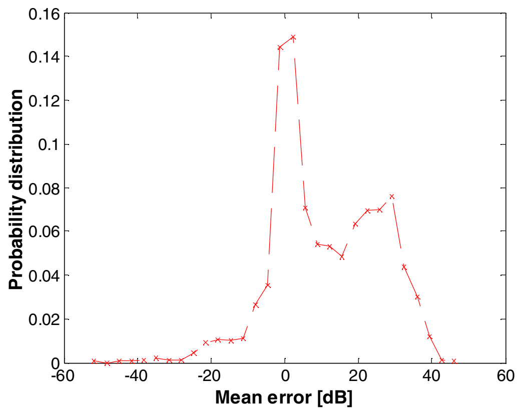

Figure 11: PDF of field strength error with AoA

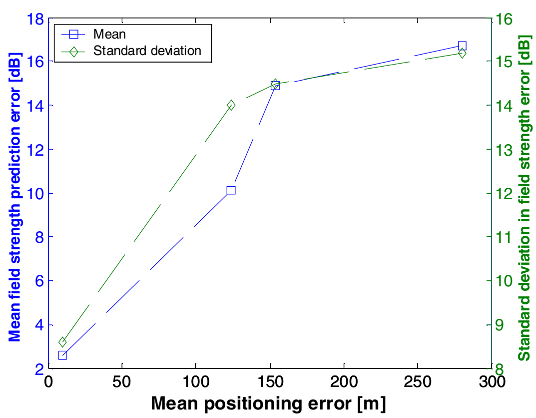

Figure 12: Field strength prediction error

Technique	μ (dB)	σ (dB)
PGWC	16.7	15.2
TDoA	14.9	14.5
AoA	10.1	14
Gaussian	2.6	8.6

Table 1: Error distribution in field strength estimates

4 Conclusions

Adaptive coverage maps have been introduced as a method to relax planning requirements and enhance future W-CDMA networks. This paper has discussed how adaptive planning maps could be generated and explored the location accuracies required for a given field strength prediction accuracy. The paper has highlighted the need for certain UE parameters to be specified. More importantly, using detailed propagation models and Monte Carlo simulation methods, it has been shown that for adaptive coverage maps to outperform commercial fixed planning tools, a mobile terminal location accuracy of at least 100m is required. Ideally, for best performance this error should be reduced to 10m. A key advantage of dynamic mapping is the ability to update the field strength predictions over time and therefore adapt to temporal or seasonal changes in the environmental. This adaption maximises the revenue potential of a W-CDMA network.

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