Cheung, J. C. S., Beach, M. A., & Chard, S. G. (1993). Propagation measurements to support third generation mobile radio network planning. 61 - 64. 10.1109/VETEC.1993.507011

Propagation measurements to support third generation mobile radio network planning

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Abstract-In this paper, we briefly describe the features of the radio network planning tool proposed by the European RACE Advanced Cell Planning Methods and Tools for Third Generation Mobile Radio Systems (PLATON) project. Some results of the propagation measurements conducted to support the planning tool are reported, and their impact on radio network planning and the design of handoff parameters are discussed.

I. INTRODUCTION

Recent introduction of the second generation mobile radio systems such as the GSM in Europe and IS-54 in the USA improve the system capacity and service quality compared to the first generation systems. However, second generation systems are designed with speech-oriented services in mind. Consequently, only a limited number of messaging and data services are supported. Research into the next generation personal communication systems are gathering pace. In Europe, the term Universal Mobile Telephone System (UMTS) is used to signify the revolutionary aspects of the proposed third generation mobile radio system. The primary target of UMTS is to provide a wide variety of high quality telecommunication services ranging from low bit rate speech, video transmission to high data rate file transfer up to a potential bit rate of 2Mb/s for a large population of users. In order to support the multitude of teleservices to a large user base, careful radio network planning is essential to ensure an optimum utilisation of the limited communication resources.

In the light of the requirement of sophisticated network planning, phase two of Research into Advanced Communications in Europe (RACE II) has commissioned the PLATON project to study the network planning aspects for third generation mobile radio systems. The PLATON consortium consists of Télédiffussion de France C2R, France; National Technical University of Athens, Greece; University of Bristol, UK; AT&T Network Systems UK Ltd., UK; Centro de Estudos de Telecommunicaçõs, Portugal and Dassault Automatismes et Télécommunications, France. In this paper, the progress of the PLATON project is described and the propagation work carried out in University of Bristol to support the development of the planning tool is reported. In Section II, an overview of the proposed planning tool is given where its capabilities are compared and contrasted with existing network planning tools. The propagation experiments and measurement results are described in Section III. The impacts of the radio propagation aspects on network planning is discussed in Section IV. The last section summarises the paper and describes future work of PLATON.

II. THE PLATON PLANNING TOOL

Existing network planning tools require the system planner to specify the cell site (base station) locations and the planning tool predicts the average signal strength, coverage area and interference level according to some propagation models such as the Hata-Okumura model [1] for macrocells and the Walfisch model [2] for microcells. Based on the information obtained, the planning tool may also produce other objective quality measures such as bit error rate, call blocking probabilities, etc. This approach works well for systems where the primary service is speech transmission. However, as more sophisticated services are proposed for the next generation personal communication systems, the simple signal level and bit error rate prediction approach may not be adequate. For example, a bit error rate of 10^{-3} is acceptable for speech transmission but it gives poor picture quality for video telephony. The PLATON planning tool goes a step further by incorporating user perceived qualities into consideration. Secondly, the PLATON planning tool attempts to take a radical approach to planning by employing "synthesis" techniques. The deployment of "synthesis" technique enables the system planner to perform *forward* planning whereby planners specify parameters such as teleservices, quality of service requirements, expected traffic, etc. The planning tool will then produce a potential network layout based on the inputs and other stored information such as terrain databases, cell topographies and propagation models. Associated with the network layouts are parameters such as cell site characteristics, i.e., transmit power, base station antenna heights, and other useful parameters such as frequency management, etc. A simplified block diagram of the proposed planning tool is shown in Fig. 1. Although we anticipate that the planning tool will primarily be used for forward planning, it will also incorporate features to allow more conventional *backward* planning where the performance of an existing system is evaluated given the location of cell sites. This feature is essential not only to provide performance evaluation for existing systems, it also provide a means to validate the forward planning proposed by the planning tool. By providing both forward and backward planning capability within a single tool, network planning can be optimised by going through an iterative cycle of modification of cell sites characteristics and evaluation of system performance to achieve the required performance objective.

0-7803-1266-x/93/$3.00

Another feature of the PLATON planning tool is the hierarchical planning it will employ for network evolution. It is anticipated that radio coverage will initially be achieved by deployment of macrocells. As more capacity and better quality are needed, microcells and eventually picocells will be used. The PLATON planning tool supports network evolution by cell splitting and site engineering such as the use directional antennas, beam steering and using buildings as obstacles to confine radio coverage. Consequently, propagation models ranging from conventional macrocells to picocells are required to support accurate network planning

III. PROPAGATION EXPERIMENTS

To achieve the high penetration rate and service quality aimed for by UMTS, it is expected that microcells will be widely deployed to obtain the capacity required. Preliminary studies show that microcell propagation characteristics differ from fourth-power decay characteristic experienced in conventional macrocellular environments. Consequently, more data is required to establish propagation models for the planning tool. Moreover, the deployment of microcells result in more handoffs when the mobile roams from cell to cell. Consequently, proper design of handoff parameters in microcell is crucial to network planning. These parameters can only be evaluated with accurate channel models.

Our measurements were performed at 1.87GHz, just below the lower allocated frequency band of Future Public Land Mobile Telephone System (FPLMTS), namely 1885MHz to 2025MHz. The measurement sites were carefully chosen to represent possible environments where UMTS will operate. They included street microcells with different base station antenna heights and indoor office areas. In this paper, we present some typical results obtained in Park Street of Bristol, which represents a typical outdoor microcellular environment. A map of the measurement locations is included in Fig. 2. Park Street is a busy road with heavy traffic and shops on both sides. It consists of a typical canyon-like street structure flanked on both sides with three-storey buildings located on a slope where the height difference was about 30m for a 400m stretch of road. The base station was located at the top, middle and bottom of the road as shown in Fig. 2.

The most widely used formula for propagation path loss prediction was developed by Hata [1] for macrocells. Without going into the details of the model, we substitute the required parameters, such as the base station antenna height ($h_b = 7.5\text{m}$), mobile station antenna height ($h_m = 1.6\text{m}$), operating frequency ($f_c = 1.87\text{GHz}$) into his path loss equation, we have

$$L_p(dB) = 28.8 + 39.1\log_{10} d \tag{1}$$

where the distance d is expressed in metres. Microcell propagation models have been proposed in COST231 [2]. The Walfisch-Ikegami model provides path loss prediction for frequency range of 800MHz to 2GHz. The BS antenna height is assumed to be in the range of 4m to 50m, while the MS antenna is between 1m to 3m. The model provides better results when the BS antenna is mounted above the mean roof top height of surrounding buildings. The Walfisch-Ikegami model divides prediction into LOS and non-LOS cases. For LOS case, the path loss is expressed as

$$L_p(dB) = 42.6 + 26\log_{10} d + 20\log_{10} f_c \tag{2}$$

Substitute $f_c = 1.87\text{GHz}$ and convert d from kilometres to metres, (2) can be simplified to

$$L_p(dB) = 30.0 + 26\log_{10} d \tag{3}$$

In the following discussion, we compare our measurement results with the prediction given by (1) and (3). Moreover, we will discuss the applicability of single-slope and dual-slope models for microcell propagation predictions.

For the single slope model we assume that the path loss can be expressed as

$$L_p(dB) = L_0 + 10n\log_{10}(d / d_0) \tag{4}$$

where L_0 is the path loss at the reference distance d_0, and n is the path loss exponent (or power decay factor). For the dual slope model, we use

$$\begin{aligned} L_{p1}(dB) &= L_0 + 10n_1\log_{10}(d / d_0) && \text{for } d \le d_1 \\ L_{p2}(dB) &= [L_{p1}]_{d=d_1} + 10n_2\log_{10}(d / d_1) && \text{for } d > d_1 \end{aligned} \tag{5}$$

where L_{p1} and L_{p2} are the path loss for $d \le d_1$ and $d > d_1$, respectively. The path loss exponents before and after the break point d_1 are n_1 and n_2, respectively.

Fig. 3 shows the propagation path loss characteristics for Park Street for a transmitter antenna height of 7.5m while the mobile antenna height was set at 1.6m. The base station (BS1) was placed at the top of Park Street as shown in Fig. 2 while the MS travelled down the hill towards BS3. The measurements were repeated for different antenna heights: 5.0m, and 9.5m. These heights corresponded to below roof top to typical lamp post heights. We noticed that changes in the antenna height did not have significant effects on the path loss characteristics. As seen in Fig. 3, the path loss resembles the dual-slope path loss model. We fit the measured data to the single-slope and dual-slope model. For the single-slope model, a path loss exponent of 2.9 was obtained with a standard error of 8.58dB. This error represented the difference between the regression line and the measured data. It can be considered as the variation caused by localised terrain that resulted in the so called shadowing effect. For the dual-slope model, path loss exponents of 1.84 and 23.5 were obtained before and after the break point at 445m. The corresponding standard errors were 4.0dB and 2.46dB for the first and second slopes, respectively. The reduction in the standard error suggested that a two path model was more suitable to characterise path loss in microcellular environments. Once the MS moved past Unity Street, the signal dropped rapidly as the direct LOS component was blocked by surrounding buildings. The decay factor for the second slope was much larger than that encountered in conventional macro-cellular environments where elevated BS antennas are used. This large increase in path loss exponent was also reported by Schilling et.al. [3] for their measurements in New York. In order to compare the path loss exponent where the LOS component was present, our analysis was then limited to the first 400m from BS1. Typical path loss exponents were $n = 2.38$, $n_1 = 1.19$ and $n_2 = 2.93$, with a break point at around 55m from the BS. Therefore, the low elevation of BS with BS height comparable with the mean roof top heights of the surrounding buildings provide a localised coverage and caused a significant reduction of the received signal level when the LOS component was blocked. The path loss predicted by the Hata's model [1] is also included in Fig. 3. It is obvious that Hata's model predicts a significantly larger path loss than those occur in typical microcellular environments since no LOS component is accounted for in the model. The Walfisch-Ikegami model predicts a path loss exponent of 2.6 for the LOS case. This is consistent with the measurement results. However, the applicability of the dual-slope model and the extension of the model to cover prediction for below mean roof top antenna need to be considered.

We then moved the BS to two different locations on Park Street and repeated the experiments. The BS was positioned at the junction between Great George Street and Park Street (BS2), and opposite Unity Street (BS3) as shown in Fig. 2. Once again, we did not notice significant changes in the received signal level due to changes in antenna height. Typical signal path loss profiles for different BS locations are shown in Fig. 4, where the BS antenna was set to 7.5m. Since the path loss profiles for different antenna locations followed similar trends, it suggested that the effect of local scatterers such as building and road junctions had a significant effect in determining the propagation characteristics. Consequently, the knowledge of the size, location and material of buildings and the position and width of roads may be useful in cell planning process, especially if analytical tools like ray tracing are employed.

IV. IMPACT ON RADIO NETWORK PLANNING

Armed with the results obtained with three different BS locations on Park Street, we now discuss the implication of propagation on cell planning. One of the most important aspects for efficient mobile communication is the correct implementation of handoff between base stations. Recently, Qualcomm [4] introduced a technique called soft handoff where the MS maintains communication links to more than one BS in the handoff region and combines the signal in order to improve communications quality. This method trades the system capacity and network signalling requirements with quality of the communication link. Consequently, soft handoff has to be implemented correctly to obtain good effect. We now consider a simple soft handoff scenario to illustrate the importance of soft handoff in cell planning.

Suppose that Park Street is served by two base stations BS1 and BS3 as shown in Fig. 2, and the soft handoff threshold levels are set at path loss levels of −86dB and −80dB[*] . Let us consider that the MS starts at BS1 and moves towards BS3, the call is initially handled by BS1. Soft handoff commences when the received signal level from BS3 exceeds the 'add threshold' (−80dB) and stays above it for a pre-determined time delay. This time delay is essential to avoid the initialisation of a soft handoff in response to fast fading. As we can see from Fig. 4, the MS communicates with both BSs at around 100m from BS1. It continues to maintain links with both BS1 and BS3 until the received signal from BS1 falls below the 'drop threshold' (−86dB) and stays below it for more than a time delay as shown. This occurs at around 240m from BS1. After this point the call is handed over to BS3. Even though the received signal from BS1 goes above −86dB the link between the MS and BS1 is not re-established since the signal does not exceed the add threshold. Following the above argument, the MS engages in soft handoff for around 140m. If we consider the range of coverage to be the area in which the received signal level is above the lower soft handoff threshold, then BS1 will have a range of around 880m (assuming coverage is symmetrical about BS1), whilst BS2 has a coverage range of 460m as shown in Fig. 4. Since each cell will have two handoff regions on either side of the base station, the MS engages in soft handoff in a large proportion of its connect time. This works out to be 32% for the BS1 cell and 60.8% for the BS3 cell. To get round this problem, we can reduce the width of the soft handoff threshold hysteresis. However, this approach has to be carried out carefully because too small a threshold hysteresis will revert us to the ping-ponging effect of conventional (hard) handoff and a possible increase in the call dropping probability. Alternatively, we can increase the distance separation between BS1 and BS3. This method reduces the proportion of time in which the MS engages in soft handoff. However, the enlarged cell size may not support the capacity required and leads to an increase in the transmit power to provide the required coverage. Wideband measurements to study the effects of soft handoff can be found in [5]

It is not possible to draw a firm conclusion on the effect of soft handoff on the system performance because it depends on the air interface technique employed in the next generation system. In Europe, this is likely to be either time division multiple access (TDMA) or code division multiple access (CDMA) which are studied by other projects within RACE and the LINK programme within UK [6]. For a CDMA system, the deployment of soft handoff may increase the system capacity since the transmit power can be reduced due to the diversity gain obtained with soft handoff. Since CDMA is an interference limited system, reduction in the transmit power reduces the interference to other users, thus resulting in a net gain in capacity. For a TDMA system, multiple channels or time slots must be used to support soft handoff. Consequently, system capacity will be reduced proportionally to the number of users engaged in soft handoff. The network signalling load will be increased for either air interface technique because the call is handled by more than one base station during soft handoff.

V. CONCLUSION

In summary, we have highlighted the need of a sophisticated network planning tool for the next generation mobile radio system and discussed the proposed PLATON planning tool and its salient features. Moreover, we presented some selected narrowband path loss propagation results for typical UMTS environments. It was found that the dual-slope model provided a better fit to microcell propagation results. However, environments with LOS and without LOS have to be considered separately in order to minimise the error in the model. Owing to the low antenna elevation, localised structures such as buildings and roads have a large influence in the propagation condition. Therefore, detailed description of the local environment may be required in order to improve the accuracy of cell planning. Finally, we highlighted the implication of

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[*] *The 6dB hysteresis window was chosen arbitrary to illustrate the impact of soft handoff on network planning.*

propagation on cell planning where careful design of handoff regions and handoff parameters are essential to the reliability of the communication link and the network capacity.

The work of University of Bristol within RACE PLATON will concentrate on the soft handoff aspects for third generation UMTS operating in microcellular environments. Moreover, study of building material characterisation will be carried out to support techniques such as ray tracing in order to provide more accurate propagation data for cell planning.

ACKNOWLEDGMENTS

The work of this paper is supported by the Commission of European Community under the RACE PLATON project (RACE II R2007). We would like to express our gratitude to Mr. Bob Butler and Mr. Michael Penney of the Faculty of Engineering of University of Bristol for equipping the vehicle for our experiment. We would also like to thank Mr. Micael Weber and Mr Thierry Balouka from INT Paris for their help in our field trials.

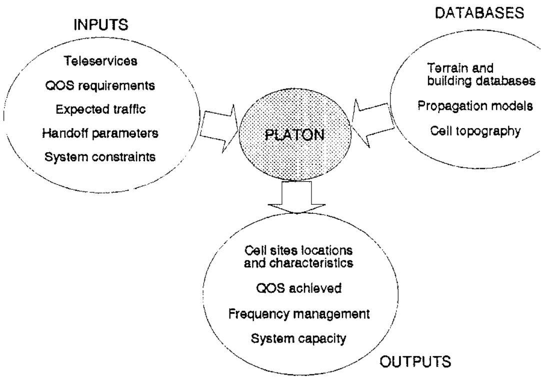

Fig. 1: The PLATON planning tool.

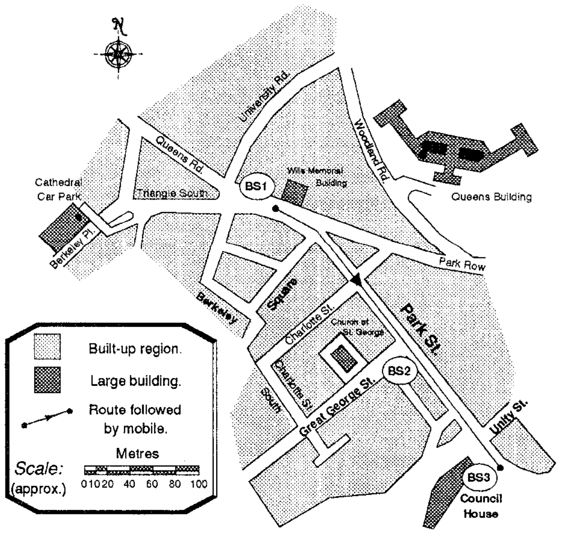

Fig. 2: Map of measurement sites and base station locations.

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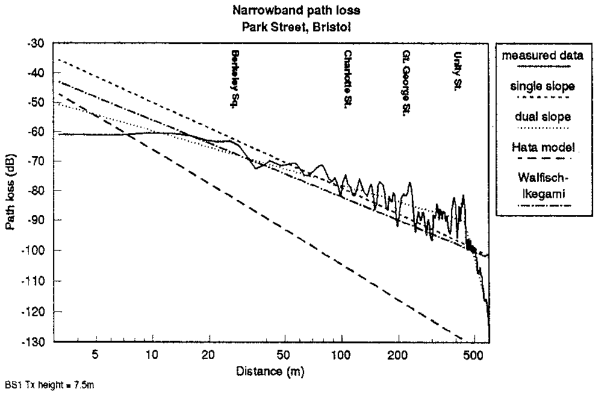

Fig. 3: Narrowband path loss characteristics in Park Street, Bristol.

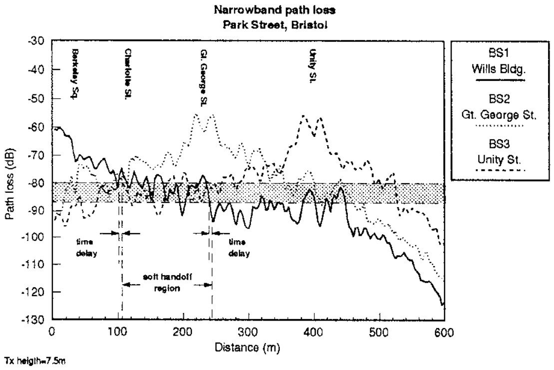

Fig. 4: An example of soft handoff scenario in Park Street, Bristol.