Modelling of Building Height Interference Dependence in UMTS

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***Abstract* — This paper studies the interference dependence in UMTS-FDD with buildings height. An interference model was developed and implemented in a simulator. This model calculates intra- and inter-cell interferences, in DL and UL. The results show that the interference has its higher value in the case of rooms directly facing outdoors. The results also show that interference has a different trend when the analysis is performed in terms of NLoS and LoS. The main conclusion is that the higher the MT is in the building, the higher the interference will be.**

I. Introduction

Since the last decade, studies in interference have been growing, because capacity in UMTS is limited by interference, thus, its evaluation is one of the fundamental procedures for UMTS radio network planning. In radio network planning, the environment cannot be neglected, and planning tools usually provide only outdoor coverage predictions. However, mobile phones are used more and more in indoor environments, and customers demand a good coverage and quality of service. Planning techniques estimate the path loss from the Base Station (BS) to the centre of the street where Mobile Terminals (MTs) are assumed to be, plus the attenuation associated to building penetration. Building construction characteristics and city morphology have a strong impact on propagation characteristics, which leads to a difficult task on the correct estimation of extra signal attenuation associated to building penetration, or on the prediction extracted from measurement campaigns. In [1] and [2] this subject is addressed.

In UMTS operating in FDD, interference happens mainly in between MT and BS, due to its nature (i.e., interference in between MTs, or BSs, does not need to be accounted for). The total interference experienced by an MT is composed of two components: intra- and inter-cells. Intra-cell interference is created within a cell, caused by MTs or the BS of that cell; inter-cell interference is caused by MTs, or BSs, out of the cell under study.

In [3], [4] and [5], models for intra-cell interference in UL are presented, which take perfect power control into account, i.e., signals arriving at the BS have the same power. In [3], the model addresses the inter-cell case, accounting for the number of users, the service used, and the target equivalent Signal-to-Noise Ratio (SNR), approximated by the E_b/N_0. The work in [4] calculates the mutual generated load between all cells in the network, in order to obtain the inter-cell interference, and then the intra-cell one. In [5], the power received by the BS, the activity factor of the service, and the number of users using that service, are the parameters used in the interference calculation, a uniform distribution by users being assumed.

In the case of intra-cell interference in DL, in [6], the model presents two approaches for calculation, when hard or soft handovers are considered. For hard handover, this model takes into account the orthogonality factor, path loss, total power transmitted of BS to MTs within the cell, and the log-normal distribution for the slow fading. For soft handover, the model is the same, but with one additional parameter, i.e., number of users in adjacent cells in handover.

In [5], a model for inter-cell interference calculation in UL is also suggested, which takes the received power by the BS, service, number of users for each service, activity factor and the distribution of users into account. Perfect power control is assumed and multi-services are supported. In [7], the previously described model is the same with the difference that the authors do not consider a non-uniform user distribution in the cell area, i.e., instead of integrating the user distribution function in the cell area, a sum of all users' distance to their serving BSs is taken into account.

In [8], inter-cell interference in DL is explored. For its calculation, the following parameters are taken into account: total BS transmitted power, path loss, slow fading, distance from MT to BS, and the angle in between MT and BS. However, this model does not allow for multi-service; in order to correct this, in [7], the orthogonality factor parameter is added.

This paper studies the interference dependence in UMTS-FDD with buildings height. An interference model was developed and implemented in a simulator. This model calculates intra- and inter-cell interferences, in DL and UL.

In Section II, the models used for interference calculation are presented, as well as the propagations models for out- and indoors. Section III contains a brief description of the simulator. The default scenarios, the results for some parameters variation, as well as the results obtained in the measurements campaign, are presented and analysed in Section IV. Finally, conclusions are drawn in Section IV.

II. Theoretical Models

A. Interference Model

1) Intra-Cell in UL

Intra-cell interference in UL is given by [5]:

$$I^{UL}_{Intra,j[W]} = \sum_{g=1}^{N_{serv}} P_{MT \to BS_i} \times \eta_g \times N_{j,g} \ , \tag{1}$$

where $P_{MT\rightarrow BSi}$ is the power received in BS j from an MT, η_g is the activity factor of service g, $N_{j,g}$ is the number of MTs using service g on the cell of BS j, and N_{serv} is the total number of services.

2) Intra-Cell in DL

The interference model for intra-cell interference in DL, on MT i, is calculated by [6]:

$$I^{DL}_{Intra,i[\mathrm{W}]} = \left(P_{Total,BS} - P_{BS\rightarrow MT_i}\right) \times \alpha \times L_p \,, \tag{2}$$

where $P_{Total,BS}$ is the total transmitted power from the BS, $P_{BS\rightarrow MTi}$ is the power transmitted by the BS to the MT in which interference is being calculated, α is the orthogonality factor, and L_p is the path loss between the BS and the MT in which interference is being calculated.

3) Inter-Cell in UL

In the case of inter-cell interference in UL, on BS j, it is given by [7]:

$$I^{UL}_{Inter,j[W]} = \sum_{k=1,k\neq j}^{N_{BS}} \sum_{g=1}^{N_{serv}} \sum_{k=1}^{N_{k,j}} P_{MT_k \rightarrow BS_j} \times L_p \times \eta_g \times A \,, \tag{3}$$

with

$$A = \sum_{n=1}^{N_{k,g}} \frac{r_{j,n}{}^{a}}{r_{k,n}{}^{a}} \,, \tag{4}$$

where $P_{MTk\rightarrow BSj}$ is the MT k power transmitted to BS j in an adjacent cell, $N_{k,g}$ the number of users using service g in interfering cell k, $r_{k,n}$ the distance from MT n using service g to BSs k, $r_{j,n}$ the distance from MT n using service g to BSs j and a the average power decay.

4) Inter-Cell in DL

For inter-cell interference in DL, the interference in MT i using service g is calculated according to [7]:

$$I^{DL}_{Inter,i[\mathrm{W}]} = \sum_{j=2}^{N_{BS}} P_{Total,BSj} \times \alpha \times L_p \,, \tag{5}$$

where $P_{Total,BSj}$ is the BS j total transmitted power, including antenna gain, and N_{BS} is the number of interfering BSs.

B. Path loss Model

Path loss has an important role in interference prediction. For its calculation, different models are used concerning the specific case, some combining outdoors with indoors. The general algorithm for estimating interference in the various cases is presented in [9].

For outdoor, four models are used: free space (FS); COST 231 – Walfish-Ikegami (WI), for line-of-sight (LoS) and non line-of-sight (NLoS) [2]; and free space plus an extra attenuation due to diffraction from the roof to the MT [10]. The conditions for the use of these models are presented in Table I.

TABLE I
Path loss different situations.

Characteristics		**Propagation Models**
LoS	Description	
Yes	Distance between BS and MT is less than 20m	FS
Yes	Distance between BS and MT is more than 20m	WI - LoS
No	Distance between BS and MT is more than 20m	WI - NLoS
No	BS on adjacent building top, distance between BS and MT is less than 20m	FS plus extra attenuation

For indoors, the model is based on [2], the Multi-Wall Model (MWM). This model is used in two ways, one when the MT is served by a BS on the top of building where it is located, the other when the BS is not in the same building as the MT.

All these models are implemented in a simulator, *UMInS*, which is fully described in [9].

III. RESULTS ANALYSIS

A. Reference Scenario

The reference scenario should be chosen in such a way that it represents a possible real network. The user under analysis is considered to be in the central building, using the reference service, i.e., Voice at 12.2 kbps, and its location is random on each building floor.

The city of Lisbon is considered, namely areas where the scenario type is a dense urban one, with 21 m of buildings height, 40 m of buildings separation, and 12 m of streets width. The centre building has 11 floors with 3 m height per floor, and 33 m of building height. The scenario has 100 users, distributed by different environments: 50 for indoors, 25 for pedestrian, and 25 for vehicular. Half users are indoor, and the others are outdoors, with 30 % using data services, and 70 % using voice. This scenario has only one BS placed in different locations, always at the buildings top, 3 m above the roof.

At least, 5 simulation runs were performed for each situation and 30 in each floor, in order to get statistical relevance. The analysis was focused in the interference behaviour. Detailed information can be found in [9].

The interference analysis is based on this scenario, i.e., parameters are changed one by one and compared with the reference. The distance between MT and BS, central building height, street width, antenna tilts, and the number of BSs were changed. In this paper, one shows only antenna tilts and number of BS analyses, results for the other parameters being found in [9].

B. Measurements

In order to evaluate the simulator, measurements in a real network were performed. The North Tower of Instituto Superior Técnico was chosen for measurements. This scenario fits is the situation when BS is in LoS with the MT, since this building is higher than other neighbouring ones.

Measurements have shown connections with 5 surrounding BSs, i.e., 15 sectors, Fig.1; however, only 3 sectors served the MT in all floors of the building, which were SC 126, 232 and 217, so, the analysis is focused on these sectors. These sectors are illuminating the tower with the upper half part of their vertical radiation pattern, but concerning the horizontal pattern, SC 126 is radiating with the main lobe in the direction of maximum, while SC 232 and SC 217 are with off this direction.

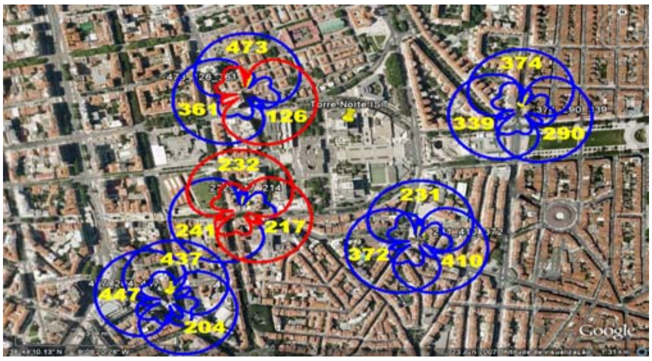

Fig. 1. Surrounding BSs and their sectors.

Both measured and simulated results present the same trend. Despite the different in the inference level for each case, 2 dB in average, they are within the standard deviation limits, Fig.2.

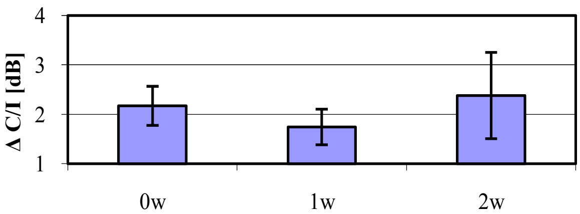

Fig. 2. Difference between measured and simulation results, for a number of different penetrating walls.

In the simulated case, the *C/I* ratio has its best values when the MT is only attenuated by 1 glass wall (0w), followed by the cases of 1 and 2 brick/concrete walls (1w and 2w). They present a slope that is almost half of the measurements, the decreases being on average of 0.1 dB per floor, and the difference between each case of penetrated being 0.5 dB. These results reinforce the idea that interference is higher as higher the MT is.

C. Results

1) Reference

In this section, the results of the simulations performed for the reference scenario are presented and analysed. Additional results obtained can be found in [9].

Interference in DL is larger than in UL, since the power transmitted by the BS is larger than the MT one. In DL, interference shows a trend to become larger as higher the MT is, i.e., it shows an increase of 2.5 dB per floor on a global view, and when the analysis is split in the cases of NLoS and LoS, one gets 1.2 and 3.2 dB, respectively, Fig.3. This happens because, while the MT is going up on the building path loss decreases, since the MT becomes visible by the BS; when the MT achieves the 7th floor, the model for path loss calculation is changed to the LoS one (FS or WI LoS). As it is well-known, when there is LoS between MT and BS, path loss is lower than in the case of NLoS, consequently the interference is higher in the case of LoS. On the other hand, in UL, interference shows a trend to be constant, because it depends on the number of users, and this number is taken constant.

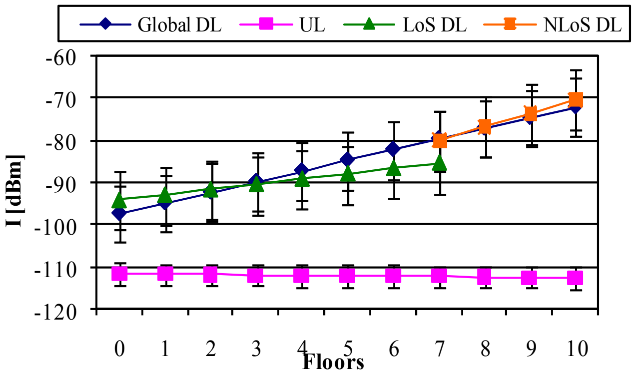

Fig. 3. Trend lines of the reference scenario for 0 walls.

2) Dependence on Antenna Tilts

Simulations with 5º and 10º of down tilt were performed. The antenna with 0º of tilt corresponds to the reference.

The change in tilt has a direct impact in the way the antenna pattern illuminates the service area. In DL, the levels of interference for -5º and -10º are better than in the case of 0º (reference one), an improvement of 2 and 4 dB being observed for the tilts of -10º and -5º, respectively, because with these tilts BSs improve the transmitter power, i.e., for the same received power and path loss, a higher gain results in a lower transmitter power, consequently lower interference. Between -5º and -10º is presented a difference of 1.65 dB, Fig. 4. The interference values for -5º are lower than for -10º because the antenna beam width is 6 dB resulting in a better performance.

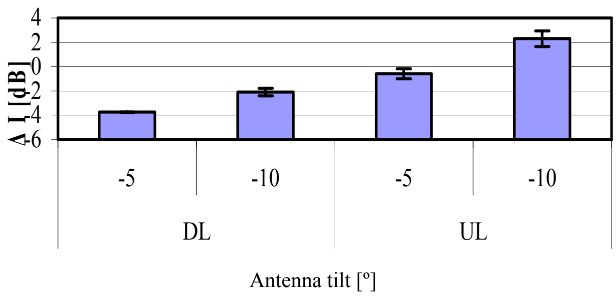

Fig. 4. Dependence on antenna tilt relative to the reference case.

In UL, the difference between 0º and -5º is almost 0 dB, and between 0º and -10º is around 2 dB. The increase on interference level leads to a growth in the number of served users.

3) *Dependence on Number of BSs*

Simulations for 2, 3 and 4 BSs around the serving BS were performed. All BSs have the same characteristics as the reference one.

In DL, an increase in the number of BSs results in an increase of the interference level, because there are more BSs causing interference in the MT. In the case of 2 BSs, interference increases 5 dB, Fig. 5; when one more BS is employed, this difference increases 3 dB, i.e., it becomes 8 dB higher; in the case of 4 BSs, interference is 12 dB higher relative to the reference case. The standard deviation suffers an increasing with the increase in the number of BSs.

In UL, the interference level becomes lower with the increase of the number of BSs, although, the difference between each other is not as high as in DL. This difference happens because with more BSs, MTs have more options to connect in the network, decreasing interference.

The variation of this parameter has more impact in DL than in UL. In DL, for each BS that is considered in the scenario, the interference becomes approximately 4 dB higher.

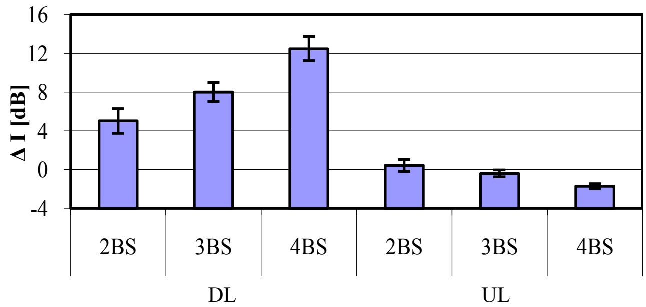

Fig. 5. Dependence on the number of BSs relative to the reference case.

IV. CONCLUSIONS

This paper deals with the problem of interference in UMTS radio networks. It presents an approach for interference prediction with buildings height, for a uniform user's distribution on a regular environment.

The main conclusion, in DL, is that the higher and closer to outdoor the MT is in the building, the higher the interference is. Interference shows an increasing trend, with a global rise of 2.5 dB per floor, and a difference of 2.8 dB in between each penetrated wall. This difference occurs because the higher the MT is, the more exposed to other sectors it is. This slope is different if the analysis is split into the cases of NLoS and LoS: when the MT is in NLoS, interference rises 1.23 dB per floor, while in LoS an increase of 3.27 dB is observed. So, the slope is almost two times higher in the case of LoS than in the NLoS one.

In UL, interference has an almost constant behaviour, because the number of users that interfere mutually is, approximately, constant.

The change in antenna tilts reveals that interference can be improved in one link, but that it can get worse in the other, therefore, this parameter should be changed very carefully, in order to get a proper balance in between the two cases. The increase in the number of BSs results in an increase in the interference level, since each MT is interfered by more BSs, regardless of its position.

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