Antenna and Propagation Parameters Modeling Live Networks

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***Abstract*—In radio network performance evaluations it is of interest to use simulation environments that represent realistic networks. In this paper two widely used simulation environments are benchmarked against live network path gain measurements. Some parameter adjustments are done to fit the simulation environments to the measured path gain and cell isolation statistics. The need to modify base station antenna model parameters to match the intra-site cell isolation in real networks is identified and elaborated. In particular an increase of maximum attenuation to 35dB, introduction of mechanical tilt and reduction of vertical beam width are needed. In addition some adjustments are done to better represent the assumed traffic distribution with 80% indoor users and expected propagation losses resulting in a path gain level on par with the measured network.**

Keywords- radio network; measurements; antenna model

I. INTRODUCTION

The statistical characteristics of radio network simulation environments have a decisive impact on the performance results. This is true for performance assessments of new technologies as well as for feature evaluations. For path loss distribution the used propagation and antenna models are important. But the actual spatial distribution of users also has an impact. If cells are planned to capture the majority of traffic in the cell center the path loss is statistically improved. Also the fraction of indoor traffic together with building types has impact. Furthermore, at high load the cell isolation defines the capacity in interference limited networks such as WCDMA and LTE with frequency reuse one.

Also the intra-site and inter-site cell isolation in simulation environments can be of importance for feature evaluations. Coordination techniques between cells are in many cases much easier to introduce within a site than between sites. Between sites X2 communication is used in LTE which may require standardization efforts and in some cases also increased back-haul capacity. Examples of features dependent on the intra-site versus inter-site cell isolation are Inter-Cell Interference Co-ordination (ICIC) and Co-ordinated Multi Point (CoMP) [7].

The 3GPP simulation environments [1] have been used for LTE evaluations, both regarding feature evaluations and general performance assessments. The ITU simulation environments [2] have been used in the IMT Advanced evaluation process.

In this paper the 3GPP case 1 environment and the ITU Urban Macro (UMa) environment have been compared to path gain and geometry factor distributions from a commercial urban WCDMA network. Measurement reports have been logged from all mobiles collecting 2 million samples. This captures the true spatial distribution of traffic including indoor usage. Also two new environments based on the 3GPP and the ITU environments have been created by adjusting some model parameters to fit the measured network better. These new environments models other measured networks better as well, such as the one studied in [5].

This paper is organized as follows: in Section II the used geometry factor measures are defined and the intra-site cell isolation measure introduced. The live traffic measurement method is described in section III. Some key characteristics of the measured network and the compared simulation environments are described in sections IV and V, respectively. The results are presented in section VI and finally conclusions are drawn in section VII.

II. GEOMETRY FACTOR AND INTRA SITE CELL ISOLATION

Cell isolation is studied through the geometry factor measure as used and described in [5]. This measure of cell isolation is suitable for comparison between measurements of real live traffic and data for simulation environments. In this paper the per neighbor geometry factor is further separated into inter-site and intra-site geometry as illustrated in Fig. 1. As will be shown, intra-site cell isolation including only the co-sited neighbor cells is useful when the base station antenna model is investigated.

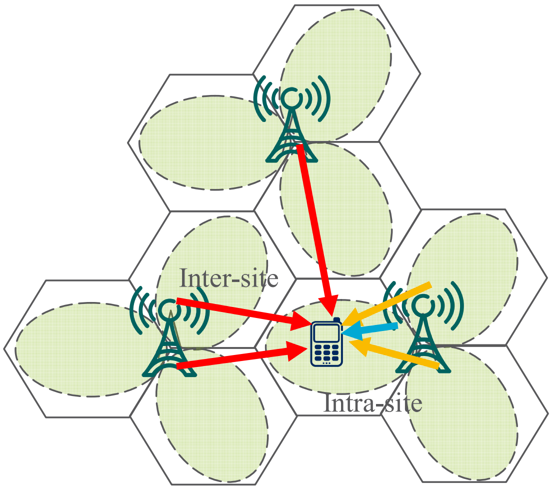

Figure 1. Intra-site cell isolation.

The geometry factor for a measured sample is based on the path gain from the best cell g_{best_cell} (in dB) relative to the path gain from neighbor cells g_i. A per neighbor i geometry factor is defined as

$$G_i = \log_{10}\left(\frac{10^{g_{best\_cell}}}{10^{g_i}}\right) \text{ [dB]} \qquad (1)$$

with a lower bound of 0dB. The intra-site geometry factor is achieved by selecting neighbor cells i as the co-sited neighbor cells. With three-sector sites, as in these measurements, it is possible to define one intra-site geometry factors to the strongest neighbor and one to the second strongest neighbor. The best cell is selected as the one having strongest path gain per sample.

Also a total geometry factor is studied using the sum of the path gains for all neighbors i

$$G = \log_{10}\left(\frac{10^{g_{best\_cell}}}{\sum\limits_{i \neq best\_cell} 10^{g_i}}\right) \text{ [dB].} \qquad (2)$$

III. LIVE TRAFFIC MEASUREMENTS

The Geo-Observability tool [6] has been used to collect mobile measurements from commercial traffic. All connected mobiles are configured to send a measurement report every 4th second to the network. This captures the true spatial traffic distribution including indoor usage. Every report includes several measures of which the Received Signal Code Power (RSCP) and scrambling code are used in this study. RSCP for connected and up to 10 neighbor cells are reported enabling both path loss and geometry factor analysis. For each measurement report the path gain per reported neighbor i is calculated as

$$g_i = RSCP_i - P_{CPICH\,i} \text{ [dB]} \qquad (3)$$

where P_{CPICH} is the CPICH (Common PIlot CHannel) power. For each measurement report the path gain values are sorted and the co-sited cells are identified by the reported corresponding scrambling code. Also the strongest cell is used instead of the connected cell when calculating geometry factors in order to eliminate handover algorithm impact. The path gain values g_i are then inserted into (1) and (2) for i {1,2} and {1,…,10} respectively.

The mobile does not always detect 10 neighbors or the two co-sited neighbors. This case is treated in two ways.

- *Measured:* $RSCP_i$ is set to –infinity resulting in an infinite corresponding per neighbor geometry factor G_i and also an infinite total geometry factor G if no neighbor is detected.
- *Measured detection level*: $RSCP_i$ is set to an assumed detection level in the mobile terminal of -124dBm

These two alternatives give an indication of a measurement interval in which undetected neighbors may exist. The neighbor detection performance of the mobiles is unknown and varies with mobile vendor and models. Also this fixed absolute detection level is a simplification and the detection level most probably depends on RSCP from the connected cell and the dynamic range of the receiver.

IV. MEASURED NETWORK

The measurements are collected in a commercial WCDMA network in an urban city environment. The network is mature and well planned. Mobile broadband is deployed with HSPA. All connected mobiles from 66 three-sector sites is logged for one and a half hour. There is a number of different base station antennas used. Most details are unknown, however both 60° and 90° horizontal half power beamwidth (HPBW) antennas exist. A summary of some known and approximated key parameter values are listed in Table I.

TABLE I. MEASURED NETWORK OVERVIEW

Parameter	Value
Frequency band	2.1GHz
Access	WCDMA with HSPA
Number of sites/cells	66/198
Sectors per site	3
Inter site distance	400-1200m
Horizontal HPBW	60° and 90°
Average antenna height	Around 30m
Average total tilt (mechanical + electrical)	Around 4°
Pilot power P_{CPICH}	Around 33dBm (2W)
Recording time	Around 1.5 hour
Number of logged samples	2 100 448

V. SIMULATION ENVIRONMENT

Two simulation environments are used: the 3GPP case 1 [1] and ITU UMa (Urban Macro) [2]. These environments are both used as is as well as modified to fit measurement data. The frequency band is set to 2.1GHz to match the measured network. Key parameters for the baseline reference models are listed in Table II. 5700 mobiles are randomly dropped in the system area. For each mobile, the path gain g_i is calculated according to the propagation, shadow fading and antenna models for all cells i {1,…,57}. The path gain values are inserted into (1) and (2) to calculate geometry factors. In line with the measurements no handover hysteresis is applied, g_{best_cell} is selected as the cell i with highest path gain.

TABLE II. SIMULATOR MODELS

Parameter	3GPP case 1	ITU UMa
Frequency band	2.1GHz	
Cell layout	Hexagonal grid 57 cells, 19 3-sector sites Wrap around	
Inter site distance	500m	
Measurement samples	5700	
NLOS propagation	15.7+37.6·log10(d)	20.0+39.1·log10(d)
LOS propagation	N.A.	34.4+22·log10(d)
NLOS shadow fading std.	8dB	6dB
LOS shadow fading std.	N.A.	4dB
Indoor shadow fading std.	8dB	7dB

d in meters, LOS: Line Of Site, NLOS: Non LOS

VI. RESULTS

In this section the simulation environments are compared to the measurements. C.D.F:s of path gain g and geometry factors G are used to show level and distributions as well as impact on different percentiles. First the parameter difference, the path gain and the geometry factors for all four simulation environments are compared. Then the impact of individual adjusted simulation parameters is elaborated on illustrated by intra-site geometry factor distributions. This is done for one of the simulation environments, ITU UMa fitted.

A. *Adjusted Model Summary*

Based on 3GPP case 1 and ITU UMa simulation environments, two adjusted models are created to better fit the measured statistical distributions. The parameter adjustments are summarized in Table III. The changes are limited to two areas, indoor propagation and base station antenna model. For the adjusted parameters a common parameter set is in general used for both environments. The exception is the electrical antenna tilt which differs because of a difference in antenna height (listed for clarity but unchanged).

TABLE III. ADJUSTED PARAMETERS

	3GPP case 1	**ITU UMa**	**3GPP fitted**	**ITU fitted**
Propagation				
Indoor fraction	100%	0%	80%	
Outer wall loss	20dB	20dB	20dB	
Outer wall distance	N.A.	[0,25]m	[0,25]m	
In building loss	N.A.	0.5dB/m	0.5dB/m	
Efficiency loss	N.A.	N.A.	14dB	
Base station antenna				
Antenna height	32m	25m	32m	25m
Mechanical tilt	0°	0°	5°	
Electrical tilt	15°	10°	5°	2°
Horizontal BW	70°	70°	75°	
Vertical BW	10°	15°	6.5°	
Front to back ratio	25dB	20dB	25dB	
Side lobe level	-20dB	-20dB	-25dB	
Max. attenuation	25dB	20dB	35dB	

In ITU UMa there are no indoor mobiles, the listed indoor parameters are from ITU UMi in [2].

The base station antenna parameters are in line with measured antenna radiation pattern in [3] as well as with comparisons to other real networks in [4] and [5]. The in building loss and efficiency loss are also defined for LTE CoMP evaluations in [7].

B. *Path Gain Comparison*

Fig. 2 shows the path gain distribution for all four simulation environments compared to the measurement. The ITU UMa environment that lacks indoor mobiles has much higher path gain levels compared to measurements. An expected 80% indoor fraction is introduced to compensate for this. As in [7], the outdoor to indoor model from the ITU Urban Micro (UMi) environment is introduced featuring 20dB outer wall penetration loss and an in building loss model of 0.5dB/m with random uniform distribution between 0 and 25 m from outer wall. Also an additional efficiency loss is introduced as in [7] to match the measured path gain. This loss may consist of receiver efficiency, feeder loss and other losses. The average inter-site-distance in the measured network is not known but may also be larger than the simulated 500m. With this loss the path gain level is on par with the measured network. Even though the 3GPP environment contains indoor loss the same in building loss and efficiency loss is required to get a path gain level similar to the measurements. Note that the efficiency loss also is applied on outdoor mobiles.

C. *Geometry Factor Comparison*

Fig. 3 shows the distribution of the total geometry factor according to (2). All four environments are compared to the measurement results. For the total geometry the measurement is rather accurate as indicated by the relatively small difference compared to the detection level. The measured line stops at 88% because 12% of the samples did not report any neighbor cell measurement.

When comparing the simulation models to the measurements in Fig. 3 it is clear that the default tilt used in 3GPP case 1 results in a significantly higher cell isolation. The ITU UMa is limited to maximum geometry factor of 17dB. The

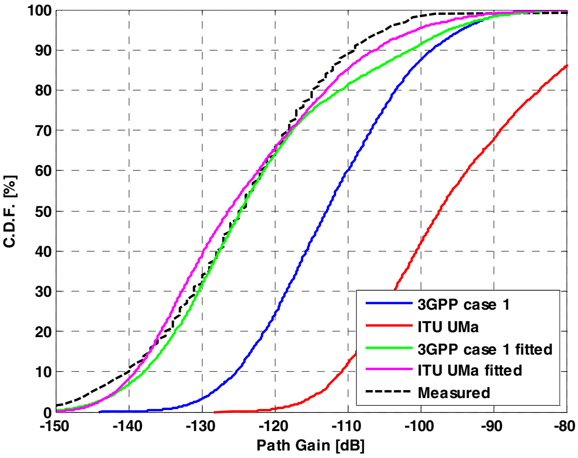

Figure 2. Comparison of path gain.

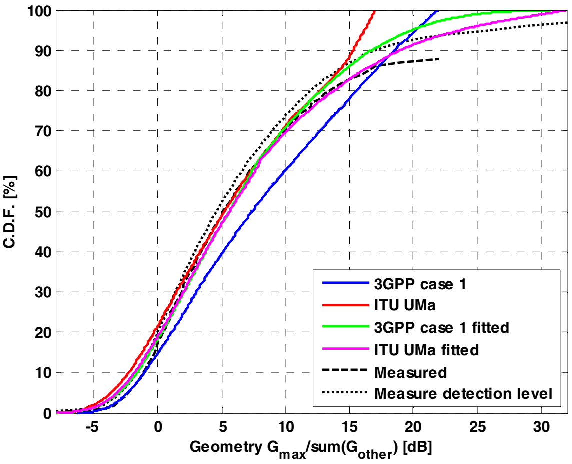

Figure 3. Comparison of total geometry factor.

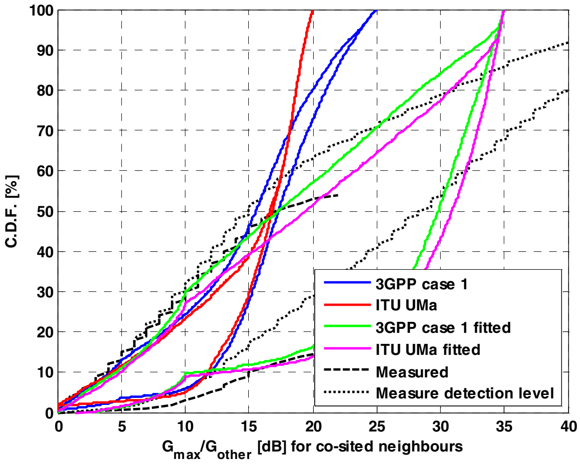

Figure 4. Comparison of intra-site geometry factor.

fitted environments do no have such clear limitation and they show a distribution more in line with the measurements. In the measurement results in [5] there is also a similar fraction of geometry factor above 20dB.

D. *Intra-Site Cell Isolation and Maximum Attenuation*

Fig. 4 shows the intra-site geometry factor distribution according to (1) for measurement and simulations. For each case there are two lines representing the geometry factor towards the stronger co-sited cell and towards the weaker co-sited cell, respectively. In the measurements, the accuracy of per cell geometry factor is somewhat worse than for the total geometry factor. 54% of the reports include one co-sited neighbor and only 15% both. It can be noted that above 22dB there is no neighbor reported and the mobiles probably do not detect neighbors 22dB weaker than the connected or strongest cell.

When comparing the simulation results with the measurements in Fig. 4 it is seen that both fitted models agree better with the measurements above a geometry factor of 10dB. The limitation on maximum geometry seen in Figs. 3 and 4 originates from the intra-site cell isolation. It is 3dB lower in Fig. 3 because of the contribution from both co-sited cells. This is caused by the base station antenna parameter maximum attenuation which is 20dB for ITU UMa and 25 dB for 3GPP case 1, see Table III.

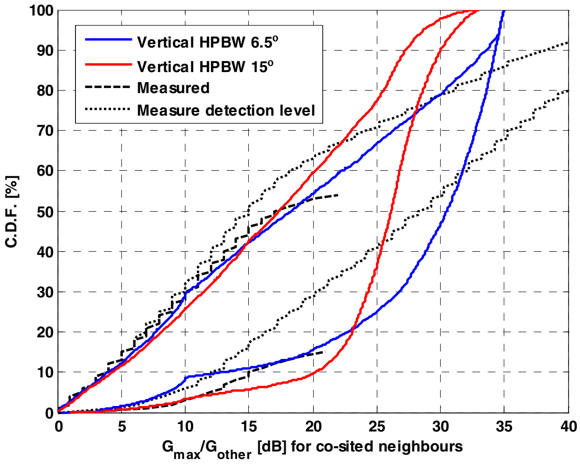

Figure 6. Vertical beam width impact, ITU UMa fitted environment.

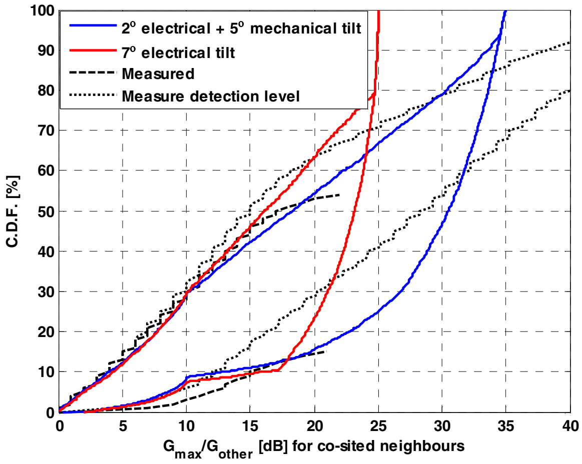

Figure 5. Mechanical tilt impact, ITU UMa fitted environment.

It can be noted that the indoor fraction and propagation model adjustments do not impact the geometry factors as these losses affect all links equally and thus cancel in the expression for the geometry factor. Thus the path gain propagation fitting can be done independent of the intra-site cell isolation antenna parameter fitting.

E. *Impact by Mechanical Tilt*

Mechanical tilt is commonly used in radio network deployments, often in combination with electrical tilt, with mechanical tilt set to a fixed preset value and electrical tilt used to dynamically adjust the total tilt. The impact of mechanical tilt in modeling is illustrated in Fig. 5. The intra-site cell isolation for ITU UMa fitted environment is shown with two alternative tilt settings resulting in a total tilt of 7°. When only electrical tilt is used the co-sited cell isolation is limited by the front to back ratio (FBR). For electrical tilt, the vertical back lobe is modeled as pointing with the same down-tilt angle as the front lobe in the direction of the center of the co-sited cells.

F. *Impact by Vertical Beam Width*

A wide vertical beam width also reduces the achievable intra-site cell isolation. In Fig. 6 the fitted ITU model is shown with two alternative vertical HPBW; the original ITU vertical HPBW of 15° as well as the fitted vertical HPBW of 6.5°. Even though the vertical beam width is not associated with a hard bound on the geometry, in contrast to maximum attenuation and front to back ratio, the beam width clearly reduces the highest percentile intra-site isolation by around 5dB. With a wide vertical beam the interference caused to co-sited cells through the back lobe is higher. With 5° mechanical tilt, 15° HPBW still transmits energy in the (mechanically up-tilted) back lobe.

Also in [3] a narrow vertical beam is found to model measured antenna radiation pattern well. Furthermore, in [8]

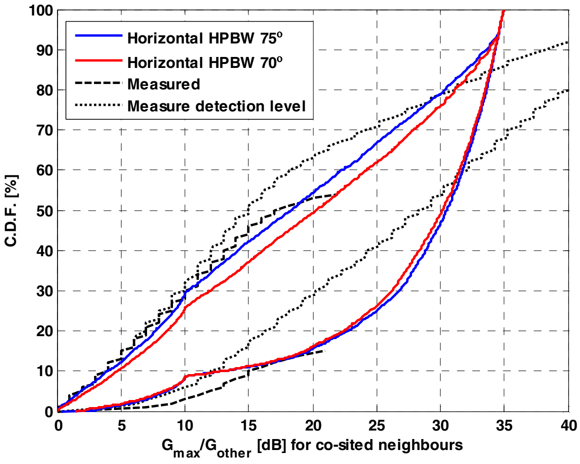

Figure 7. Horizonal HPBW impact, ITU UMa fitted environment.

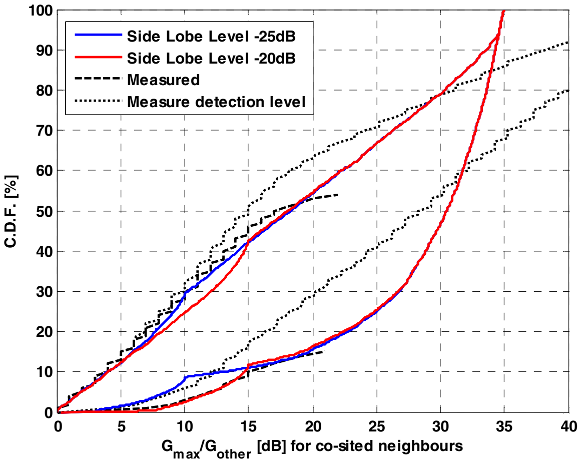

Figure 8. Side lobe level impact, ITU UMa fitted environment.

the elevation spreads is estimated to be in the order of one degree or less indicating no need for increased vertical beam width to model reflection paths. A wide vertical beam also is found to result in a rather unrealistically large tilt, such as the 15° in [1].

G. *Impact by Horizontal Beam Width*

In the measured network the horizontal HPBW was a mixture of 60° and 90°. It was found that a HPBW of 75° modeled this network well. The impact of the increased HPBW is shown in Fig. 7 for the fitted ITU model. The intra-site isolation to the strongest co-sited cell is reduced by 1 to 2dB. This adjustment results in better fit to the measurements in relation to the strongest co-sited cell.

H. *Impact by Side Lobe Level*

An increased vertical side lobe level attenuation degrades the coverage at the sector edge somewhat. This also reduces the intra-site cell isolation but in contrast to the horizontal beam width mainly at lower percentiles, see Fig. 8 where the fitted ITU model is shown with two different side lobe levels. This adjustment gives a better fit to the measurements but is difficult to logically motivate from an antenna modeling view, at least when comparing to the peak of the first side lobe below the main beam in commercial sector antennas, which is typically higher than –20 dB. One possible explanation for this can be that when deployed on roof tops the sector antennas are sometimes separated and placed at the edges of the roof resulting in higher isolation than can be motivated for antennas mounted on a mast. In the simulations such a distributed antenna placement is not modeled.

VII. CONCLUSION

This paper compares the characteristics of two widely used simulation environments, namely 3GPP case 1 and ITU UrbanMacro, against live network data. The results reveal deviations from the measured network in two aspects; the path gain level and the intra-site cell isolation. The latter also results in a less representative modeling of the interference situation, the geometry factor, in the measured network.

The commonly used antenna model parameters give less realistic intra-site cell isolation and it is motivated to consider adjustments for future evaluation campaigns. Specifically the maximum attenuation should be increased to around 35dB and mechanical tilt modeling should be introduced. This eliminates the unrealistic upper limit of isolation between co-sited cells and results in a more reasonable higher percentile of intra-site cell isolation. Also a narrower vertical beam width is strongly recommended reducing the back lobe interference to co-sited cells to a more realistic level and resulting in a more reasonable tilt behavior.

To get a path gain level in line with that of the measured network, increased loss modeling must be introduced. An expected 80% fraction of indoor mobiles, ITU in-building loss, and introducing efficiency loss results in a better alignment with the measurements. The efficiency loss is a non-specified sum of feeder loss, receiver efficiency, and inter-site distance mismatch.

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