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UMTS Multi-Service Uplink Capacity and Interference Statistics of Femtocells

Bazil Taha Ahmed and Marta Anaya de Paz

Universidad Autonoma de Madrid- Escuela Politecnica Superior

Abstract: In this work, the multiservice uplink capacity of single and multiple femtocells is given. The COST231 multiwall and multifloor indoor propagation model has been used to calculate the indoor propagation loss. Results show that the uplink capacity of a deployed femtocell will reduce by 2% if two extra femtocells are deployed in the same building higher and lower of it. Results also show that the uplink capacity is slightly affected if there are several femtocells deployed in the buildings around the one at which the femtocell under study is already exists. It is demonstrated that uplink capacity is interference limited if the femtocell is deployed to serve the users in three floors. Results show that the uplink capacity will be interference and noise limited if the femtocell is deployed to serve the users in five floors. Finally, it is found that the effect of the interference due to the uniformly distributed users within the macrocell around the femtocell is insignificant.

Keywords: UMTS, Uplink capacity, Femtocells, Power control, Indoor propagation.

1- Introduction

In this section we will present a brief idea about UMTS (Universal Mobile Telecommunications Service) system and femtocells. The related work with this subject and the main contribution of this work will be also presented.

UMTS is a third-generation (3G) broadband, packet-based transmission of text, digitized voice, video, and multimedia. UMTS offers a consistent set of services to mobile computer and phone users, no matter where they are located in the world. It is endorsed by major standards bodies and manufacturers as the planned standard for mobile users around the world. Once UMTS is fully available, computer and phone users can be constantly attached to the Internet wherever they travel and, as they roam, will have the same set of capabilities. The electromagnetic radiation spectrum for

UMTS has been identified as frequency bands 1885-2025 MHz for future IMT-2000 systems, and 1980-2010 MHz and 2170-2200 MHz for the satellite portion of UMTS systems. UMTS uses the WCDMA (Wideband Code Division Multiple Access) technology with a capacity limited by interference.

In telecommunications, a femtocell (also called Home NodeB) is a small cellular base station, typically designed for use in a home or small business. It connects to the service provider's network via broadband (such as DSL or cable). A femtocell allows service providers to extend service coverage to the indoor environment, especially where access would otherwise be limited or unavailable. Although much attention is focused on WCDMA, the concept is applicable to all standards, including GSM, CDMA2000, TD-SCDMA, WiMAX and LTE solutions.

1-1 Related work

The femtocell concept is studied in [1] and [2]. Work [3] , has identified the key benefits of femtocells, the technological and business challenges, and research opportunities.

In [4], femtocells deployment using WiMAX, UMTS and WiFi has been discussed. In [5], the UMTS femtocell capacity in massive deployments has been studied without taken into account the interference variance [See equation 6 of the reference]. In [6], the UMTS mutual interference between the macrocells and the femtocells has been studied. Here also, the effect of the interference variance has not been taken into account. In [7], the uplink coverage and capacity of UMTS femtocells in enterprise environment have been studied without taken into account the effect of the interference variance [See equation 5 of the reference]. In [1], the feasibility of user deployed femtocells in the same frequency band as an existing macrocell network has been investigated. Key requirements for co-channel operation of femtocells such as auto-configuration and public access have been discussed. A method for power control for pilot and data that ensures a constant femtocell radius in the downlink and a low pre-definable uplink performance impact to the macrocells has been proposed, and the theoretical performance of randomly deployed femtocells in such a hierarchical cell structure has been analyzed for one example of a cellular UMTS network using system level simulations. The resulting impact on the existing macrocellular network has been also investigated. In [8], adaptive attenuation at the femtocell and limiting the Tx power of the femtocell users are proposed for uplink interference management. Coverage

performance and capacity results are presented to quantify the benefits of femtocells. In [9], a two-tier UMTS network has been considered where a large number of deployed Wideband Code Division Multiple Access (WCDMA) femtocells are laid under macrocells where they share the same spectrum. The uplink of this hybrid network has been studied, and critical scenarios that give rise to substantial interference have been identified. The mechanism for generating the interference has been analyzed and guidelines for interference mitigation have been provided. The impacts of the cross-tier interference, especially caused by increased numbers of users and higher data rates has been evaluated in the multi-cell simulation environment in terms of the noise rise at the base stations, the cell throughput and the user transmit power consumption. Authors of [10] investigated the performance of open-access femtocell networks for different scenarios, where macrocell users were allowed to join a particular femtocell if it was preferable to do so. Both dedicated-channel and co-channel femtocell deployments were considered. They investigated different cell selection metrics, and argued that a capacity-based cell selection typically results in higher capacities for the users. Impact of wall penetration loss and how it relates to the capacities of indoor and outdoor users were also evaluated.

In a two tier cellular network – comprised of a central macrocell underlaid with shorter range femtocell hotspots – cross-tier interference limits overall capacity with universal frequency reuse. To quantify near-far effects with universal frequency reuse, work [11] derived a fundamental relation providing the largest feasible cellular Signal-to-Interference-Plus- Noise Ratio (SINR), given any set of feasible femtocell SINRs. It provided a link budget analysis which enables simple and accurate performance insights in a two-tier network. A distributed utility based SINR adaptation at femtocells was proposed in order to alleviate cross-tier interference at the macrocell from cochannel femtocells. Each femtocell maximizes their individual utility consisting of a SINR based reward less an incurred cost (interference to the macrocell). Numerical results showed greater than 30% improvement in mean femtocell SINRs.

Femtocells which assume an increasingly important role in cellular coverage can be configured to be either open access or closed access. Obviously, the network operator would prefer an open access deployment since this provides an inexpensive way to expand their network capabilities, whereas the femtocell owner would prefer closed access, in order to monopolize their femtocell capacity and backhaul. In [12], a novel analytical framework for studying this problem has been developed, and results show

that the open access in CDMA benefits both parties in almost the whole range of cellular user density. It has been demonstrated that open access can typically provides gains of more than a factor of three for the home user by reducing the near-far problem experienced by the femtocell, resulting in a “win-win” scenario for overlaid open access femtocell deployments in modern CDMA networks.

In [13], authors investigated how femtocells can make conventional cellular networks *greener*. They presented an energy consumption modelling framework to evaluate total energy consumption in a cellular network with femtocells. Using the proposed framework, they investigated the energy consumption and performance of the cellular network with femtocells. They considered various network environments, including indoor propagation environment, user distribution near the femtocells, and a femtocell access policy, which have effect on the performance of the cellular network. Simulation results in the various environments show that femtocell is, in general, a greener technology that reduces the total energy consumption in a cellular network. They obtained system performance and energy consumption for three different scenarios: different femtocell penetration rate, different open access rate, and different cell coverage. They provided a guideline that helps system operators to deploy and manage a cellular network with femtocells in a greener way.

Work [14] proposed two interference mitigation strategies that adjust the maximum transmit power of femtocell users to suppress the cross-tier interference at a macrocell base station (BS). The open-loop and the closed-loop control suppress the cross-tier interference less than a fixed threshold and an adaptive threshold based on the noise and interference (NI) level at the macrocell BS, respectively. Simulation results show that both schemes effectively compensate the uplink throughput degradation of the macrocell BS due to the cross-tier interference and that the closed-loop control provides better femtocell throughput than the open-loop control at a minimal cost of macrocell throughput.

In [15], the UMTS multiservice uplink capacity of highways cigar-shaped microcells has been investigated taking into account the expected value and the variance of the interference.

1-2 Paper contribution

The main contribution of this paper is to calculate the multiservice uplink capacity of femtocells taking into account the expected value and the variance of the interference

assuming that they use a frequency band that is not shared by the macrocells around them.

1-3 Paper organization

The rest of the paper is organized as follows. In Section 2, the used propagation loss model is presented. In Section 3, the uplink interference analysis is given. In Section 4, different numerical results are presented. Finally, Section 5 draws the conclusions.

2- Propagation Model

The electromagnetic propagation mechanism in femtocells is an indoor propagation. Thus an adequate propagation loss model has to be used to characterize the indoor channel. In our analysis, we will use the COST231 multi-wall and floor indoor propagation model (representing the most sophisticated empirical indoor propagation model) is used to determine the indoor propagation loss. The propagation loss L in dB is given by [16]:

$$L(\text{dB}) = L_{fs} + L_c + \sum_{i=1}^I k_{wi} L_{wi} + k_f \left[\frac{k_f+2}{k_f+1} - 0.46 \right] L_f + \xi \quad (1)$$

where

- L_{fs} is the free space loss between the transmitting antenna and the receiving one given in dB.
- L_c is constant loss.
- k_{wi} is the number of penetrated walls of type i .
- L_{wi} is the penetration loss of the walls of type i in dB.
- k_f is the number of penetrated floors.
- L_f is the floor penetration loss in dB.
- ξ is a Gaussian variable with zero mean and a standard deviation σ_{sh} representing the shadowing effect.

All walls intersecting the direct ray between transmitter and receiver are considered and for each wall individual material properties (and therefore L_w) are taken into account.

From equation (1), it can be noticed that the effective number of floors is lower than the real one when the real number of floors is two or more. This is due to the fact that the

term $k_f \left[\frac{k_f+2}{k_f+1} - 0.46 \right]$ is lower than k_f when k_f is two or more.

3- Uplink Analysis

In WCDMA systems, each femtocell controls the transmitted power of its users to have a given received signal power for all users.

Assuming that L_{im} (given in dB) is the propagation loss between the user i and the base station of its femtocell m and that L_{id} (given in dB) is the propagation loss between the user i and the base station of the reference femtocell d as shown in Fig. 1, then **the interference to signal ratio (given in real numbers)** $L(r_{id}, r_{im})$ due to the distance and penetration loss is given as:

$$L(r_{id}, r_{im}) = 10^{(L_{im} - L_{id})/10} \quad (2)$$

where

Now, **the interference to signal ratio (given in real numbers)** $L_{shd}(r_{id}, r_{im})$ due to the distance, penetration loss and shadowing is given by:

$$L_{shd}(r_{id}, r_{im}) = 10^{(\xi_{id} - \xi_{im})/10} L(r_{id}, r_{im}) \quad (3)$$

Where $\xi_{id} = \xi_{im} = \xi$.

Total interference to signal ratio is the sum of the individual interference to signal ratio due to all of the interfering users.

Let the mean value of the desired signal power received by the base station for a given service s be $P_{r,s}$. The mean value of the interference from an active user communicating with the reference microcell assuming the same service will be also $P_{r,s}$. A user i will not communicate with the reference base station of the femtocell d but rather with the base station of the femtocell m whenever the propagation loss between the user i and base station of femtocell m is lower than the propagation loss between the user i and the base station of the femtocell d , i.e., if $\phi(\xi_{id} - \xi_{im}, r_{id}/r_{im}) = 1$, where

$$\phi(\xi_{id} - \xi_{im}, r_{id}/r_{im}) = \begin{cases} 1, & \text{if } L(r_{id}, r_{im}) 10^{(\xi_{id} - \xi_{im})/10} \leq 1 \\ 0, & \text{otherwise.} \end{cases} \quad (4)$$

Assuming that each femtocell has a capacity of $N_{u,s}$ users per service s , the expected value of intercellular interference for a given service s is given as:

$$E[I_{inter}]_s = \alpha_s \sum_{n=1}^{N_{u,s}} L(r_{id}, r_{im}) f\left(\frac{r_{id}}{r_{im}}\right) dr \quad (5)$$

where

$$f\left(\frac{r_{id}}{r_{im}}\right) = E\left[10^{(\xi_{id}-\xi_{im})/10} \phi(\xi_{id} - \xi_{im}, r_{id}/r_{im})\right] \quad (6)$$

$$= e^{(\beta\sigma)^2/2} Q\left[\beta\sqrt{\sigma^2} + \frac{10}{\sqrt{\sigma^2}} \log_{10}\{1/L(r_{id}, r_{im})\}\right] \quad (7)$$

Where $\beta = \frac{\log_e 10}{10}$ and α_s is the activity factor of the user for the service s (0.66 for voice users and 1.0 for data users).

The value of σ^2 is given as:

$$\sigma^2 = 2(1 - C_{dm})\sigma_{sh}^2 \quad (8)$$

where C_{dm} is the shadowing inter-sites correlation coefficient.

$Q(x)$ is given by

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{-v^2/2} dv \quad (9)$$

The expected value of the total intercellular interference power for the service s is given as:

$$E[P_{inter}]_s = P_{r,s} E[I_{inter}]_s \quad (10)$$

The expected value of the intracellular interference power due to the service s is given by:

A- If it is the service under study

$$E[P_{int ra,s}] = P_{r,s} E[I_{int ra}]_s = P_{r,s} \alpha_s (N_{u,s} - 1) \quad (11)$$

B- Else it is given as:

$$E[P_{int ra,s}] = P_{r,s} E[I_{int ra}]_s = P_{r,s} \alpha_s N_{u,s} \quad (12)$$

Taking into account an imperfect power control with standard deviation error of σ_c (dB), the total expected interference power for the service s will be:

$$E[P_{int}]_{r,s} = e^{\beta^2 \sigma_c^2 / 2} (E[P_{int ra}]_s + E[P_{inter}]_s) \quad (13)$$

The expected value of the total interference power due to all services will be:

$$E[P_{int}]_r = \sum_{s=1}^S E[P_{int}]_{r,s} \quad (14)$$

where S is the number of the services that the system supports.

The variance of the intercellular interference power for the service s is given as:

$$\text{var}[P_{\text{inter}}]_s = P_{r,s}^2 \sum_{n=1}^{N_{u,s}} [L(r_{id}, r_{im})]^2 \left\{ p\alpha_s g\left(\frac{r_{id}}{r_{im}}\right) - q\alpha_s^2 f^2\left(\frac{r_{id}}{r_{im}}\right) \right\} dr \quad (15)$$

where

$$g\left(\frac{r_{id}}{r_{im}}\right) = E\left[10^{(\xi_{id}-\xi_{im})/10} \phi(\xi_{id} - \xi_{im}, r_{id}/r_{im})\right]^2 \quad (16)$$

$$= e^{2(\beta\sigma)^2} Q\left[2\beta\sqrt{\sigma^2} + \frac{10}{\sqrt{\sigma^2}} \log_{10}\{1/L(r_{id}, r_{im})\}\right] \quad (17)$$

$$p = e^{2\beta^2\sigma_c^2} \quad (18)$$

$$q = e^{\beta^2\sigma_c^2} \quad (19)$$

The variance of the intracellular interference power due to the service s is calculated as:

$$\text{var}[P_{\text{intra}}]_s = (N_{u,s} - 1) P_{r,s}^2 (p\alpha_s - q\alpha_s^2) \quad (20)$$

The variance of the total interference power due to the service s is given by:

$$\text{var}[P_{\text{int}}]_{r,s} = \text{var}[P_{\text{inter}}]_s + \text{var}[P_{\text{intra}}]_s \quad (21)$$

The variance of the total interference power due to all service s is given by:

$$\text{var}[P_{\text{int}}]_r = \sum_{s=1}^S \text{var}[P]_{r,s} \quad (22)$$

Thus, for a given outage probability, the uplink carrier-to-interference ratio $\left[\frac{C}{I}\right]_s$ for a

given service s is given as:

$$\left[\frac{C}{I}\right]_s = \frac{P_{r,s}}{P_N + E[P_{\text{int}}]_r + \gamma\sqrt{\text{var}[P_{\text{int}}]_r}} \quad (23)$$

Where P_N is the receiver noise power and γ is a factor that depends on the outage probability (2.05 for outage probability of 2% and it is 2.33 for an outage probability of 1%). In the denominator of (23), the first term represents the noise meanwhile the second and the third term represent the interference.

For a given service, the $(E_b/N_o)_s$ ratio is given as:

$$\left[\frac{E_b}{N_o}\right]_s = \left[\frac{C}{I}\right]_s G_{p,s} \quad (24)$$

Where $G_{p,s}$ is the processing gain of the service s.

Assuming a given number of users for each service, the relation (outage probability versus number of users) can be got using (23 and 24).

For mixed services of voice and data, the data user maximum transmitted power to the maximum transmitted power of the voice users given in dB should be:

$$\left(\frac{P_{td}}{P_{tv}} \right)_{dB} = (1 + \delta) \left[10 \log_{10} \left(\frac{G_{pv} / \left(\frac{E_b}{N_o} \right)_v}{G_{pd} / \left(\frac{E_b}{N_o} \right)_d} \right) \right] \quad (25)$$

Where

- P_{td} is the transmitted power of the data users the exists in the sector border,
- P_{tv} is the transmitted power of the voice users the exists in the sector border,
- δ is a constant with a value of 0.0 if only the mean value of the interference is considered. When the interference variance is also considered, it has a value of (-0.1 to 0.1) depending on the parameters of the services under study.
- G_{pv} is the voice service processing gain,
- G_{pd} is the data service processing gain,
- $(E_b/N_o)_v$ is the required (E_b/N_o) for voice service given in real numbers and
- $(E_b/N_o)_d$ is the required (E_b/N_o) for data service given in real numbers.

4- Numerical Results

We assume that the capacity of the femtocell is the number of simultaneous users that can be supported with an outage of 1%. To calculate the uplink capacity of the femtocell we have assumed the following:

- For data service

- $E_b/N_o = 3$ dB
- $G_p = 32$
- $\alpha = 1.00$
- $P_{t-max} = 23$ dBm

- For voice service

- $E_b/N_o = 7$ dB
- $G_p = 256$
- $\alpha = 0.66$
- $P_{t-max} =$ to be calculated

- Interference and propagation parameters

- $\sigma_{sh} = 3$ dB
- $C_{dm} = 0.5$
- $L_w = 6$ dB
- $L_f = 18$ dB
- $L_{facade} = 10$ dB

In this section we will analyze the uplink capacity for single, three femtocells within the same building and 9 femtocells within three near buildings. Also we will present the effect of the around macrocell users upon the uplink capacity of the femtocell when they share the same frequency band.

Firstly, we will study the case of single femtocell scenarios shown in Figure 2. In this case the user under study suffers from only the intracellular interference. The femtocell is assumed to be deployed in three-floor building with a width of 25 m and a height of 10 m.

Fig. 4 shows the femtocell performance for voice users only for two different σ_c namely 0.5 and 1 dB. It can be noticed that the femtocell uplink capacity is 63.2 and 61.1 voice users respectively. In this case the maximum transmitted power has been calculated to be 17.9 dBm. It can be noticed that increasing σ_c from 0.5 dB to 1 dB reduces the uplink capacity by 3.3%.

Fig. 5 shows the femtocell performance for data users only for two different σ_c namely 0.5 and 1 dB. It can be noticed that the femtocell uplink capacity is 14.86 and 13.58 data users respectively. It can be noticed that increasing σ_c from 0.5 dB to 1 dB reduces the uplink capacity by 8.6%.

Fig. 6 shows the femtocell performance for a mixture of data users and voice users for two different σ_c namely 0.5 and 1 dB. It can be noticed that the femtocell capacity is 31.8 and 28.5 voice users respectively assuming that 7 data users are also exist within the femtocell.

If we consider a single femtocell deployed in a building of 5 floors, uplink capacity will be 13.67 data users for σ_c of 0.5 dB and 12.46 data users for σ_c of 1 dB. Uplink capacity

will be 57.5 voice users for σ_c of 0.5 dB and 55.6 voice users for σ_c of 1 dB. This indicates that uplink capacity is now limited by interference and noise.

Secondly, let us now study the case of three femtocells scenario shown in Fig. 3, where the femtocell under study is the central one. In this case the user under study will suffer from the intracellular interference due to the users of the central femtocell and intercellular interference due to the users of the upper and lower femtocells. The three femtocells have been deployed in nine-floor building with a width of 25 m and a height of 30 m.

Fig. 7 shows the femtocell performance for voice users only for two different σ_c namely 0.5 and 1 dB. It can be noticed that the femtocell uplink capacity is 61.9 and 59.9 voice users respectively. In this case the maximum transmitted power has been calculated to be 17.7 dBm. Comparing these results with those of Fig. 4, we can notice that the capacity reduction is 2% due to the intercellular interference caused by the users of the upper and lower femtocells.

Fig. 8 shows the femtocell performance for data users only for two different σ_c namely 0.5 and 1 dB. It can be noticed that the femtocell uplink capacity is 14.53 and 13.30 data users respectively. Comparing these results with those of Fig. 5, we can notice that the capacity reduction is 2.1% due to the intercellular interference caused by the users of the upper and lower femtocells.

Fig. 9 shows the femtocell performance for a mixture of data users and voice users for two different σ_c namely 0.5 and 1 dB. It can be noticed that the femtocell uplink capacity is 27.8 and 24.4 voice users respectively assuming that 7 data users are also exist within the femtocell.

It has been noticed that almost all of the intercellular interference is due to the users of the extra femtocells that exist at the nearest floor to the femtocell under study. If all of the extra femtocell users exist in the nearest floor to the femtocell under study, then, the uplink capacity reduction will be almost the triple of the uplink capacity reduction assuming a uniform distribution of users in the two extra femtocells. This case (almost impossible case) represents the worst case. The best case will be got when all the extra femtocells' users exist in the same floor of the femtocell node with almost null effect.

In a 15 floors building with 5 deployed femtocells, the uplink capacity of the central femtocell will be almost the same as its uplink capacity in the 3 femtocells scenario.

Thirdly, let us study the case when 9 femtocells exist within three contiguous buildings assuming that each one of them has a brick facet.

Fig. 10 shows the femtocell performance for voice users only for two different σ_c namely 0.5 and 1 dB. It can be noticed that the femtocell uplink capacity is 60.7 and 58.8 voice users respectively.

Fig. 11 shows the femtocell performance for data users only for two different σ_c namely 0.5 and 1 dB. It can be noticed that the femtocell uplink capacity is 14.22 and 13.03 data users respectively.

Comparing these results with the results shown in Figures 7 and 8 it can be noticed that the effect of the intercellular interference due to the users of the 6 femtocells within the lateral buildings is relatively small.

Fourthly, let us study the case when 9 femtocells exist within three near buildings (with a 25 m distance between each lateral building and the central one) assuming that each one of them has a glass facades with 6 dB insertion loss.

Fig. 12 shows the femtocell performance for voice users only for two different σ_c namely 0.5 and 1 dB. It can be noticed that the femtocell uplink capacity is 60.8 and 58.8 voice users respectively.

Fig. 13 shows the femtocell performance for data users only for two different σ_c namely 0.5 and 1 dB. It can be noticed that the femtocell uplink capacity is 14.24 and 13.05 data users respectively.

Comparing these results with the results given by Fig. 10 and 11, it can be noticed that the uplink capacity is almost the same.

If the distance between the buildings is reduced to 15m, uplink capacity reduces to 59.9 voice users and 58 voice users for σ_c of 0.5 dB and 1 dB respectively. Uplink capacity reduces to 14.02 data users and 12.85 data users for σ_c of 0.5 dB and 1 dB respectively.

Finally, let us study the effect of the interference due to the users of the macrocell around the femtocell assuming that both of them use the same frequency band. Here we will assume that the macrocell users are at the macrocell edge transmitting the maximum possible power and they are only 10m from the building containing the femtocells. This scenario represents an extreme impractical case. Thus results represent the worst case uplink capacity. Propagation loss between the macrocell users and the

femtocell is assumed to be the sum of the free space propagation loss and the indoor propagation loss dealing with the facade, walls and floors penetration losses.

Table 1 shows the femtocell uplink capacity for the data service as a function of the number of near data users within the macrocell. For 12 macrocell data users, the uplink capacity is reduced by only 5.6%.

Table 2 shows the femtocell uplink capacity for the voice service as a function of the number of near voice users within the macrocell. For 36 macrocell voice users, the uplink capacity is reduced by only 9.8%.

If the users of the macrocell around the femtocell are uniformly or almost uniformly distributed, the effect of their interference on the femtocell uplink capacity is insignificant (lower than the effect of one near macrocell user).

5- Conclusions

In this work, the multiservice uplink capacity of femtocells has been given for single and multiple femtocells. The uplink capacity of a deployed femtocell will reduce by 2% if two femtocells are deployed in the same building up and lower of it. It has been noticed that the uplink capacity is little bit affected if there are several femtocells in the buildings around the one at which the femtocell under study is deployed. It has been noticed that uplink capacity is interference limited if the femtocell is deployed to serve the users in three floors. Uplink capacity will be interference and noise limited if the femtocell is deployed to serve the users in five floors. It is shown that the uplink capacity is little bit affected by the interference due to macrocell users when they share the same frequency band used by the femtocells. It has been found that the effect of the interference due to the uniformly distributed users within the macrocell around the femtocell is insignificant.

References

- [1] H. Claussen, "Performance of Macro- and Co- Channel Femtocells in a Hierarchical Cell Structure," Proc. IEEE 18th Internat. Symposium on Personal, Indoor and Mobile Radio Communications. (PIMRC '07), Athens, Greece, 2007.
- [2] H. Claussen, L. T. W. Ho, and L. G. Samuel, "An Overview of the Femtocell Concept," Bell Labs Tech. Journal, Vol. 13, No. 1, pp. 221–245, 2008.
- [3] V. Chandrasekhar and J. G. Andrews, "Femtocell Networks: A survey". University of Texas at Austin Alan Gatherer, Junio 2008.
- [4] Q. Kalhoro, M. A. Kalhoro, S. Abbasi, K. Khoumabti," Analysis of Femtocells Deployment with Different Air-Interfaces", 2010 12th International Conference on Computer Modeling and Simulation, pp.439-443, 2010.
- [5] F. Duran and G. G. Carrasco, "UMTS Femtocell Performance in Massive Deployments: Capacity and GoS Implications", Bell Labs Technical Journal Vol. 14, No. 2, pp. 185–202, 2009.
- [6] Femto Forum "Interference Management in UMTS Femtocells", December 2008.
- [7] Z. Shi, M. Zhao, M. C. Reed, and H. Wang, "On the Uplink Coverage and Capacity of UMTS Femtocells in Enterprise Environment". Available at: www.nicta.com.au/pub?doc=4110.
- [8] M. Yavuz, F. Meshkati, S. Nanda, A. Pokhariyal, N. Johnson, B. Raghothaman and A. Richardson," Interference Management and Performance Analysis of UMTS/HSPA+ Femtocells", IEEE Communications Magazine, pp. 102-109, September 2009.
- [9] Z. Shi, M. C. Reed M. Zhao, and H. Wang, "Uplink Interference Scenarios in Two-Tier Networks", 2010 Conference Record of the Forty Fourth Asilomar Conference on Signals, Systems and Computers (ASILOMAR), pp. 471-476, 2010.
- [10] H. A. Mahmoud, I. Güvenç, F. Watanabe, "Performance of Open Access Femtocell Networks with Different Cell-Selection Methods", VTC-2010-Spring, pp. 1-5.
- [11] V. Chadrasekhar, J. G. Andrews, T. Muharemovic, Z. Shen and A. Gatherer, "Power control in two-tier femtocell networks" IEEE Trans. Wireless Commutations, Vol. 8, No. 8, pp. 4316-4328, August 2009.

- [12] P. Xia, V. Chandrasekhar , J.G. Andrews, “CDMA Uplink Capacity in both Open and Closed Access Two-tier Femtocell Networks”, IEEE Globecom. 2010 Workshop on Femtocell Networks, pp. 648-652.
- [13] D. Chee; M. S. Kang; H. Lee; B. C. Jung, “A study on the Green Cellular Network with Femtocells” , Third International Conference on Ubiquitous and Future Networks (ICUFN), pp. 235-240, 2011 .
- [14] H. JO, C. Mun, J. Moon and J. G. Yook, "Interference mitigation using uplink power control for two-tier femtocell networks," IEEE Trans. Wireless Communications, Vol. 8, No. 10, pp. 4906- 4910, Octubre 2009.
- [15] B. T. Ahmed and M. C. Ramón, “WCDMA Multiservice Uplink Capacity of Highways Cigar-Shaped Microcells”, EURASIP Journal on Wireless Communications and Networking, Vol. 2007, pp. 1-8, 2007.
- [16] D. J. Cichon, T. Kürner , “Propagation Prediction Models”, available at: www2.it.lut.fi/kurssit/04-05/010651000/Luennot/Chapter4.pdf

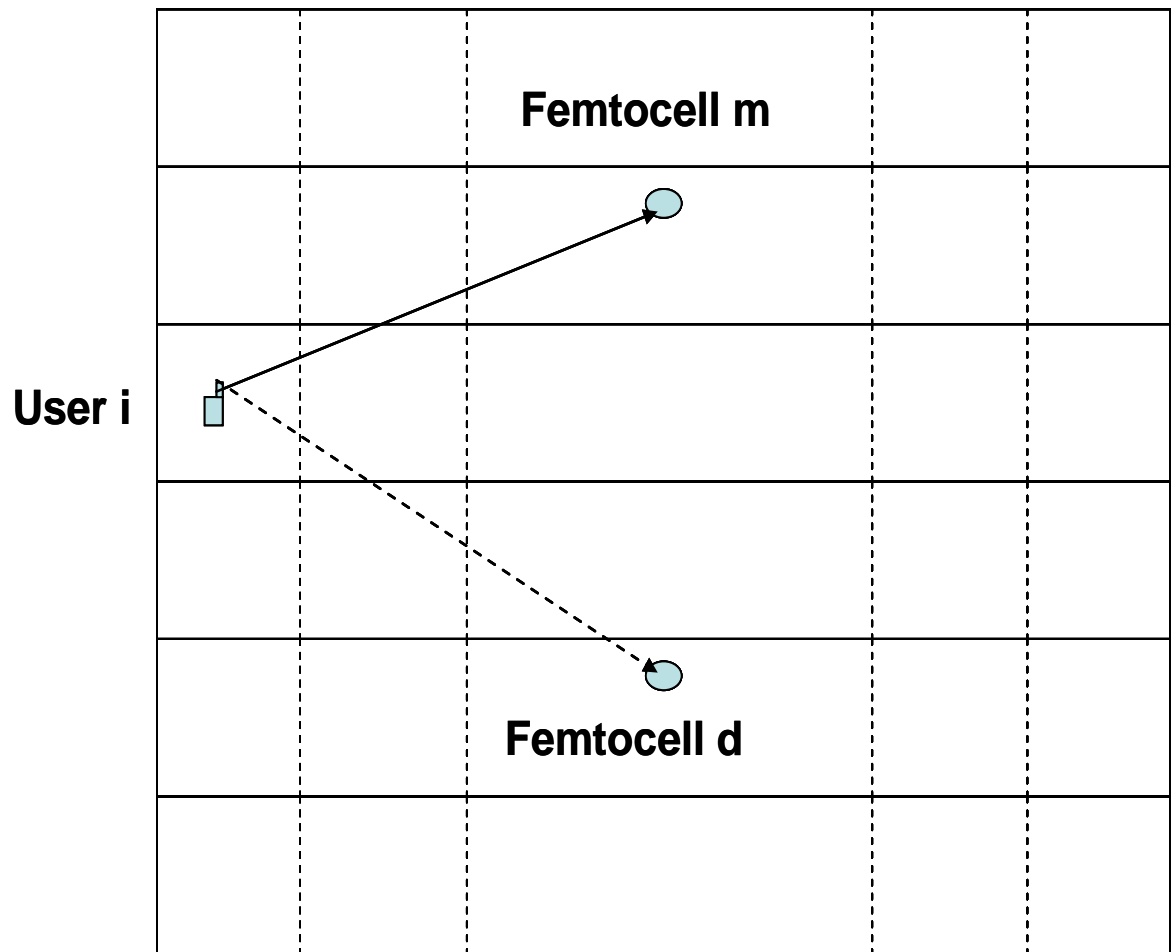


Fig. 1: Interference analysis.

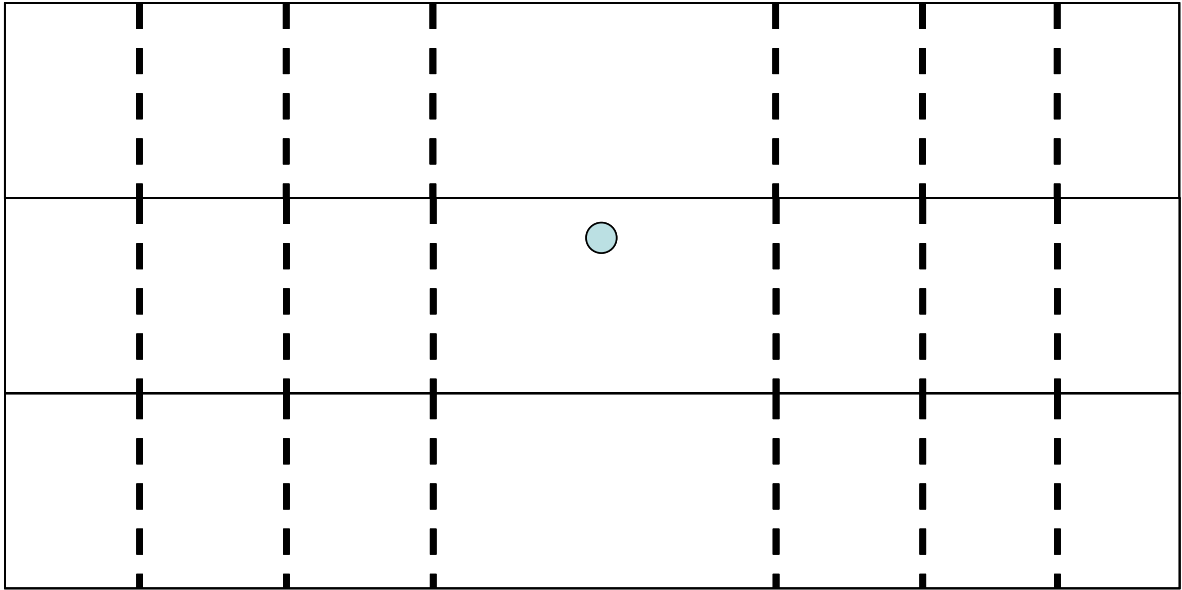


Fig. 2: Single femtocell configuration.

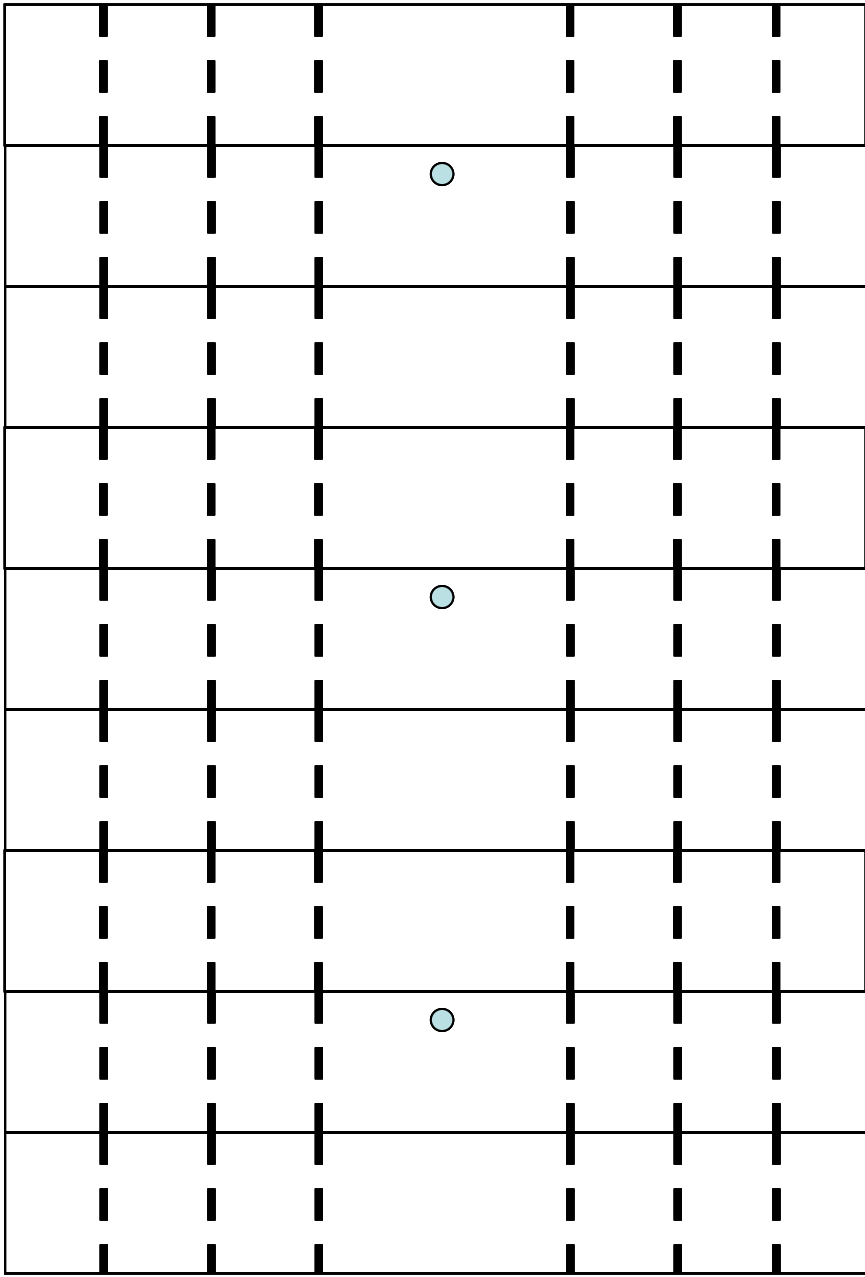


Fig. 3: Three femtocells configuration.

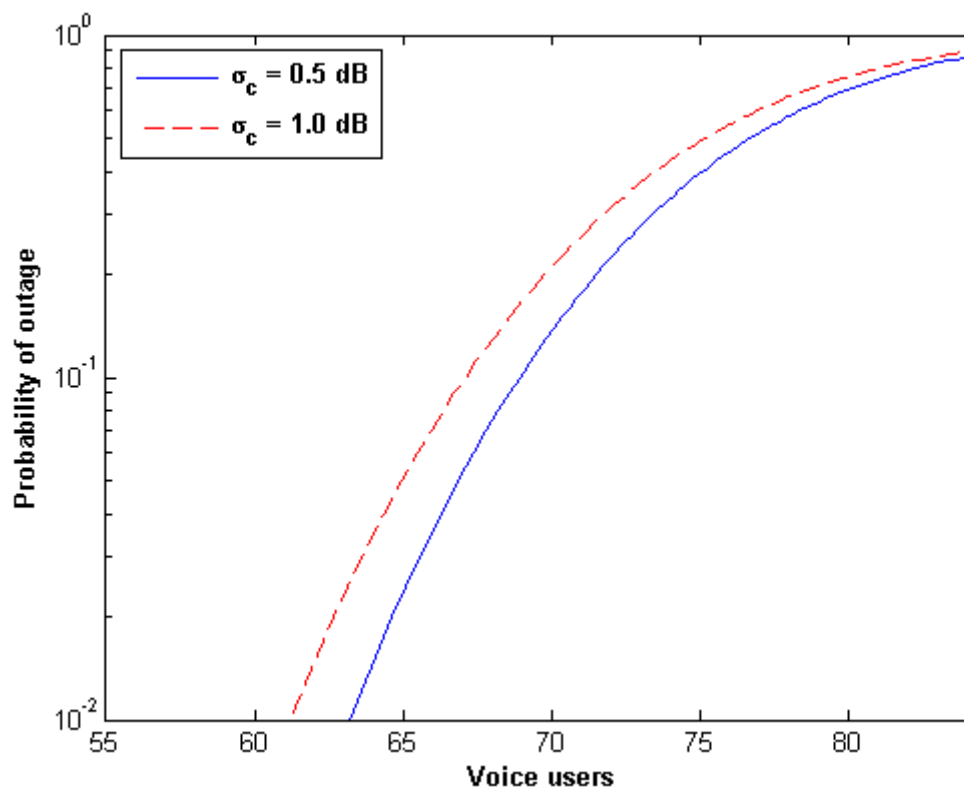


Fig. 4: Single femtocell performance for voice users only.

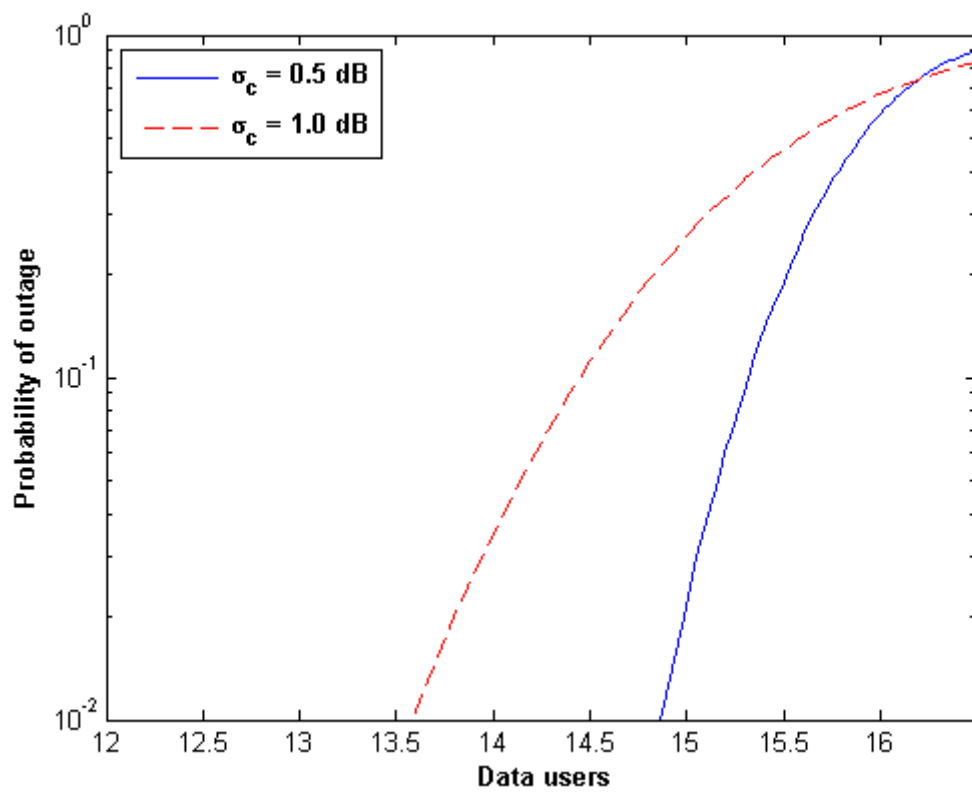


Fig. 5: Single femtocell performance for data users only.

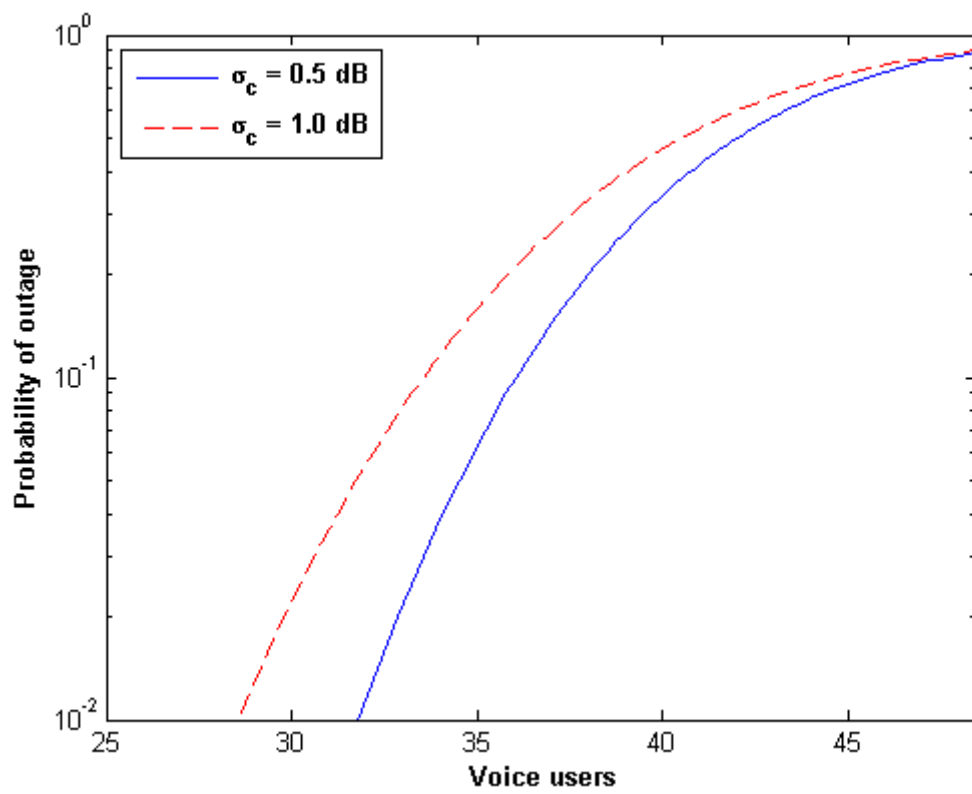


Fig. 6: Single femtocell performance for 7 data users and a given number of voice users.

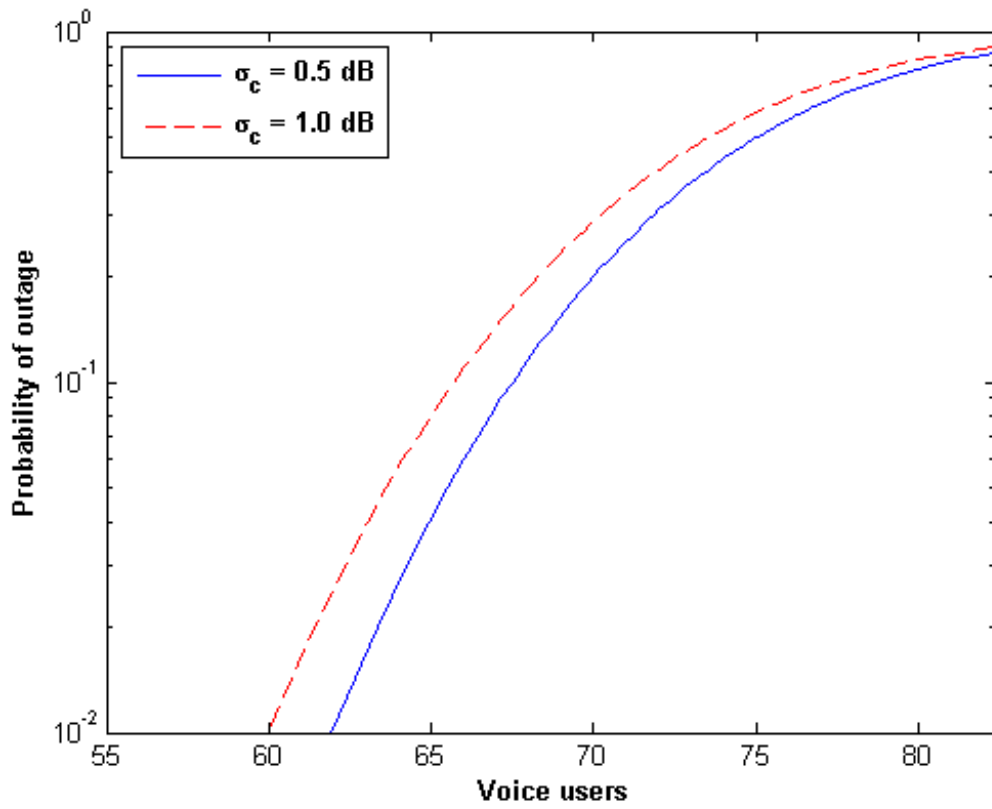


Fig. 7: Femtocell performance in the three femtocells scenario for voice users only.

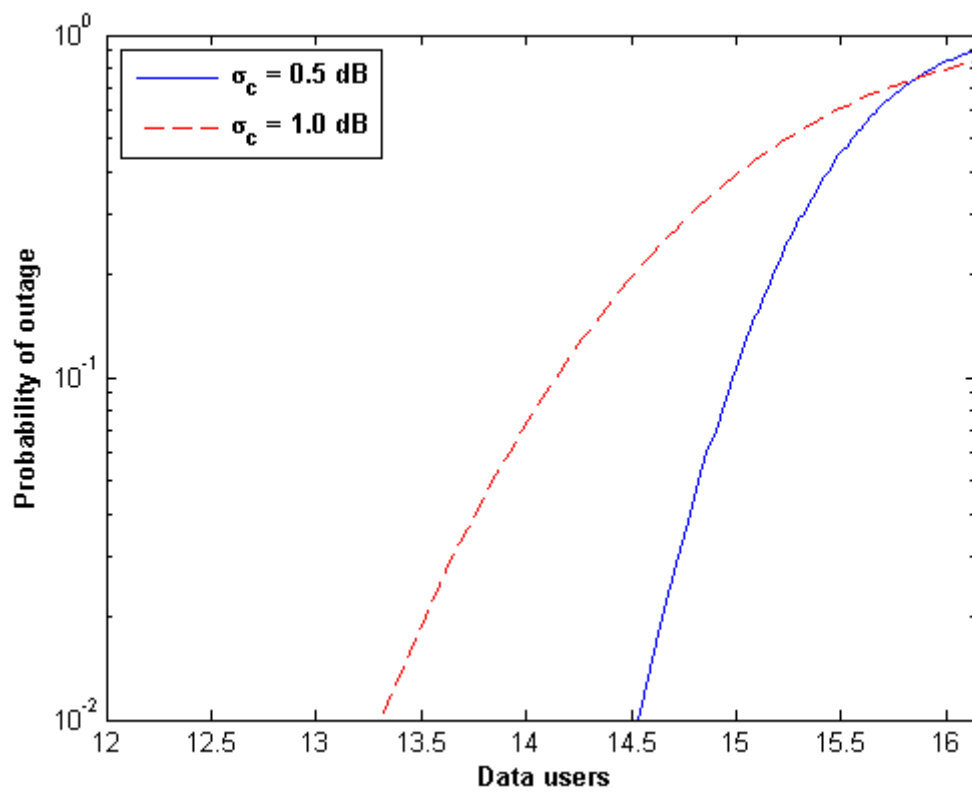


Fig. 8: Femtocell performance in the three femtocells scenario for data users only.

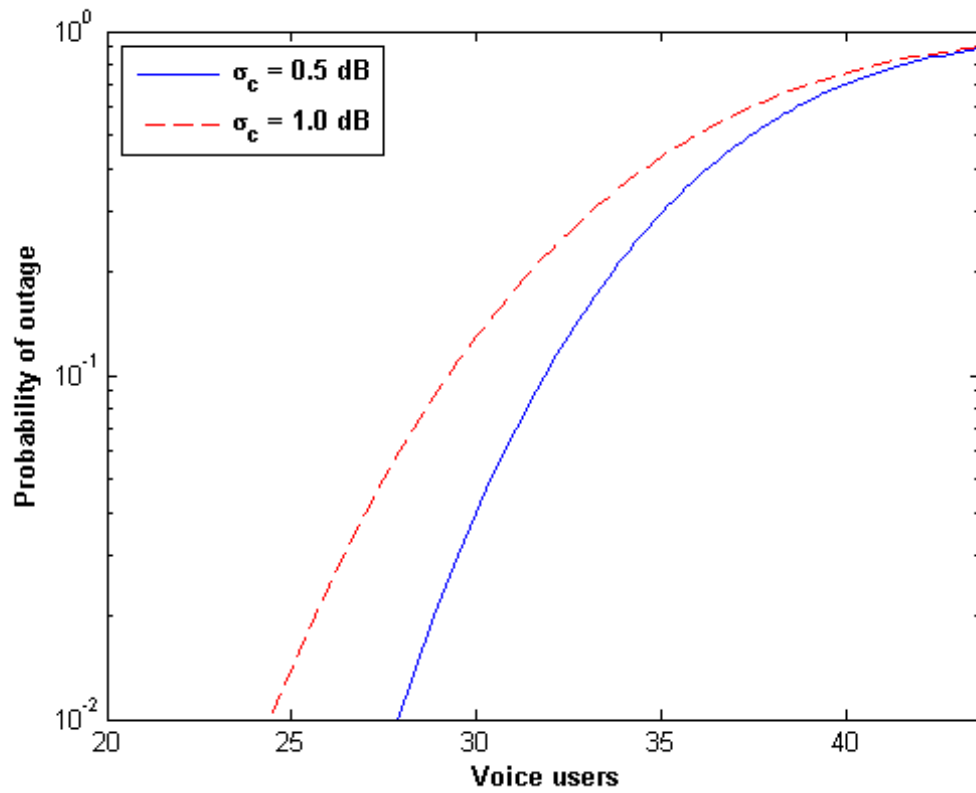


Fig. 9: Femtocell performance in the three femtocells scenario for 7 data users and a given number of voice users.

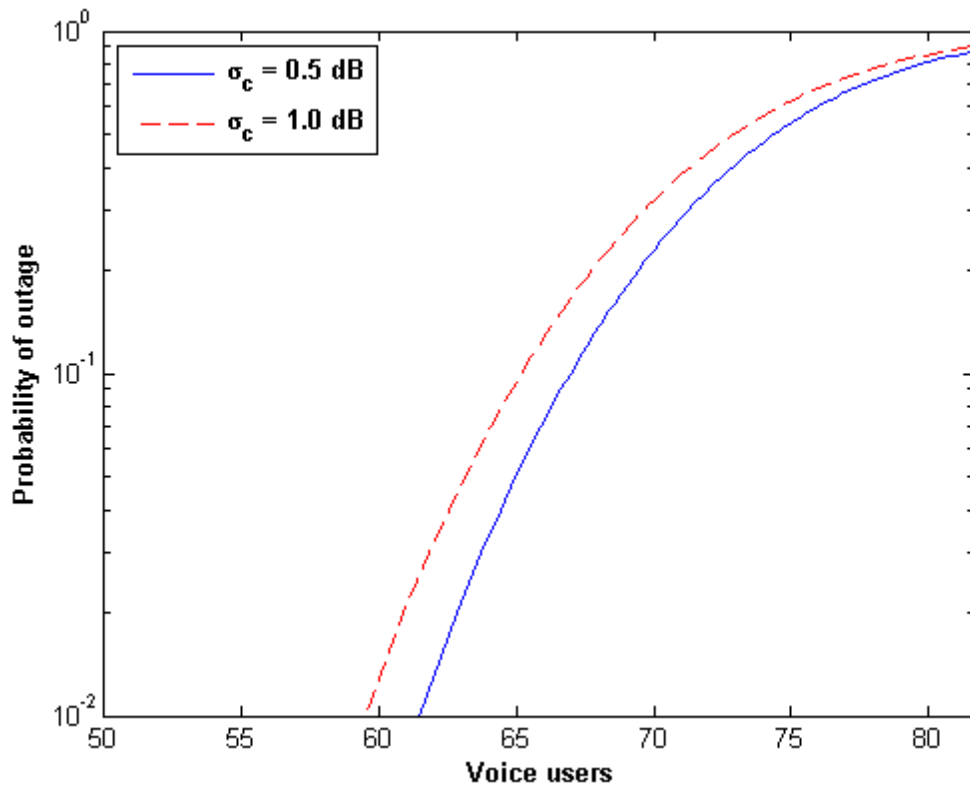


Fig. 10: Femtocell performance in the nine femtocells scenario for voice users only (for three building with brick facet).

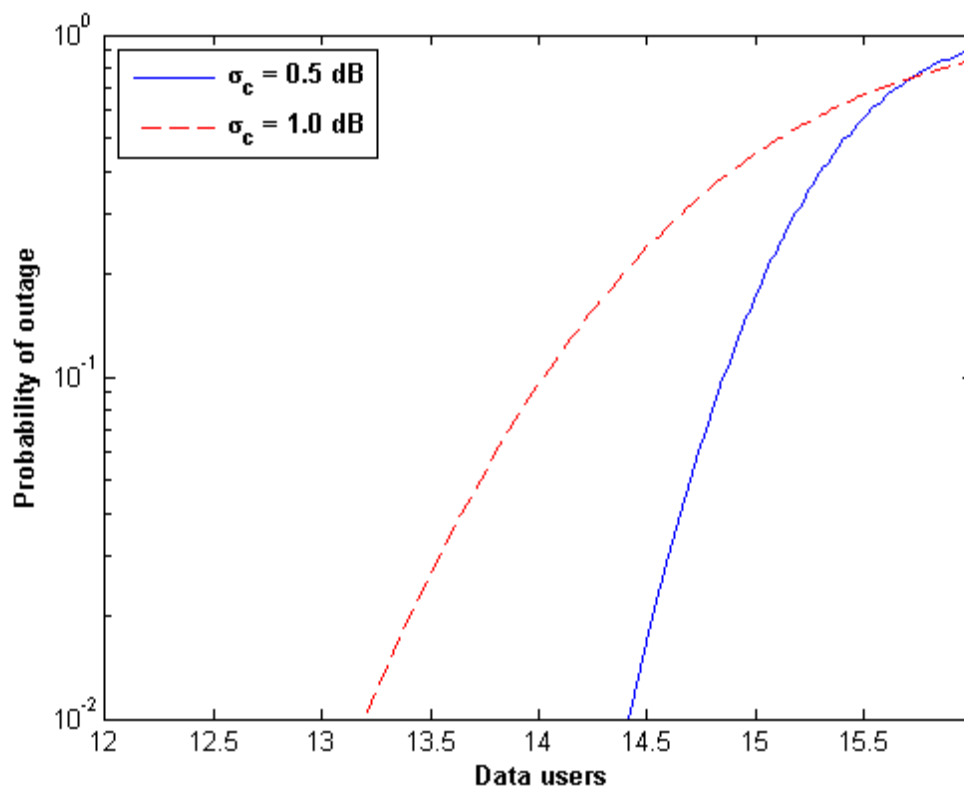


Fig. 11: Femtocell performance in the nine femtocells scenario for data users only (for three building with brick facet).

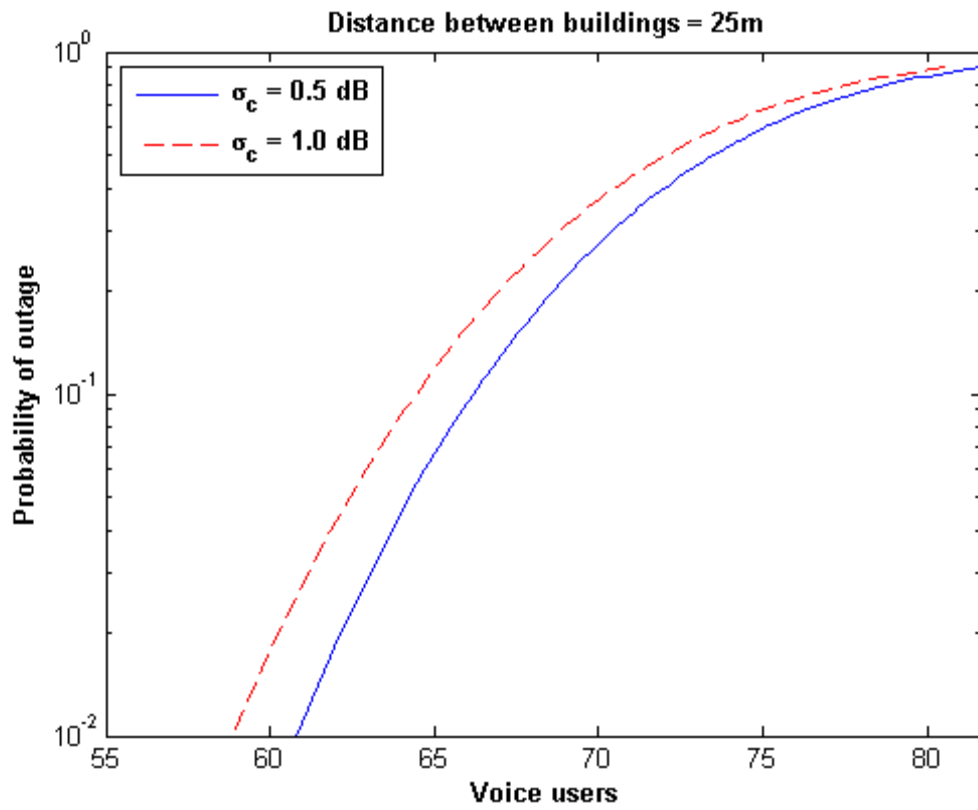


Fig. 12: Femtocell performance in the nine femtocells scenario for voice users only (for three building with glass facet).

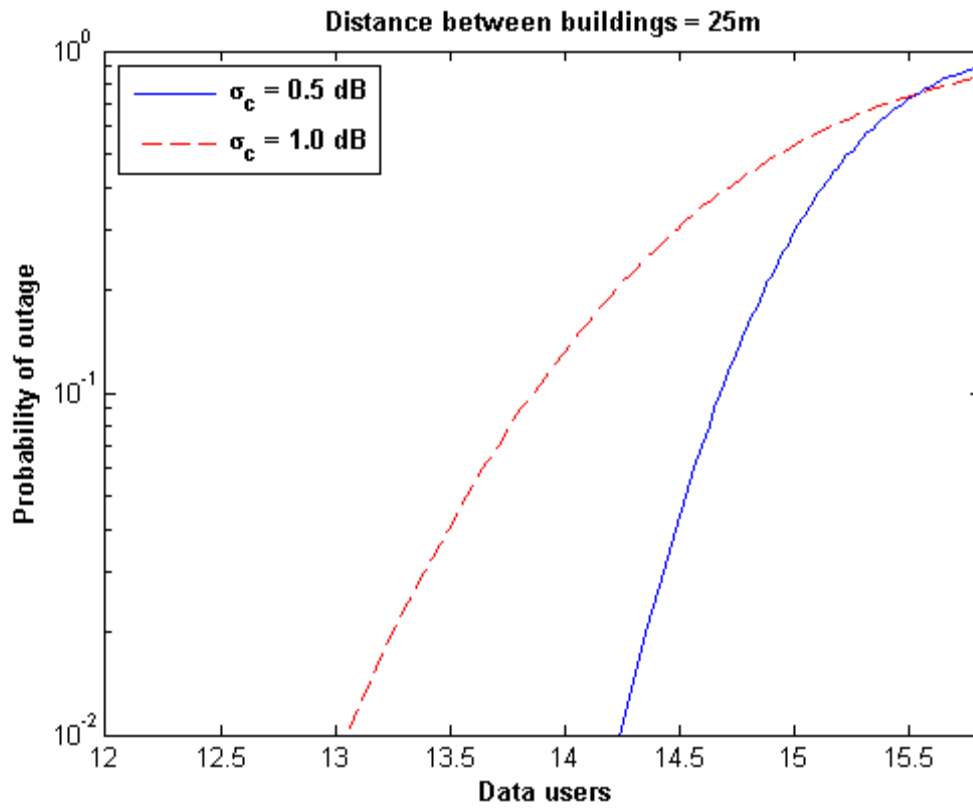


Fig. 13: Femtocell performance in the nine femtocells scenario for data users only (for three building with glass facet).

Table 1- Femtocell uplink capacity for data service as a function of the number of near data users within the macrocell around the femtocell.

Number of the near data users within the macrocell	Femtocell uplink capacity (data users)
0	14.53
1	14.46
4	14.26
12	13.72

Table 2- Femtocell uplink capacity for the voice service as a function of the number of near voice users within the macrocell around the femtocell.

Number of the near voice users within the macrocell	Femtocell uplink capacity (voice users)
0	61.93
1	61.76
4	61.26
12	59.90
36	55.85

Bazil Taha Ahmed was born in Mosul, Iraq, in 1960. He received the B. Sc. and M. Sc. degrees in Electronics and Telecommunication Engineering from the University of Mosul, in 1982 and 1985, respectively. He got the D.E.A and Ph. D degrees both in Telecommunication Engineering from the Polytechnic University of Madrid, in 2001 and 2003 respectively. Now he is working as an Associate Professor at the Universidad Autonoma de Madrid. He has published more than 90 scientific journal and conference papers in the area of the electromagnetic propagation and CDMA systems, particularly the CDMA capacity. His research interests include coexistence and wireless access technologies such as UMTS, WiMAX, Ultra Wideband systems and Personal Area Network (WPAN).



Marta Anaya de Paz was born in Madrid, Spain, in 1988. She is working toward the M. Sc. Degree in Telecommunication Engineering. Her research interests include coexistence and wireless access technologies such as UMTS, WiMAX and Personal Area Network (WPAN).

