Dynamic power allocation and RRM parameters

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ABSTRACT

This paper describes a powerful formulation to solve UTRA-FDD Power Allocation for both UL and DL, considering Soft Handover, multiple services, as well as dynamic changes. Some of the parameters obtained as outputs of the Power Control algorithm (PC) can be also easily used to optimise the admission procedure and evaluate system capacity, while avoiding cell congestion.

I. INTRODUCTION

Computer time optimisation in reallocating resources in a UTRA-FDD environment is of great importance. For this reason we propose the use of a fast macroscopic algorithm to solve power control equations [1], jumping automatically to a classical iterative algorithm only when the interference level is so high that there is no macroscopic solution. So the objective of this work is the complete description of the equations required to solve the fast dynamic power control allocation, as well as the analysis of the results obtained under different UMTS scenarios. The developed system accounts for: UL/DL connections, macrodiversity, variation of the UE Active Set parameters (maximum number of BS's included and window size in dB), soft handover mechanisms, variation of the BS's pilot power, user mobility, scenario with different services and RAB's formats. As will be shown, the power control algorithm returns, as outputs of the system and with a frame periodicity, a set of parameters that allow a fast evaluation of the BS's load, the interference factor, the accumulated SSIR, etc. This parameters can be easily used as inputs of the admission and congestion control algorithms. The algorithm described in this paper has been applied to an OPNET UTRAN platform to study RRM and QoS issues for the ARROWS project in the frame of the IST research program, and it is under implementation to a real time UTRAN emulator.

II. UL SYSTEM MODEL

An scenario with M BS's and K UE's is considered. A reduced set of UL input parameters are required: target SIR $\gamma(k)$ for each UE, Base Station acting as Best Server s(k) for each UE, BS thermal noise N(m), attenuations between BS's- UE's $L_p(m,k)$.

The number of UE's performing macrodiversity can be high, in a real scenario. Then the system should be solved for all the combination of possible connections, which has no sense. Through this paper, a macrodiversity UE will be modelled as independent UE's, each one connected to one BS's of the AS (what we have previously called BS acting as Best Server). So the equivalent number of UE in the scenario is K'>K.

$P_T(k)$ is the power transmitted by UE k, $P_R(m,k)$ power received in BS m from UE k, $P_{R,tot}(m)$ and $N_T(m)$ total received power in BS m without/with thermal noise, and $P_{R,tot}(m)|_{k\in m}$ the power received in BS m coming only from the users served by m.

The SSIR ($\gamma'(k)$) depending on the SIR ($\gamma(k)$) for UE k is:

$$\gamma'(k) = \frac{\gamma(k)}{1+\gamma(k)} = \frac{P_R(s(k),k)}{P_{R,tot}(s(k)) + N(s(k))} = \frac{P_R(s(k),k)}{N_T(s(k))} = \frac{P_T(k)}{N_T(s(k))L_p(s(k),k)} \quad (1)$$

The Accumulated SSIR for BS m is obtained from:

$$P_{R,tot}(m)\ \Big|_{k\in m} = \sum_{\substack{k=1 \\ k\in m}}^{K'} P_R(m,k) = N_T(m)\cdot \sum_{\substack{k=1 \\ k\in m}}^{K'} \gamma'(k) \quad (2)$$

As $P_{R,tot}(m)$ is always lower than $N_T(m)$, the following condition should be accomplished:

$$ASSIR(m) = \sum_{\substack{k=1 \\ k\in m}}^{K'} \frac{1}{1+\dfrac{SF_k}{(E_b/N_o)_k}} \le 1 \quad (3)$$

The ASSIR is equivalent to the cell load factor in a single cell scenario. The way to add and remove BS's from a UE AS follows [2], considering also the evolution of ASSIR and the cell load factor, which will be later expressed.

A.. Power Control Algorithm

The set of equations to solve is $AN_T = N$ with A(m,n) a MxM matrix given by:

$$A(m,n) = \delta_{m,n} - \sum_{\substack{k=1 \\ k\in n}}^{K'} \frac{L_p(n,k)}{L_p(m,k)}\cdot \gamma'(k) \quad (4)$$

After solving, UE's with more than one BS in the AS choose the connection with lower $P_T(k)$ and remove the other ("virtual connection”). The connection to a given BS will be maintained for a TTI (10 ms to 40 ms depending on the service), so during this time no “virtual connections” will be considered. A fine adjust can be performed solving the system once the virtual connections have been eliminated.

To test the behaviour of different RRM algorithms, which is the main objective of the ARROWS project, high interference scenarios should be simulated. Unfortunately, in overloaded cells, when adding the “extra virtual load” due to macrodiversity UE’s, the interference could be so high than macroscopic algorithm is not able to solve the equation system. Another drawback is that the macroscopic algorithm gives no indication of which are the conflictive UE’s nor the cells. To solve this problem a combination of macroscopic and iterative algorithm is proposed (for both UL and DL), that automatically jumps to the iterative if necessary. As the iterative algorithm starts with $P_T(k)$ from the previous frame, the convergence criterion is quickly achieved. If the power transmitted by a given UE $P_T(k)$ is higher than the maximum allowed transmitted power ($P_{T,max}$), the UE transmits $P_{T,max}$ and will not met SIR target. As this is undesirable, the UE-MAC should anticipate to this, by observing the evolution of its $P_T(k)$, and selecting a lower Transport Format (TF), if it is close to $P_{T,max}$.

B. Cell load and interference factor

The PC algorithm returns directly $N_T(m)$, and then the cell load factor is quickly obtained, helping congestion and admission protocols to take decisions. The load factor is given by the balance between users received power and total power:

$$\eta(m) = \frac{N_T(m) - N(m)}{N_T(m)} < \eta_{\max} < 1 \qquad (5)$$

This is periodically checked to decide if new connections can be accepted and also to manage RRM algorithms. From (5) and (1), the total received power at BS m is:

$$P_{R,tot}(m)\Big|_{k\in m} = \frac{N(m)}{1-\eta(m)} ASSIR(m) \qquad (6)$$

Following the definition of ASSIR it is possible to express the power transmitted by user k as function of the load factor.

$$P_T(k)\Big|_{k\in m} = \frac{N(m)}{1-\eta(m)} \cdot \gamma'(k) \cdot L_p(m,k) \qquad (7)$$

Finally the interference (f) factor is:

$$f(m) = \frac{N_T(m) - N(m)}{P_{R,tot}(m)\Big|_{k\in m}} - 1 = \frac{\eta(m)}{ASSIR(m)} - 1 \qquad (8)$$

C. Admission protocol

The cell load can change significantly in consecutive frames, even if no new connections have been admitted. For this reason the admission protocol takes decisions over the load and interference factor averaged by a sliding window. The following steps define the admission protocol:

- Calculate the extra load added by the possible new connection:

$$\eta_{new}(m) = \eta_{sl}(m) + \left[1 + f_{sl}(m)\right] \cdot \gamma'(k) < \eta_{\max} \qquad (9)$$

- Calculate the transmitter power required by the new connection to achieve the Eb/No target.

$$P_T(k)\Big|_{k\in m} = \frac{N(m)}{1-\eta_{new}(m)} \cdot \gamma'(k) \cdot L_p(m,k) < P_{T,\max}(k) \qquad (10)$$

Expressions (9) and (10) are an approximation (they don’t include the variation in f due to the new connection). If the new load is lower than maximum load considered (0.75 in the simulations), and the transmitted power is lower than $P_{T,max}$ with an additional margin (5 dB in the simulation), to assure that new connection will not be immediately in a soft handover process, then the new connection is accepted. If we decide to use the lowest TF (highest SF) the admission will be maximized, but congestion problems should appear, and QoS of the connections will not be assured. For this reason a medium TF or even the highest TF will be considered in the admission.

III. DL SYSTEM MODEL

A UE could receive signal from all the BS in its AS, combining them to obtain the target SIR. Input parameters, not defined in UL are: thermal noise N(k) for each user, pilot power i(m) for each BS, orthogonality factors between BS’s and UE’s ρ(m,k) (ρ < 1 for the BS’s in the AS of user k and ρ=1 for the rest), combining matrix c(m,k) with the fraction of target Eb/No of UE k that is fulfilled by BS m ($c(m,k) \cdot \gamma(m) = \gamma(m,k)$). $P_{T,tot}(m)$ is the total transmitted power of BS m and $P_T(m,k)$ transmitted power from BS m to UE k.

The SSIR received by UE k from BS m, is expressed by:

$$\gamma'(m,k) = \frac{\gamma(m,k)}{1+\rho(m,k)\cdot\gamma(m,k)} = \frac{P_T(m,k)/L_p(m,k)}{\sum_{n=1}^{M}\frac{P_{T,tot}(n)\cdot\rho(n,k)}{L_p(n,k)} + N(k)} = \frac{P_T(m,k)}{N_T(k)\cdot L_p(m,k)} \qquad (11)$$

The power transmitted by BS m is:

$$P_{T,tot}(m)=\frac{i(m)+\sum_{k=1}^{K}\gamma'(m,k)L_p(m,k)\left[X(k)+N(k)\right]}{1-\sum_{k=1}^{K}\gamma'(m,k)\rho(m,k)} \quad (12)$$

where $P_{T,tot}(m)$ should be lower than $P_{T,max}$ and:

$$X(k)=\sum_{\substack{n=1\\ n\notin m}}^{M}\frac{P_{T,tot}(n)\rho(n,k)}{L_p(n,k)} \quad (13)$$

In this case:

$$\begin{aligned}ASSIR&=\sum_{k=1}^{K} SSIR(m,k)=\sum_{k=1}^{K}\gamma'(m,k)\rho(m,k)=\\&=\sum_{k=1}^{K}\frac{\gamma(m,k)\rho(m,k)}{1+\gamma(m,k)\rho(m,k)}\leq 1\end{aligned} \quad (14)$$

A.. Power Control Algorithm

The linear system to solve is $A\cdot P_{T,tot}=B$, being A and B:

$$A(m,n)=\delta_{m,n}-\sum_{\substack{k=1\\ k\in m}}^{K}\frac{L_p(m,k)\cdot\rho(n,k)}{L_p(n,k)}\cdot\gamma'(m,k) \quad (15)$$

$$B(m)=i(m)+\sum_{\substack{k=1\\ k\in m}}^{K}\gamma'(m,k)\cdot N(k)\cdot L_p(m,k) \quad (16)$$

If $P_{T,tot}$ (m) is close $P_{T,max}$ while their neighbours are far from this limit, the BS reduces its pilot power and can also reduce the TF of some connections.

B. Cell load and interference factor

DL cell load is the sum of load factors of UE's served by m. The load factor of a UE, is the relation between interference and total noise, averaged by the fraction of transmitted power by m, devoted to him. From (11):

- for user k

$$\begin{aligned}\eta(m,k)&=\left[\frac{N_T(k)-N(k)}{N_T(k)}\right]\frac{P_T(m,k)}{P_{T,tot}(m)}=\\&=\left[1-\frac{N(k)\cdot\gamma'(m,k)\cdot L_p(m,k)}{P_T(m,k)}\right]\frac{P_T(m,k)}{P_{T.tot}(m)}\end{aligned} \quad (17)$$

- for BS m

$$\eta(m)=\sum_{\substack{k=1\\ k\in m}}^{K}\eta(m,k)=1-\frac{1}{P_{T,tot}(m)}\sum_{\substack{k=1\\ k\in m}}^{K}N(k)\cdot\gamma'(m,k)\cdot L_p(m,k) \quad (K>0) \quad (18)$$

Load factor is easily obtained, because the algorithm returns the total transmitted power by all the BS's in the scenario. The transmitted power by BS m as function of the load factor is:

$$P_{T,tot}(m)=\frac{1}{1-\eta(m)}\sum_{\substack{k=1\\ k\in m}}^{K}N(k)\cdot\gamma'(m,k)\cdot L_p(m,k) \quad (19)$$

DL interference factor for a given UE, and for the cell, are:

- for user k

$$\begin{aligned}f(m,k)&=\left[\frac{N_T(k)-N(k)}{\rho\cdot P_{T,tot}(m)/L_p(m,k)}\right]\frac{P_T(m,k)}{P_{T,tot}(m)}=\\&=\frac{\eta(m,k)}{\rho\cdot\gamma'(m,k)}-\frac{P_T(m,k)}{P_{T.tot}(m)}\end{aligned} \quad (20)$$

- for BS m

$$f(m)=\sum_{\substack{k=1\\ k\in m}}^{K}f(m,k)=\sum_{\substack{k=1\\ k\in m}}^{K}\frac{\eta(m,k)}{\rho\cdot\gamma'(m,k)}-1 \qquad K>0 \quad (21)$$

IV. SIMULATION AND RESULTS

Results will be given for:

- rural area (20x20 km) with 14 sites with cell radius 2 km (3 sectors/site) with simultaneous uniformly distributed UE.
- urban area (5x5 km) with 14 sites with cell radius 500 m (3 sectors/site) with simultaneous uniformly distributed UE.

Five cases have been analysed (500 runs/each):

- 1000, 2000, 3000 UE (at a speed of 50 km/h) with an Active Set Window of 3 dB and maximum number of BS in the AS equal to 2.
- 2000 UE with 80% of indoor UE (7 dB building penetration loss) and 20% at a speed of 50 km/h. (same AS parameters). To analyse the influence of indoor users.
- 3000 UE (at 50 km/h) without macro diversity (AS size equal to 1).

Figures 1 to 4 show the UL/DL distribution of the load factor in rural and urban areas respectively. The legend is the same for all the figures and for this reason it has been included only in the first one. As K increases, wider variance is observed in UL/DL. Mean load factor values are low in rural scenario (<0.6), but the tail to higher values means that, even in this case, congestion algorithms are necessary to avoid instability. In urban areas the DL is almost equal to rural areas while the UL load distribution is more flat and extends to higher load values. This is due to the fact that $N_T(m)$, the total received power at the BS concentrates between –106 and –102 dBm in rural scenarios, while in urban a high variation is observed (between –106 and –94 dBm). The number of users per cell is the same but as the cell size is lower, the number interfering users coming from other cells increases considerably. Differences between indoor and outdoor. are due to the lower target Eb/No demanded by indoor UE.

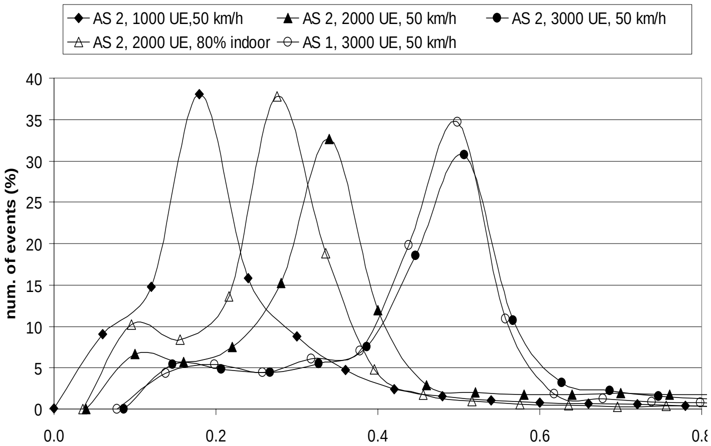

Figure 1: rural UL load factor distribution

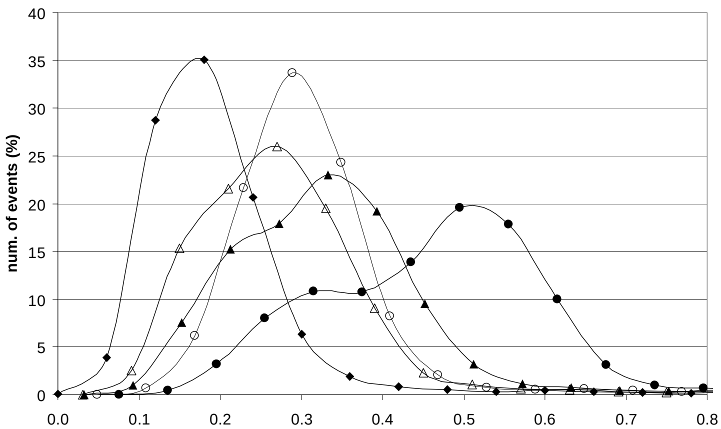

Figure 2: rural DL load factor distribution

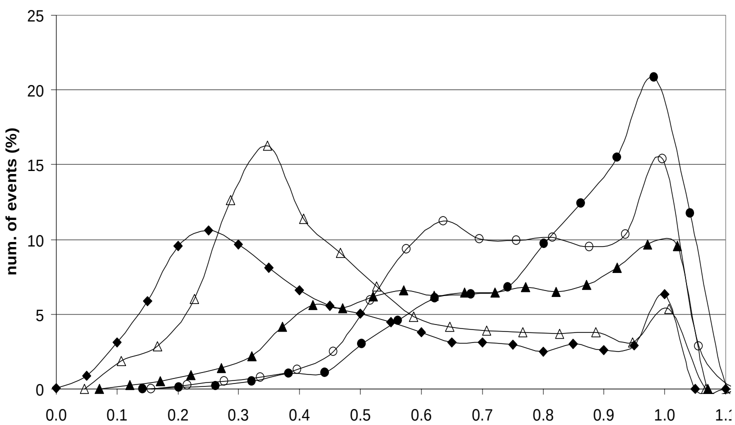

Figure 3: urban UL load factor distribution

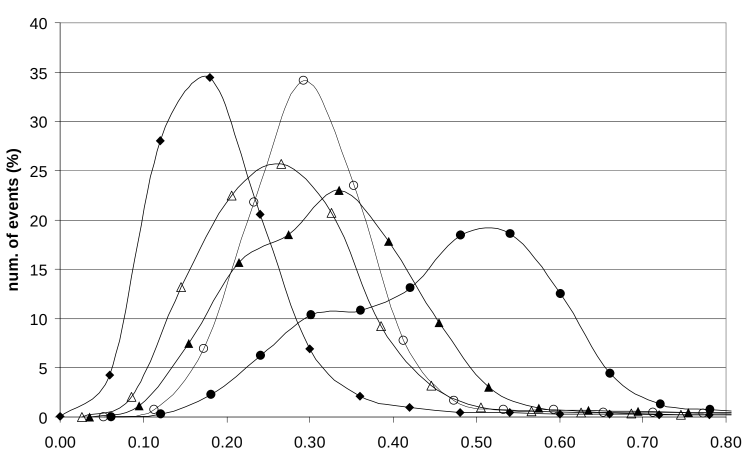

Figure 4: urban DL load factor distribution

There is similarity between AS 1 and 2 in UL. This is due to the fact that the load is calculated on a frame by frame basis and after solving the power control algorithm, so a UE in macro diversity, already knows to which BS is connected (demands less transmitted power). Nevertheless, in DL the scenario with AS=2 shows higher load and interference factors than with AS=1. The number of UE's attended by the BS in the DL is considerably higher due to macrodiversity. Macrodiversity connections are usually the most demanding connections because correspond to UE in the limits of the coverage area.

Figures 5 and 6 show f factor for UL/DL for rural scenario.

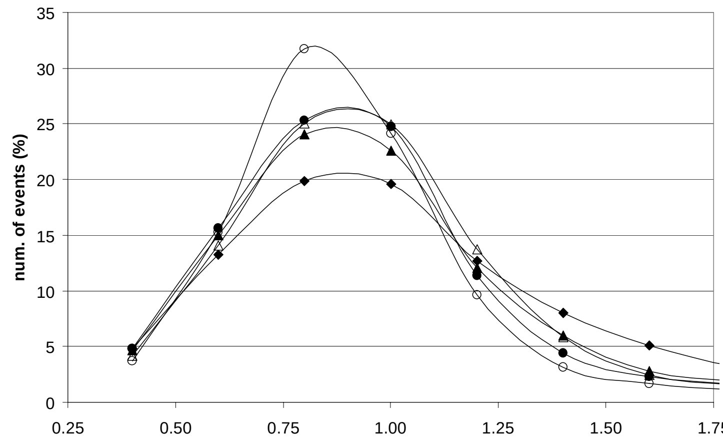

Figure 5: rural UL interference factor (f) distribution

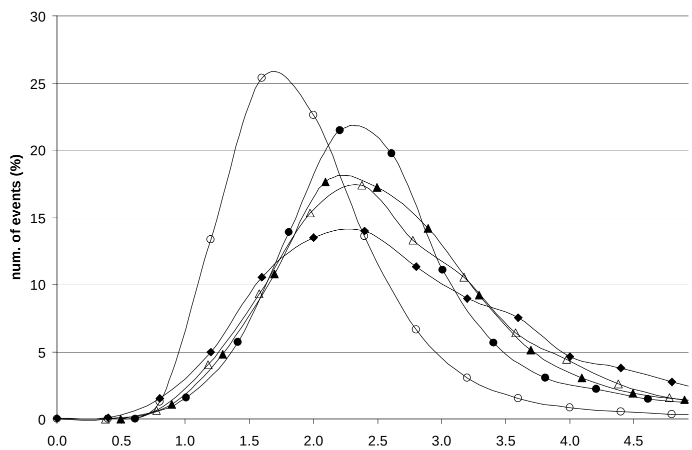

Figure 6: rural DL interference factor(f) distribution

The high variance in f shows that real instead of mean f values, should be used when testing RRM algorithms. Mean values are quite similar in UL (as the number of UE increases, both the inter and intracell interference increase), while in DL the case without macrodiversity has lower mean f value, as is expected. Analysing f factor for the urban scenario the same behaviour that in rural is obtained for the DL. In the UL the distribution extends to higher f values. When performing the distribution of users in the scenario, a uniform distribution over the scenario, not on a cell per cell basis, is considered. This means that sometimes we can have a cell with few connections (low intracell interference) surrounded by heavy loaded cells (causing a high intercell interference), which gives a high interference factor. As this is also a realistic situation.

Figures 7 to10 show the distribution of BS and UE transmitted powers for rural and urban environments respectively.

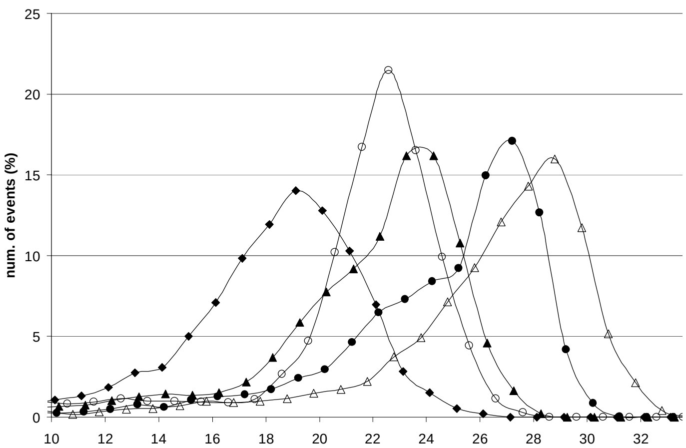

Figure 7: rural BS transmitted power distribution (dBm)

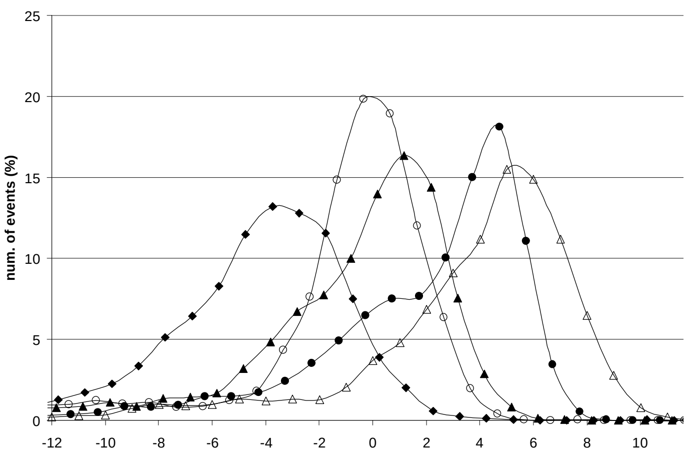

Figure 8: urban BS transmitted power distribution (dBm)

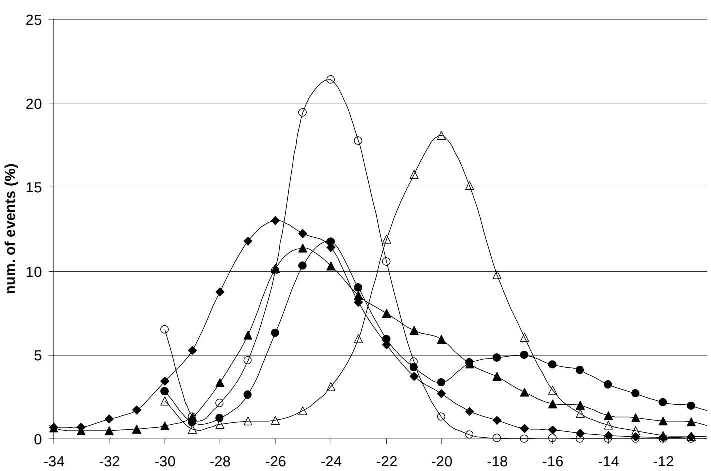

Figure 10: urban UE transmitted power distribution (dBm)

Comparing indoor and outdoor results we obtain the same shape but with a difference around 22 dB in both BS-UE transmitted powers. DL cell load is similar for both environments, meaning that the extra power transmitted by the BS is mainly due that the cell area is higher, so UE with higher attenuation will be connected to the BS. As the number of UE increases, the distribution of the power transmitted by the UE is more flat in urban than in rural scenarios. This is in concordance with the previous results obtained for the cell load and the interference factor. Even with low transmitted powers (mean value around –24 dBm) the urban scenario can be close to maximum load, due to system interference. Scenario with indoor UE is the closer to maximum allowable values in both UL and DL (an indoor UE has to transmit higher power to compensate the building penetration loss, and a BS serving indoor UE has to transmit more power also) . There are no differences between AS 1 and 2 in the UL powers, while in the DL, the scenario with macro diversity demands more BS transmitted power (to serve UE in the macro diversity area, usually at the borders of the cell).

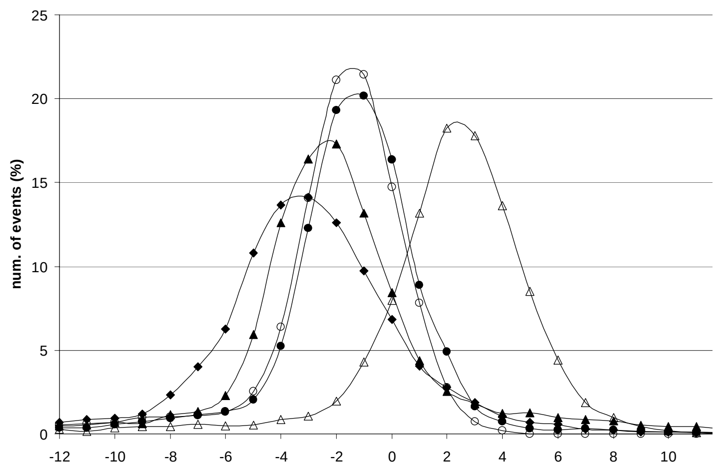

Figure 9: rural UE transmitted power distribution (dBm)

V. CONCLUSION

A fast power control algorithm has been implemented. It also returns a set of parameters, which allow to calculate very quickly the load and interference factors of the cells. This set of algorithms allow to test different Admission and Congestion control protocols to evaluate and compare their performance. Also the importance of a good estimations of the interference factor, due to its variability, has been proved. Finally we have shown that it is important to include realistic indoor traffic in the scenarios when analysing RRM algorithms and UMTS capacity.

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