Capacity Estimation of Multi-Service Cellular Network

Dimensioning and Planification Network

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***Abstract*—Planning and dimensioning process of a multi-service network WCDMA should consider the whole parameters characterising the radio cell. Among these, we are interested in the required total BTS power and maximum capacity supported by the cell in the downlink direction. This direction requires more radio resources, thus it is more delicate to optimize.**

In this context, we express these two parameters as a function of the quality of service (QoS) received at the level of a mobile station activating a certain service (voice, video, etc) and as a function of various radio interface problems such as: multipath, neighbouring cells effect, pathloss, thermal noise due to equipment, etc.

Keywords*— *WCDMA, downlink, multi-service network, capacity estimation, interferences, total power BTS estimation.

I. INTRODUCTION

The estimation of the WCDMA cell capacity is based on the signal to interferences ratio received at the level of an active mobile station in downlink and at the level of the base station [1]. This ratio is expressed as a function of the required power of a mobile station i activating a service j and as a function of various problems harming the radio interface, such as: other-to-own cell interference and thermal noise [1-3]. Thus, WCDMA network must allocate power by taking into account the required quality of service characterizing each service, and environmental conditions. This power is dynamically adjusted several times to preserve the bit energy to noise density (E_b/N_0) constant [1-7].

Our work starts by studying the total BTS power variation as a function of the number of users in the cell in downlink direction, for different values of other-to-own-cell interference ratio, in the case of voice service based network and then in the case of two services, voice and video. The downlink capacity is based on the total BTS power; however uplink capacity is based on the interferences level supported by the cell.

II. TOTAL BTS POWER ESTIMATION IN A MULTI-SERVICE NETWORK

A. Link quality equation

In a WCDMA network, cell capacity and BTS total power estimation is based on the link quality equation E_b/N_0 required for user i activating a certain service j (voice, voIP, web browsing, etc) in a cell m. This equation takes into account various radio interface problems: multipath propagation, neighbouring cell effect, path loss, thermal noise equipment etc…

The expression of E_b/N_0 equation for a user i $(i = 1..N_{user(j)}^{(m)})$ activating a service j $(j = 1...k)$ in the cell m can be written as:

$$(E_b/N_0)_{ij}^{(m)} = \frac{W P_{ij}^{(m)}/L_{ij}^{(m)}}{R_{ij}^{(m)}\left((1-\alpha_{ij}^{(m)}) P_{Tot}^{(m)}/L_{ij}^{(m)} + P_{Tot}^{(m)} \sum_{n=1, n\neq m}^{M} 1/L_{ijm}^{(n)} + P_N\right)} \qquad (1)$$

Where: W: Debit Chip; P_{Tot}: Total downlink transmission power of the cell m; M: Number of cells in the network; P_N: Thermal noise power of the mobile; $R_{ij}^{(m)}$: The bit rate of a user i activating a service j in a cell m; $P_{ij}^{(m)}$: Transmission power required for a user i activating a service j in a cell m; $L_{ij}^{(m)}$: Pathloss between base station (m) and a user i activating a service j; $L_{ijm}^{(n)}$: Pathloss between a base station (n) and a user i activating a service j in the cell m; $\alpha_{ij}^{(m)}$: Orthogonality factor of a user i activating a service j in the cell m.

B. BTS total power expression

From equation (1) the required power expression of a mobile i activating a service j in a cell m is :

$$p_{ij}^{(m)} = \frac{(E_b/N_0)_{ij}^{(m)} R_{ij}^{(m)}}{w}\left[(1-\alpha_{ij}^{(m)})P_{Tot}^{(m)} + P_{Tot}^{(m)} \sum_{n=1,n\neq m}^{M} \frac{L_{ij}^{(m)}}{L_{ijm}^{(n)}} + P_N L_{ij}^{(m)}\right] \quad (2)$$

The emission power of each radio link is corrected several times by calculating the difference between the found and the target value of E_b/N_0 until we reach the target value of E_b/N_0.

Equation (2) is multiplied by the channel activity factor $v_{ij}^{(m)}$ and summed up over k services of $N_{user(j)}^{(m)}$ and we consider that:

$$P_{Tot} = \sum_{j=1}^{k} \sum_{i=1}^{N_{user(j)}^{(m)}} p_{ij}^{(m)} \quad (3)$$

Consequently, the total BTS required power in a multi-service network is:

$$P_{Tot} = \frac{P_N \sum_{j=1}^{k} \sum_{i=1}^{N_{user(j)}^{(m)}} \frac{(E_b/N_0)_{ij}^{(m)} R_{ij}^{(m)} v_{ij}^{(m)}}{w} L_{ij}^{(m)}}{1 - \sum_{j=1}^{k} \sum_{i=1}^{N_{user(j)}^{(m)}} \left(\frac{(E_b/N_0)_{ij}^{(m)} R_{ij}^{(m)} v_{ij}^{(m)}}{w} \left((1-\alpha_{ij}^{(m)}) + f_{DLij}^{(m)} \right) \right)} \quad (4)$$

Where:

$$f_{DLij}^{(m)} = \frac{I_{inter}}{I_{intra}} = \sum_{n=1,n\neq m}^{M} \frac{P_{Tot}/L_{ijm}^{(n)}}{P_{Tot}/L_{ij}^{(m)}} = \sum_{n=1,n\neq m}^{M} \frac{L_{ij}^{(m)}}{L_{ijm}^{(n)}} \quad (5)$$

is defined as the other-to-own-cell interferences ratio received at a user i activating a service j in a cell m.

In downlink, this ratio $(0 \leq f_{DL} \leq 1)$ depends mainly on the user geographical position as well as on the neighbouring base stations power. Thus it's different for each user. If the user is located on the cell edge, the f_{DL} value is high. Contrary, if the user is close to his serving cell, f_{DL} value is small.

If $f_{DL}>1$, the mobile station is situated in an area where the neighbouring cell can serve it in a better manner than his serving cell.

The total transmission power is based on the user average transmission power and not on the required transmission power at the cell edge. Consequently, we consider the user in an average position in the cell, we assume that:

$$\alpha_{ij}^{(m)} = \alpha_{(moy)},\ f_{DLij}^{(m)} = f_{Dl(moy)} \text{ and } L_{ij}^{(m)} = L_{(moy)} \quad (6)$$

Where $\alpha_{(moy)}$, $f_{DL(moy)}$ and $L_{(moy)}$ are respectively, the average orthogonality factor, the average other-to-own-cell interferences ratio and the average pathloss in the cell. Consequently, equation (4) becomes:

$$P_{Tot} = \frac{P_N L_{(moy)} \sum_{j=1}^{k} \sum_{i=1}^{N_{user(j)}^{(m)}} \frac{(E_b/N_0)_{ij}^{(m)} R_{ij}^{(m)} v_{ij}^{(m)}}{w}}{1 - \left(1-\alpha_{(moy)} + f_{Dl(moy)}\right) \sum_{j=1}^{k} \sum_{i=1}^{N_{user(j)}^{(m)}} \left(\frac{(E_b/N_0)_{ij}^{(m)} R_{ij}^{(m)} v_{ij}^{(m)}}{w} \right)} \quad (7)$$

C. WCDMA cell loading estimation:

Equation (7) can be written as:

$$P_{Tot} = \frac{P_N L_{(moy)} \sum_{j=1}^{k} \sum_{i=1}^{N_{user(j)}^{(m)}} \frac{(E_b/N_0)_{ij}^{(m)} R_{ij}^{(m)} v_{ij}^{(m)}}{w}}{1 - \eta_{Dl(moy)}} \quad (8)$$

Where:

$$\eta_{DL(moy)} = \left(1-\alpha_{(moy)} + f_{DL(moy)}\right)\sum_{j=1}^{k}\sum_{i=1}^{N_{user(j)}^{(m)}}\left(\frac{(E_b/N_0)_{ij}^{(m)} R_{ij}^{(m)} v_{ij}^{(m)}}{w}\right) \quad (9)$$

$\eta_{DL(moy)}$ is the loading factor of the cell. It gives an idea about the maximum load supported by a cell. It increases with the number of user in the cell;

When $\eta_{DL(moy)} = 1$, the BTS total power tends towards infinity. So, the system reaches its pole capacity;

Generally, we take $0 \le \eta_{DL(moy)} < 1$ in order to maintain the system stability.

The pole capacity is obtained when $\eta_{DL(moy)} = 1$, thus in the case of a voice service only; (k=1) , we obtain:

$$N_{user\_pôle}^{(m)} < \frac{w}{(E_b/N_0 Rv)(1-\alpha_{(moy)} + f_{DL(moy)})} \quad (10)$$

Therefore:

$$N_{user\_max}^{(m)} < \frac{w}{(E_b/N_0 Rv)(1-\alpha_{(moy)} + f_{DL(moy)})} \quad (11)$$

Where R and v are respectively, the bit rate and the activity factor of the service. The cell loading can be written as:

$$\eta_{DL(moy)} = \frac{N_{user}^{(m)}}{N_{user\_pôle}^{(m)}} \quad (12)$$

Thus,

$$\eta_{DL(max)} = \frac{N_{user\_max}^{(m)}}{N_{user\_pôle}^{(m)}} \quad (13)$$

In the case of two services, the loading factor expression is the sum of loading factor generated by each service [5, 6].Thus:

$$\eta_{DL(moy)} = \sum_{j=1}^{k} \eta_{DL(moy),j} \quad (14)$$

Where $\eta_{DL(moy),j}$ is the loading factor of a cell activating a service j.

Thus,

$$\eta_{DL(moy)} = \eta_{DL(moy),1} + \eta_{DL(moy),2} \quad (15)$$

Consequently,

$$\eta_{DL(moy)} = \frac{N_{user,1}^{(m)}}{N_{user\_pôle,1}^{(m)}} + \frac{N_{user,2}^{(m)}}{N_{user\_pôle,2}^{(m)}} \quad (16)$$

Where $N_{user,1(m)}$ and $N_{user,2(m)}$ are respectively the number of user activating services 1 and 2. $N_{user\_pôle,1(m)}$ and $N_{user\_pôle,2(m)}$ are respectively the pole number of user activating services 1 and 2 in a cell m.

D. Simulation parameters

The simulation parameters correspond to a macro-cellular network using three sectored antennas and Okumura-Hata propagation model which is written as:

L=137+35,2log10 (d), d is in (km) (17)

Where d is the distance separating the mobile and the serving base station.

The average pathloss value was 133 dB and the maximal BTS power was 20 W (43 dBm). The value of W is 3,84Mcp, the average orthogonality factor is 0,6 and the thermal noise is -100 dBm.

Figure 1 shows the variation of the required total BTS power as a function of the number of users in a cell activating a voice service (R=12,2 kbit/s) , for various values of f_{DL}. The target ratio (E_b/N_0) for this voice service was 5,5 dB and the activity factor was 0,67.

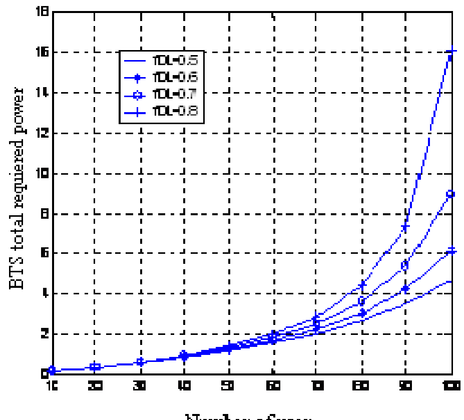

Figure 1. Variation of the required total BTS power as a function of the number of users in the cell activating only voice service

According to figure 1, we notice that the required total BTS power increase with the number of active users in the cell for a fixed value of f_{DL}. By fixing the number of users and by varying the factor f_{DL}, we notice that the total BTS power increase proportionally with f_{DL} ratio. This increase is due to the significant level of interference in the cell harming the useful signal.

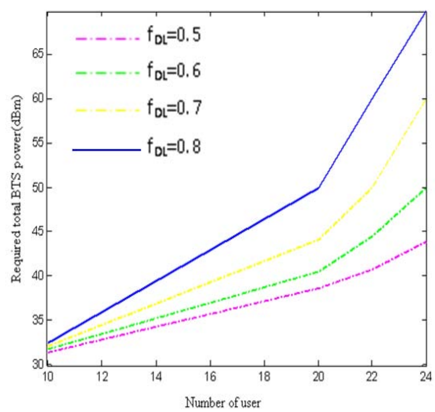

Figure 2. Variation of the required total BTS power as a function of the number of users in a cell activating two services, voice and video.

In figure 2, the required total BTS power has been plotted as a function of the number of users activating two services: voice and video (12,2 kbit/s and 66,5 kbit/s respectively). The target ratio (E_b/N_0) for this video service was 6,5 dB and the activity factor was 1. According to this figure, we notice that the need of the total BTS power as a function of the number of users in the case of two services increases in a significant manner in comparison with the one in a cell activating only one service. In addition, the maximum capacity of a network using two services is much lower than the one in a network activating only one service.

According to the figure bellow, $N_{user\_pôle(m)}$ is 147 and $N_{user\_max(m)}$ is 140. Thus to serve 147 users, the BTS power must be very important.

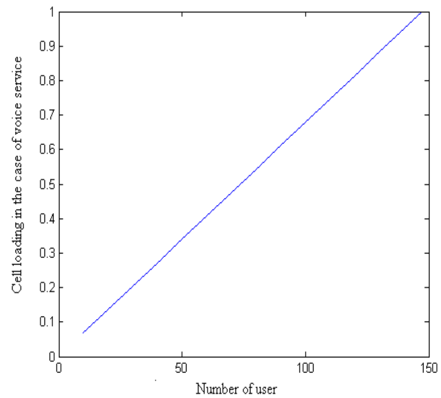

Figure 3. Variation of the cell loading factor as a function of the number of users, case of voice service.

From equation (9) we have:

$$\eta_{DL(moy)} = 1 - \left(\frac{P_N}{P_{Tot}} \sum_{j=1}^{k} \sum_{i=1}^{N_{user(j)}^{(m)}} \frac{(E_b/N_0)_{ij}^{(m)} R_{ij}^{(m)} v_{ij}^{(m)} L_{ij}^{(m)}}{W} \right) \quad (18)$$

Thus, for a network activating one service, the maximum loading factor of a cell is:

$$\eta_{DL(max)} = 1 - \left(\frac{P_N (E_b / N_0) R\, v\, L\, N_{user\_max}^{(m)}}{P_{Tot\_max} W} \right) \quad (19)$$

By taking into account the simulation parameters, the value of $\eta_{DL(\max)}$ is 0, 9. In the case of a network activating two services, we obtain the result illustrated by figure 4.

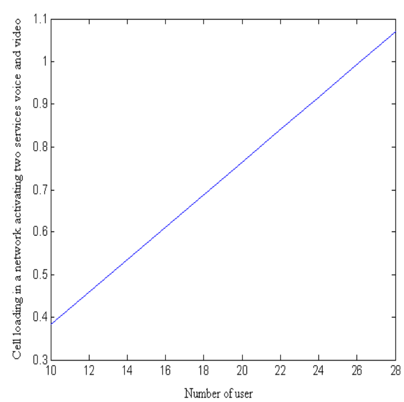

Figure 4. Variation of the cell loading factor as a function of the number of users in the cell activating two services: voice and video.

According to figure 4, the value of $N_{user\_pôle(m)}$ is 26 and the value of $N_{user\_max(m)}$ is 24. Consequently, the pole loading factor of a cell activating two services is reached when the number of users in the cell is only 26.

III. CONCLUSIONS

In this work, we have studied the required total BTS power variation as a function of the number of users simultaneously active in the cell, for different values of f_{DL}, in the case of a network activating one service and then in the case of two services. We noticed that the need of the required total BTS power in the case of a cell offering two services is much important than the one activating only one service. In both cases, this need depends on the level of interferences in the cell.

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