The Modification of WCDMA Capacity Equation

Alma Skopljak Ramović, *Member, IEEE*

Abstract – **There are a lot of different ways to calculate capacity of WCDMA system. Some of them are quite simple and has an explicit form, but some of them are very complicated. The main aim of this workpaper is modification of existed WCDMA capacity expressions for the uplink, integrating more parameters which directly or indirectly affect on it. Even it is more complex, there is a real need for new, modificated WCDMA capacity formula(s).**

Keywords – **Capacity, interference, power control, SDMA, WCDMA**

I. INTRODUCTION

WCDMA capacity is one of the key atributes in UMTS network. There are various of definitions of WCDMA capacity but the most of them are referred on maximum number of users per cell or of the whole observed system. Even the definition of WCDMA capacity as it is defined as the total traffic load which is generated in one cell respecting the allowed frequency band (Erl / cell/ 10MHz) [1] can be found, we shall be focused on this one:

The capacity of a WCDMA network is the maximum number of simultaneous users for all services which satisfy certain conditions. [2] – Definition 1.

The uplink and downlink capacities do not have just the different values, but they are not comparable because the uplink capacity is mostly related to number of users, and the downlink capacity is related to transmitted power of node-B. Also, the WCDMA capacity should be parted from the WCDMA throughput and link-budget, even they are related.

This workpaper will try to comprise different parameters and relations which affect on WCDMA capacity and suggest the new WCDMA capacity expression(s).

II. WCDMA CAPACITY ON THE UPLINK

The WCDMA capacity is basically determined by processing gain and required signal-to-noise ratio. The interference is already included in noise power density and it comprises the Multiple Access Interference (MAI), (interference of other users from observed, home cell and interference of users from the adjacent cell), self interference and co-channel interference. The real case also includes the paralell signal covering by more than one operator, so the influence of this „overlaping" also could be considered because it impacts on adjanced channel interference [3]. Other parameters which impact on WCDMA capacity are based on:

- Structure of the radio-network. Cell size and formation determine the interference value and for the WCDMA capacity calculation it is also important to stress if isolated sector-cell or multisectorized system is observed.
- User distribution, if it is uniform or not. The user position is determined in relation to its jammers and the node-B position or precisely, to direction of its signal coverige. So the case becomes more complicated if the observed active user is surrounded by its jammers. This is very good described in [1] and [2].
- Type of used services: real-time and non-real-time (conversational, interactive, streaming and background services). Real-time applications need some guaranteed minimum transmission rate which requires reservation of system capacity. The multi-service environment impacts on the activity factor and also on required signal-to-noise ratio. Related to service type, the traffic load and traffic model also could be considered as they are in [4].
- The characteristics of node-B receiver (for the uplink) and its antenna system. The signal processing of the node-B is probably the most important thing for the WCDMA capacity. Also the antenna construction and antenna's parameters significally impact on WCDMA capacity.
- Power control (perfect or imperfect). Since the capacity of a WCDMA network is interference-bound, the study of capacity characteristics focuses primarily on the methods of reducing interference. Fast and precise power control is a key requirement for CDMA technology. Power control aims to reduce interference by minimizing the effects of the near-far problem.
- Transmitted power of a node-B and a path loss (for the downlink).

Let a cell with K active users which simultaneously access to network on the same frequency be considered. Every user has its own PN sequence. So, if the P is carrier power, E_b – energy per signal bit, B_c – bandwitdh of the spread sequence, f_{data} – information rate, l – interference power and N_b – noise power density, than it can be written:

$$E_b = \frac{P}{f_{data}}; \quad \frac{E_b}{N_0} = \frac{P}{N_0 f_{data}}; \quad N_0 = \frac{I}{B_c} \quad (1)$$

$$\frac{E_b}{N_0} = \frac{P}{I}\frac{B_c}{f_{data}} = \frac{P}{I}PG \quad (2)$$

where the PG is the processing gain. This definition of the processing gain is derived from the QPSK modulation

Alma Skopljak Ramović, BH Telecom, BH Mobile (telefon: 387-33-641-466; e-mail: alma.skopljak@bhtelecom.ba)

characteristic: the RF bandwidth matches with PN sequence rate $B_c = f_{čip}$. E_b/N_0 is constant for defined BER. If the power of signals of all active users has the same value and all PN sequences have the same rate, than it is, according to [5]:

$$\frac{I}{P} = \frac{(K-1)P}{P} = K - 1 = \frac{PG}{E_b/N_0}; \quad (3)$$

$$K = 1 + \frac{PG}{E_b/N_0}. \quad (4)$$

The equation (4) which defines the number of simultaneously active users is the basic for the WCDMA capacity and all forward modifications will be done based on it. Analyzing the (4) it can be concluded that the raising of PG value for the constant value of the E_b/N_0 ratio leads to increased system capacity. Or if the PG has the fixed value, decreasing E_b/N_0 (if the QoS is not disturb), the capacity also could be raised.

Traffic load of uplink in ideal case, assuming the power control is ideal, according to [6] is:

$$\mu_{UL} = \frac{K}{1 + \frac{PG}{E_b/N_0}}, \quad (5)$$

where K is the number of active users.

Relation between traffic load and continuity of usage of some service is defined with *service activity factor* ν. It could be explained by this: during voice or data connection establishment there are certain gaps in data flow which can be used for other data flows. It is inversely proportional to WCDMA system capacity, which means the more intesive information flow - the less capacity of CDMA system:

$$K = 1 + \frac{PG}{E_b/N_0}\frac{1}{\nu}. \quad (6)$$

Originally, the service activity factor ν has been the voice activity factor, but if more services than conversational service are considered, the description of this activity factor has to be changed.

The power control is certanly not perfect because of multipath signal propagation conditions and because the transmitted signals from the all users are not equal. That can be defined using the log-normal distribution with the deviation 1,5 – 2,5 dB or using the suitable correction factor α_p. So the capacity could be defined similar to equation (6), according to [5]:

$$K = 1 + \frac{PG}{E_b/N_0}\frac{\alpha_p}{(1+\beta)\nu} - \frac{\sigma^2}{S} \quad (7)$$

Here, σ^2/S is introduced as the background noise power to received power (of the certain referent user) ratio which also affects on WCDMA capacity, according to [2].

where the α_p is correction factor which describes power control (im)perfection, the β is the factor which describes co-channel interference from the other cells and the ν is the service acitivity factor. The typical values of these parameters which impact on WCDMA capacity are shown in the Table 1. [7]

TABLE 1: CORRECTION FACTORS WHICH IMPACT ON WCDMA CAPACITY

Parameter	*Average values*
Correction factor of power control α_p	0,5 – 1,0
Voice activity factor – ν_{vo}	0,4 – 0,6
Co-channel interference from the other cells (neighbours) β	0,5 – 0,9

Analyzing the β as the effect of co-channel interference from the other cells in a multicell system, it can be found that the typical value for β for a triple-sector cell is 0,85. If the omnidirectional antenna is used, than β *=0,6*.

In order to exprime WCDMA capacity in accordonance with Definition 1 (Introduction) it is very important to consider various services $g = \overline{1,G}$ that are provided by operator. Every type of service has its own data rate, and therefore processing gain, service activity factor, required signal-to-noise ratio and even co-channel interference. So we will include these facts in equation (8):

$$K^* = \sum_{g=1}^{G} K_g = \\ = 1 + \alpha_p \sum_{g=1}^{G} \frac{PG_g}{(E_b/N_0)_g} \cdot \frac{1}{(1+\beta_g)\nu_g} - \frac{\sigma^2}{S} \quad (8)$$

Non-real time services (like data transport services) does not require as high QoS (*Quality of Service*) as real-time services does. This allows E_b/N_0 to be reduced which will increase WCDMA capacity. [8]

The equation (8) is the first suggested expression for calculation of WCDMA capacity derived from the known equations and WCDMA atributes which are mentioned earlier.

III. HOW TO INCREASE WCDMA CAPACITY

System capacity can be increased by interference elimination methods. Some of mentioned methods are: usage of directional antenna instead of omnidirectional ones, diversity, improved antenna processing system, Rake receiver, various types of interference cancellers etc.

First, the interference due to other users can be reduced by replacing an omnidirectional antenna with a directional one.

For example, a 3-sector antenna would increase the capacity by a factor of about 2—3. Usage of the adaptive (multi)antenna system with above mentioned assumptions will increase WCDMA capacity, so the parameter A_b which describes antenna gain of referent user to antenna gain of its jammers ratio could be input directly to (7) according to [1]. WCDMA capacity for a single service can be written now as:

$$K = 1 + \frac{PG \cdot A_b}{E_b / N_0} \frac{\alpha_p}{(1+\beta)\nu} - \frac{\sigma^2}{S} \tag{9}$$

We use the equation (9), as another suggested expression, to show affects of usage the multiantenna system, which is represented here by the A_b, on increasing the overall capacity. Even the A_b could be easily related with the number of the antenna elements *B*, as it is indirectly in [9]:

$$a_b[dB] = 10\log B \tag{10}$$

where a_b is antenna gain expressed in dB, here we'll not use this approximation. The reason is that, the improvement in performance with adaptive antenna depends upon the antenna type: linear, planar or circular — the number of elements in the array, and the spacing between adjacent elements (which is usually one half of the carrier wavelength), so these facts are not included in (10). The improvement in signal-to-interference ratio is about 3 dB with two elements, 6 dB with four elements, 7.75 dB with six elements, and 9 dB with eight elements. [5]

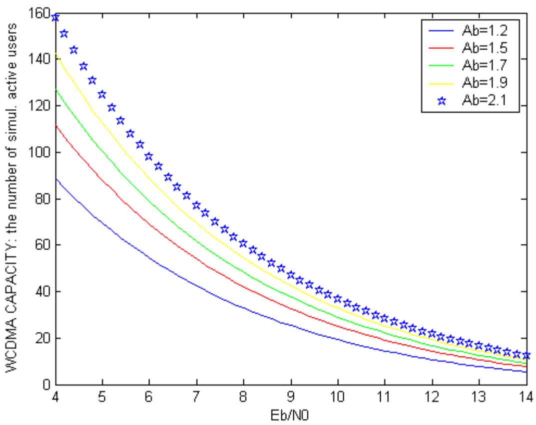

Fig.1 Number of active users as function of signal-to-noise ratio for the different antenna gain ratio A_b

Obviously, the implementation of multiantenna system will reduce the average interference level from all users particullary, so the total channel capacity increases. [10]

The expression (9) could also be used for comparing the values of WCDMA capacity depended on signal-to-noise ratio for the different antenna gain ratio as it described above. This is shown on Fig. 1. So, for demanded signal-to-noise ratio 9,6dB (for the BPSK or QPSK with coherent detection), for one service, the number of simultaneously active users will be 23 for $A_b = 1{,}2$ for example.

Minimizing the value of the E_b/N_0, the use of certain correction code becomes necessary. It is known that in WCDMA systems convolutional coding brings 4 to 6 dB of gain. [5]

Now, we'll modify the (8) inserting the antenna gain ratio A_b in equation:

$$K^* = \sum_{g=1}^{G} K_g = $$
$$= 1 + \alpha_p \cdot A_b \sum_{g=1}^{G} \frac{PG_g}{(E_b/N_0)_g} \cdot \frac{1}{(1+\beta_g)\nu_g} - \frac{\sigma^2}{S} \tag{11}$$

for *G* services in WCDMA system.

This modificated expression for the WCDMA capacity for *G* different services includes few significant parameters and it has the more precised result comparing to other expressions. Obvioulsy, expression (11) could be adapted further.

Here, we'll mention also the SDMA (*Space Division Multiple Access*) re-use functionality as another method for increasing the WCDMA capacity. SDMA re-use functionality is multiple access technique which could be activated by more than one user located on the area of one cell for using same resources: time / frequency / code sequence (t/f/C), dependently on user location and spatial distance to other user(s). It is shown on Fig.2.

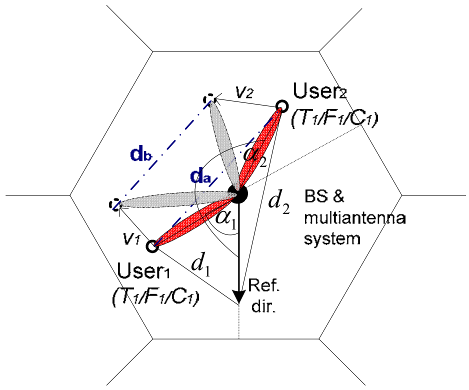

Fig. 2 Example of SDMA re-use functionality [11]

SDMA techniques are also implemented with adaptive antenna systems and obviously have a great influence on WCDMA capacity, but it is hard to find some expression which describes their relation.

IV. CONCLUSION

Probably it is not possible to comprehend all parameters which affect on WCDMA capacity and implement them in simple and usable expession. This workpaper has been shown the way of modifying the basic expression of

WCDMA capacity, inserting elements which have significant impact on it.

The modified expression for the calculation of WCDMA capacity has been also suggested. The usage of multiantenna (adaptive) system as the method for increasing the system capacity is strongly recommended and it has been inserted in WCMA capacity equation as parameter which describes it.

Implementing SDMA re-use functionality into the WCDMA capacity expression could be the next step in modifying and adapting it. Also, finding the other methods which increase the WCDMA capacity and overall system capacity should be the imperative.

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