Uplink and Downlink Traffic Capacity Performance in WCDMA Systems

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This article describes a simulation model for WCDMA systems including closed-loop effects, and presents some results comparing uplink and downlink capacity in asymmetric traffic conditions.

INTRODUCTION

The relationship between coverage and capacity in cellular CDMA systems complicates the tasks of capacity estimation and network planning, and requires the use of simulation. The process is usually split into *link-level* and *network-level* simulations. The former analyses the aspects related to transmission of the signal between a mobile and a base station. In the latter, user spatial distribution and traffic generation are modelled, each link being characterised by a reduced set of parameters obtained from the previous stage. In WCDMA systems, due to the effects of closed-loop power control, SIR alone does not adequately characterise the radio link from a system point of view (Holma and Toskala, 1), meaning that additional parameters are required to get a complete description, namely average transmit power rise, power headroom, and soft hand-off gains (Sipilä *et al*., 2, 3). Network-level simulations can be classified into *dynamic* or *static*, depending on whether user mobility is explicitly modelled or not, respectively. Static simulations are widely used. In this kind of approach, independent "snapshots" of the network are generated. Eliminating time-dependence considerably reduces simulation time, while key performance parameters can still be obtained.

In this article, simulation results are shown for the uplink and downlink of a typical microcellular WCDMA system. Comparisons are made regarding traffic capacity of both links, taking into account traffic asymmetry of foreseen Third-Generation services.

The capacity estimation procedure is based on static, Monte-Carlo type simulation. The analysis relies on adequate propagation, traffic and radio link models. The scheduling process, which assigns bearer services to teleservices, and mobile-to-base station assignment must also be modelled. The core of the simulation being the power control mechanism, one remarkable feature of our approach is that the previously mentioned closed-loop effects are taken into account (unlike most planning tools). This is essential in order to obtain an accurate description of real network behaviour.

In the following, the models used in the simulation are briefly described, and results are presented.

SIMULATION MODEL

Capacity limitation and simulation outline

The simulation process is sketched in figure 1. A simulation consists of several "*realisations*". In each realisation, which corresponds to a snapshot of the network, active users are generated according to a traffic model; their attenuation matrix is computed, and the base-station assignment and power control algorithms are run (no admission control is applied). This procedure may give rise to two different situations:

- All users can reach their desired quality of service with transmission powers within their range of allowed values.
- Otherwise, some users must necessarily suffer quality degradation in order to comply with power restrictions. In this case, the system is said to be in *outage*. Outage, as it has been defined, is a *global* concept, since it applies to the network as a whole.

In an outage situation, a congestion control policy determines which users are degraded and how much. These mechanisms are not specified by the standards, and are therefore operator- or vendor-dependent. For this reason, in our analysis the global outage probability is used as a performance measure to determine system capacity, in the following manner. For a given set of values of the traffic parameters, a sufficient number of realisations are carried out, and outage probability is estimated as the proportion of realisations in which the network turns out to be in outage.

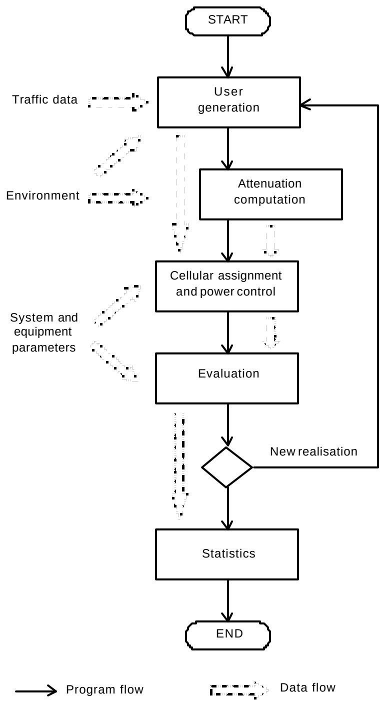

Figure 1. Simulation process

In general, distinct traffic conditions yield different outage probabilities; network capacity is reached when the outage probability equals a given threshold. Along with outage probability, several statistics are collected in order to help the assessing of system performance.

In the following, the models that are used in the different parts of the simulation are briefly described. For a complete description see Mendo (4).

Simulation environment and propagation model

A regular, Manhattan-like microcellular environment with four-sectored cells is considered, with either 400√2-m 200√2-m spacing between sites, and antennas placed 10-m above ground. The COST 231-Lund microcellular attenuation prediction model is used.

Traffic model

Six teleservice classes are considered as described in UMTS Forum (5): Speech, Simple Messaging, Switched Data, Medium Multimedia, High Multimedia, and High Interactive Multimedia. The cited reference characterises each service giving a complete valued list of parameters, both for uplink and downlink. Bearer services, taken from ETSI (6), are: Speech (circuit-switched voice); LCD64, LCD144, LCD384 (circuit-switched data); UDD64, UDD144, and UDD384 (packet-switched data). The correspondence between teleservices and bearers is modelled in a random way by means of a *scheduling matrix*, which expresses the probability that a given teleservice is carried by each of the bearers. Using the parameters described in the cited references, a traffic model is devised in Mendo (4) which can be applied to generate the number, positions, teleservices and bearers of the active users.

The traffic values used in our study are taken from the UMTS Forum forecast for the year 2005, considering only pedestrian users. User density is assumed constant across the street area, and zero inside buildings. All traffic parameters are fixed except user density, which was varied in the simulations.

Radio link characterisation

A complete radio link modelling is foreseen on the basis of the link-level analyses in ETSI (6), Sipilä *et al.* (2), (3), as described in Mendo (4). This characterisation is employed to generate the required SIRs, average transmit power rise, power headroom, and soft hand-off gains.

Base station assignment and power control

In the simulations described in this paper, base station assignment is carried out on a minimum attenuation basis. Hand-off is controlled by a relative attenuation threshold (hand-off window), which is fixed to 6 dB. Only two-way hand-off is considered. In the downlink, both active stations for a given hand-off user are assumed to transmit with equal power.

The power control problem in the uplink gives rise to a non-linear set of equations, due to the mentioned closed-loop effects (Mendo, 4). In the downlink, linearity can be preserved, and dimension reduction can be exploited (Mendo, 7). In both cases, iterative algorithms can be devised that converge to the required transmission powers, provided the solution is compatible with power restrictions, or otherwise converge to a point conforming to transmitter restrictions (Mendo, 4). In the uplink, power limitations affect to each mobile user. In the downlink, the power restrictions apply to the total power transmitted by each base station (no individual channel limitations are imposed). After convergence, it can be easily recognised whether the system is in an outage situation or not.

System parameters and radio equipment data

System parameters correspond to the 3GPP specifications (Release 99) for UMTS. Radio equipment parameters such as maximum powers, noise factors and antenna patterns are usual values from manufacturers.

Maximum outage probability

The maximum outage probability, which determines system capacity, is estimated in Mendo (4) in a typical microcellular deployment. A simple congestion control algorithm is simulated, from which *individual* outage probabilities can be obtained as experienced by the users. The condition that the individual outage probability be 2%, or less, for the worst-case bearer (which turns out to be LCD384) is shown to be equivalent to a maximum global outage probability of 10% in the uplink and 5% in the downlink. Although only valid in the assumed case, these values can be used as representative. The larger value for the downlink is explained by the fact that a power limitation in the downlink affects a larger number of users than in the uplink, namely those assigned to the concerned base station.

SIMULATION RESULTS

Figure 2 displays outage probability as a function of user density, relative to UMTS Forum values, with 400√2-m base station spacing, and figure 3 corresponds to 200√2-m spacing. It can be seen that capacity is much higher in the lower spacing scenario. The capacity improvement is significantly larger than the reduction in base station area (which corresponds to a factor of 4). Furthermore, outage probabilities increase more slowly with user density in the latter situation than in the former, where an abrupt change is observed. These facts indicate that in the first case the system is coverage-limited, whereas in the second it is traffic-limited.

It can be seen from the figures that in the coverage-limited case the uplink is more restrictive, whereas in a traffic-limited situation the downlink determines system capacity. A similar behaviour was reported in Holma and Toskala (1), sec. 8.2.2. In the considered traffic-limited scenario, downlink capacity is roughly 6,8 (for 5% outage probability) and uplink capacity is 11,3 (for 10% outage probability), relative to UMTS Forum (year 2005) densities.

The uplink load factor and downlink total transmitted power per bearer service are shown in figures 4–7, for both values of base-station spacing.[1] The histograms are shown, in each case, for the relative user density that is closest to the maximum outage probability (figures 2 and 3), i.e. for system capacity. All histograms in this article are computed for non-outage realisations only,

The coverage-limited character in the larger spacing can be recognised in the load factor histogram in figure 4, which shows smaller values than that in figure 5. The power transmitted by the base-station, on the contrary, is not significantly lower in the coverage-limited case, because, although less users are present compared with the traffic-limited scenario, they require higher transmit powers than they do with lower spacing.

Figures 8 and 9 compare the individual transmit powers in uplink and downlink. For hand-off users in the downlink, each active base-station is considered separately to compute the histogram. It is observed that individual required powers increase with bit rate, due to lower processing gain. However, figures 5 and 7 indicate that, in terms of system load, speech is the more demanding service. This due to the fact that, although a speech user requires a relatively low transmit power, there are much more speech users than users of the other bearers, according to UMTS Forum forecasts.

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[1] Total power transmitted by the base station is used as a measure of downlink load, analogous to the uplink load factor, with the desired property of additivity across services.

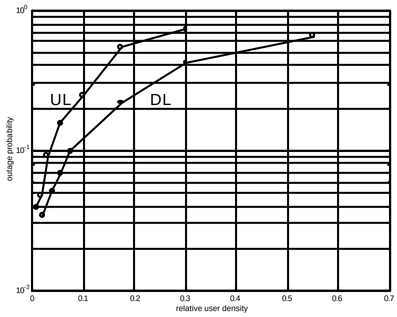

Figure 2. Outage probability for 400√2-m spacing

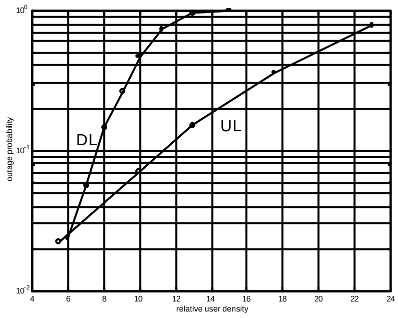

Figure 3. Outage probability for 200√2-m spacing

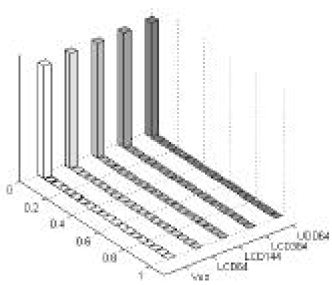

Figure 4. Uplink load factor per bearer for 400√2-m spacing

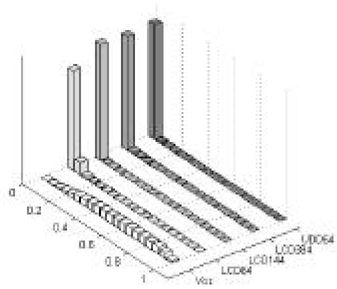

Figure 5. Uplink load factor per bearer for 200√2-m spacing

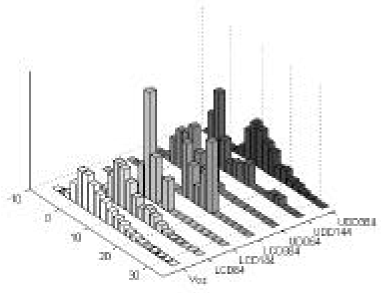

Figure 6. Downlink total transmit power per bearer for 400√2-m spacing (relative user density 0.04)

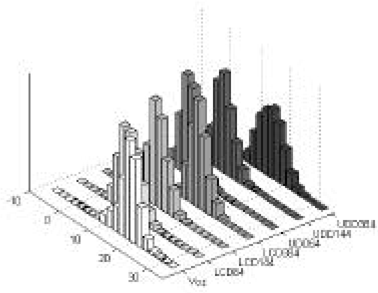

Figure 7. Downlink total transmit power per bearer for 200√2-m spacing (relative user density 7)

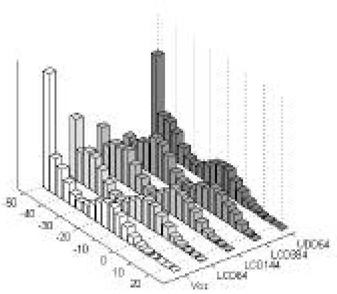

Figure 8. Uplink transmit power per bearer for 200√2-m spacing (relative user density 10)

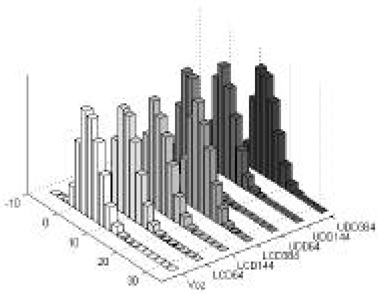

Figure 9. Downlink individual transmit power per bearer for 200√2-m spacing (relative user density 7)