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Quality-based Tuning of Cell Downlink Load Target and Link Power Maxima in WCDMA

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Abstract- **The objective of this paper was to validate the feasibility of auto-tuning WCDMA link power maxima and adjust cell downlink load level targets based on Quality of Service. The downlink cell load level was measured using total wideband transmission power. The quality indicators used were call-blocking probability, packet queuing probability and downlink link power outage. The objective was to improve performance and operability of the network with control software aiming for a specific quality of service. The downlink link maxima in each cell were regularly adjusted with a control method in order to improve performance under different load level targets. The approach was validated using a dynamic WCDMA system simulator. The conducted simulations support the assumption that the downlink performance can be managed and improved by the proposed cell-based automated optimization.**

I. Introduction

A. Background

The WCDMA radio interface for third generation mobile networks can carry voice and data services with various data rates, traffic requirements, and quality-of-service targets [1]. Moreover, the operating environments vary greatly from indoor micro cells to large macro cells. Efficient use of limited frequency band in the diverse conditions requires careful setting of numerous vital network and cell parameters such as maximum load levels and allocated common channel powers. The parameter setting is referred to as radio network planning and optimization. Once a WCDMA network is built and launched, an important part of its operation and maintenance is monitoring of performance or quality characteristics and changing parameter values in order to improve performance. The operability of the network would greatly benefit from automated monitoring and parameter tuning. The automated parameter control mechanism can be simple but it requires an objectively defined performance indicator that unambiguously tells whether performance is improving or deteriorating. Conceiving of such indicators is a major task. WCDMA network auto-tuning and advanced monitoring are discussed in [5], for instance.

The radio resource management (RRM) controls the system load. The optimization and adaptivity of RRM is of great importance both for the operators and for manufacturers, since RRM has a lot to answer for when it comes to the stability and the utilized capacity of mobile network. The cell load level targets used by RRM can be e.g. throughput based, interference based or based on number of connections [1]. The preferable method is interference-based or total power-based, which leads to soft capacity gains [1].

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The performance of the WCDMA cellular radio network is highly dependent on the amount of interference in the system. High interference reduces the cell size and increases the link powers that mobile users need in downlink (forward link). Interference is increased as the number of admitted users grows in the system. This means that there is a trade-off between the capacity and coverage and between the capacity and quality of service (QoS).

Study [9] suggest that there should be guard channels and different power thresholds for hand over AC. Study [11] also suggest total power AC to be used and compares single-cell AC with multi-cell AC. According to [11] there are gains with multi-cell AC, but they do not motivate the increased complexity. Also [12] found that there are gains with global AC compared to single cell AC and discussed the complexity without any clear conclusions. Study [13] states that setting the total power threshold in uplink is a trade-off between blocking and dropping. An auto-tuning study of cell uplink load targets is presented in [8]. Study [15] provides a method for adjusting the cell-site transmitter power. Studies [11] and [12] used the same cost function to evaluate the grade of service (GoS) for different load levels, i.e.:

$$GoS = 10 * DR + BL, \tag{1}$$

DR stands for dropping ratio and BL for blocking ratio in (1). This means that a dropped call is considered ten times worse than blocked call.

Study [12] introduces certain AC requirements, e.g. that it is necessary to maintain Quality of Service (QoS) stability (blocking, dropping, BER, or delay), to have adaptability in different situations (system load inter-cell interference), ability to reconfigure the AC for new services, simplicity of design and minimization of processing time. Advanced analysis methods for analyzing the performance of UMTS networks are provided in [14].

In this paper, DL interference based admission control and packet scheduling is studied. The selected AC strategy is cell-based, due to the complexity of global AC.

B. Parameter control

This paper addresses the problem of controlling the downlink link power maxima under different downlink planned total transmitted power targets, denoted PtxTargets. These parameters are very critical network parameters and setting them is a trade-off between capacity and coverage/quality. The downlink link maximum in each cell is auto-tuned based on quality of real-time (RT) circuit-switched (CS) calls, non-real-time (NRT) traffic queuing and RT CS blocking. The trade-off in the auto-tuning is bad quality ratio vs. blocking and queuing. The auto-tuning method is the same as that described in [5] pp. 418-422 and in [8].

C. Network simulator

The automated control method was verified with an advanced WCDMA radio network simulator developed at Nokia Research Center in Helsinki [2]. The simulator is able to model various cell deployments. A set of mobile terminals move in the area with constant speed and, with random intervals, make calls of different services: voice, circuit-switched data, and packet-switched data. The main difference between voice and circuit-switched-data calls is that the former have talk spurt silence periods. The data rates of voice and circuit-switched-data calls are fixed but packet data rates can vary. The simulation step is one frame or 10 ms, at which the transmission powers, received interferences, and signal-to-interference ratios are recalculated for each connection in uplink and downlink. The method of [3] is used to obtain correctness of received frames from signal-to-interference ratios. The simulator implements many advanced features such as total power based admission control, closed-loop and outer-loop power controls, soft and hard handover controls, packet scheduler, load control, and quality manager. Previous studies with the simulator are described in [6] and [10], for instance.

D. Quality manager

The quality manager is a logical unit in the simulator that collects statistics of various performance indicators, summarizes the overall performance with a cost function, and modifies or suggests modification of specific network or sector parameters in order to improve the system performance. Examples of the statistics output by the quality manager are load, throughput, RT quality, blocking, dropping and NRT queuing.

E. Summary of results

The conducted simulations support the assumption that the downlink performance can be managed and improved by the proposed cell-based automated optimization. The increase in system throughput compared to throughput with default parameter setting was significant, in particular when the defaults were sub optimal.

II. METHODS

A. Performance Indicators

This section provides a description of the performance indicators available for the auto-tuning.

Load – At specific intervals, the quality manager samples the uplink received power or the downlink transmission power.

Throughput – The uplink throughput is the number of received bits in the sector divided by the control period time and by the chip rate. In downlink, the throughput is measured with sent bits.

Quality – At specific intervals, the quality manager goes through all connections of the sector and checks the call quality. In DL it is the ratio RT calls in power outage, i.e. links transmitting with maximum link power. Here RT calls stand for the monitored RT service with planned coverage in the whole cell e.g. RT CS 64 kb/s with 1% BLER-target or RT speech.

Blocking – The ratio of the power blocked RT calls to the total number of admission requests during the control period.

Dropping – The ratio of calls ended by dropping to the total number of ended calls during the control period.

Queuing – At specific intervals, the quality manager checks the number of packet users and the number of queuing packet users in the sector and accumulates them in two counters for the control period. The packet queuing ratio is obtained as the ratio of the queuing counter value to the sum of both counter values. The queuing ratio would highly correlate with the NRT traffic delay.

B. Parameter Control

The PtxTarget determines whether to admit a new user or not and additionally how to schedule packets. Accordingly the PtxTarget determines how much traffic is allowed in the cell. To have correct load targets is important. If the targets are too low, not all the capacity of the network is utilized. On the other hand, if the targets are too high too many connections are admitted in the cell and the increased interference causes bad quality or in worst case dropped calls. This is in DL caused by connections that hit the maximum connection specific transmission powers, reducing the coverage of the cell and making the quality of calls worse.

In DL, the maximum link transmission power can be set for the reference radio access bearer (RAB) (e.g. AMR speech 12.2 kb/s) with respect to the CPICH (Common Pilot Channel) transmission power [1]. The parameter is called CPICHToRefRABOffset. The maximum connection powers for other services are then set by scaling the maximum power of the reference RAB using bit rate and planned DL Eb/No of the service in question. The Eb/No requirement is the level of received bit energy to the interference and noise density that the receiver equipment requires for proper decoding of the signal. Below an example of how the parameter is used.

CPICH TX Power = 200 mW = 23 dBm

CPICHToRefRABOffset = 5.5 dB

Maximum TX power for reference RAB = CPICH TX Power / CPICHToRefRABOffset = 23dBm – 5.5dBm = 17.5 dBm = 56 mW

Maximum TX power for other services is obtained using the formula:

$$P_{tx,\max} = P_{tx,\max,ref} \frac{\rho \cdot R}{\rho_{ref} \cdot R_{ref}} \quad (2),$$

where $P_{tx,max,ref}$ is the maximum TX power for the reference service, $P_{tx,max}$ is the maximum TX power for the other service, ρ_{ref} is the DL planned Eb/No for the reference service, ρ is DL planned Eb/No for the other service and R correspondingly bit rate. For CS RT 64 kb/s with 2.5 dB lower Eb/No requirement than that of the reference service, the maximum link power would be about 250 mW in this case (CPICHToRefRABOffset equals to 5.5 dB).

The CPICHToRefRABOffset in each cell, and with it, the downlink connection power maxima, is auto-tuned during high load based mainly on quality of RT CS calls i.e. DL single link power outage (alternatively BLER target satisfaction rate problems could also be used) of the service that has been planned to have coverage in the whole cell (e.g. speech or RT 64kb/s), but also PS traffic queuing and CS power blocking. Depending on the quality level achieved different PtxTargets can be tried for optimal performance.

The CPICHToRefRABOffset of a cell is auto-tuned using quality measurements from that specific cell gathered during high downlink load. The CPICHToRefRABOffset of a cell is auto-tuned so that it is as high as possible, when taking into account the quality of calls, packet queuing, and power blocking of calls. If the dropping and bad quality situation is significantly poorer than allowed levels and poorer than the power blocking and queuing situation, the CPICHToRefRABOffset is lowered. If the bad quality and dropping on the other hand has a lower cost than the cost of queuing plus power blocking, which are checked for significance, the CPICHToRefRABOffset is increased, i.e. auto-tuned in a direction, which increases capacity. Equation (3) shows the criteria used for checking which of the bad quality situation and the lack of capacity situation is poorer:

$$C(DR) + C(BQ) < C(BL) + C(Q) \quad (3)$$

$$C(DR) = 10 * DRf \quad (4)$$

$$C(BQ) = 5 * BQf \quad (5)$$

$$C(BL) = 1 * BLf \quad (6)$$

$$C(Q) = 0.25 * Qf \quad (7)$$

In the above equations Q stands for queuing ratio, BQ for bad quality ratio (link power outage), DR for dropping ratio and BL for blocking ratio. Parameters DRf, BQf, BLf, and Qf stand for the number of binomial standard deviations over the quality indicator allowed level. The call dropping has double weighting (ten) compared to the weight of degraded BLER (five), which is motivated that it is worse if the call is dropped than if the quality is poor. The same weighting relation as in (1) is used for blocking (weight 1) and dropping (weight 10). The call-dropping indicator was not used as a quality criterion in this study, only the bad quality in terms of link power outage, since it is hard to determine an absolute criterion for call dropping. A call that would have been dropped would also normally be in power outage.

In downlink the main bit rate to be monitored for power outage the bit rate that has been planned to have coverage in the whole cell area (e.g. CS RT 64 kb/s or speech).

This method provides means to do capacity vs. quality/coverage trade-off. The trade–off can be adjusted by adjusting the costs and allowed levels of bad quality, blocking of calls and packet queuing. The allowed level of bad quality ratio was 2%, the allowed level of call blocking was 5% and the allowed level of queuing was 5%. By giving a lower cost to bad quality of calls or allowing poorer quality the capacity is increased, thus in particular a higher throughput and/or lower blocking of calls is enabled, while it is correspondingly decreased by giving high cost to bad quality or allowing very small amount of bad quality.

Table I shows the different states possible in the auto-tuning and the corresponding adjustment. The different quality indicators can be significantly below the allowed level, significantly above allowed level and within confidence margins of allowed level. The adjustment is then either no adjustment, upward adjustment, downward adjustment or up (+) or downward (–) adjustment after comparison of costs. In Table I, Compare Cost+ means checking (2) and, if true, increasing the CPICHToRefRABOffset. Compare Cost– correspondingly means checking (2) and, if false, decreasing the CPICHToRefRABOffset. Compare Cost+/- means that the CPICHToRefRABOffset is increased or decreased if (2) is true or false, respectively. The step size used when tuning the CPICHToRefRABOffset was 0.5 dB. The confidence margins were calculated using binomial confidence intervals. If good quality was achieved the PtxTarget was increased. On the other hand if the quality was poor the target was decreased.

TABLE I
RULES FOR THE AUTO-TUNING

Bad Quality	Blocking	Queuing	Adjustment
Below	Below	Below	No adjustment
Below	Below	Within	No adjustment
Below	Below	Above	Increase
Below	Within	Below	No adjustment
Below	Within	Within	No adjustment
Below	Within	Above	Increase
Below	Above	Below	Increase
Below	Above	Within	Increase
Below	Above	Above	Increase
Within	Below	Below	No adjustment
Within	Below	Within	No adjustment
Within	Below	Above	Compare Cost+
Within	Within	Below	No adjustment
Within	Within	Within	No adjustment
Within	Within	Above	Compare Cost+
Within	Above	Below	Compare Cost+
Within	Above	Within	Compare Cost+
Within	Above	Above	Compare Cost+
Above	Below	Below	Decrease
Above	Below	Within	Compare Cost-
Above	Below	Above	Compare Cost+/-
Above	Within	Below	Compare Cost-
Above	Within	Within	Compare Cost-
Above	Within	Above	Compare Cost+/-
Above	Above	Below	Compare Cost+/-
Above	Above	Within	Compare Cost+/-
Above	Above	Above	Compare Cost+/-

It is very important to cope with the mobility of the mobiles. It is necessary to associate to a cell only quality measures of the parts of the call that the call is connected to that cell in question. It would not be good, e.g. that poor quality periods of calls that started far away but ended in the auto-tuned cell affected the auto-tuning of the cell's power DL link maxima and power targets. Also diversity handover issues must be taken into account when evaluating the quality of calls, so that poor quality is associated with all cells in the active set of the UE. A possible addition before raising the power target in a cell is to check if adjacent cells are suffering from poor quality.

III. Simulation Parameters

The parameters for the simulated micro-cell scenario can be found in Table II. An area of 9 km^2 of downtown Helsinki was planned with 46 micro cells (Fig. 1). The channel multi-path profile was that of ITU Outdoor-to-Indoor A [7] with 2-path propagation. The path gains are shown in Table II. The propagation loss was calculated using the Okumura-Hata model with average correction factor of –6.2 dB. The shadow fading process conformed to the buildings, streets, and water areas. Short-term fading with 7-dB deviation was added to the process. The fast fading process was that of Jakes [4].

TABLE II
Network Parameters

Parameter	Value
Chip rate	3.84 MHz
Frequency	2.0 GHz
Bandwidth	5.0 MHz
Base station maximum transmission power	4 W
CPICH transmission power	0.2 W
Power control dynamic range in DL	20 dB
Base station antenna sector and gain	Omni, 11.0 dBi
Downlink system noise	–99.9 dBm
Minimum coupling loss with O-H model	–50 dB
Propagation loss model	Okumura-Hata
Shadow fading deviation	7 dB
Multi-path propagation gains	94 and 6 %
Mobile station speed	3 km/h
Number of mobile stations	8000
Call arrival rate for a mobile station	0.0333 s^{-1}
Probability of voice service	0 %
Probability of circuit-switched service	10 %
Probability of packet service	90 %
Average voice call length	120 s
Average discontinuous transmission period	3.0 s
Average CS RT 64 kb/s data call length	10 s
Mean number of packets in DL packet call	100
Mean packet size in downlink packet call	81.5
Voice data rate	8 kb/s
Circuit-switched data rate	64 kb/s
Packet data rates	8, 12, 64, 144, 512 kb/s
Voice and CS data outer loop FER target	1 %
Packet-switched data outer loop FER target	20 %
Handover control add window	3 dB
Handover control drop window	7 dB
Initial admission control transmission power target	Micro cell 2 W
Initial CPICHToRefRABOffset, range	5.5 dB, [0, 10]
Auto-tuning interval	20 s
Simulation time	600 s

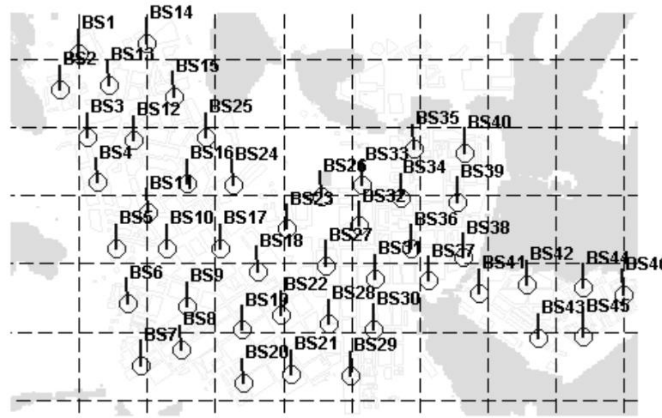

Fig. 1. The deployment of 46 micro cell sites in Helsinki center area. Water areas are shown in gray.

Figure 1 shows the general view of the simulated network. The mobile stations were uniformly distributed along the streets of simulated area and they made new calls according to a Poisson inter-arrival distribution. The packet size of packet calls was generated according to a Pareto distribution. The service of new calls was generated according to the probabilities shown in Table II.

IV. Results and Discussion

TABLE III
Micro 46 Cell Scenario: Results for CS speech and PS traffic

Measure	Parameter Setting			
	PtxTarget 33 dBm, fixed offset 5.5 dB	PtxTarget 33 dBm, DL link maxima tuned	PtxTarget 35.5 dBm, fixed offset 5.5 dB	PtxTarget 35.5 dBm, DL link maximum tuning
Number of ended RT CS calls	14472	13696	15057	14674
Probability of degraded RT CS BLER	7.0%	2.0%	18.9%	3.8%
RT CS blocking probability	8.2%	13%	4.5%	6.9%
RT CS throughput kb/s/cell	500	473	520	507
NRT PS through-put kb/s/cell	264	255	542	494
DL Total through-put kb/s/cell	764	728	1063	1001

Only downlink was simulated due to the fact that downlink auto-tuning methods were validated and downlink was assumed to be the limiting link. The soft handover overhead was about 50% for both the CS traffic and packet traffic in all simulation cases. Table III shows that the system performance with the auto-tuning turned on improved when the CPICHToRefRABOffset was set to a somewhat incorrect value of 5.5 dB. In comparison with fixed CPICHToRefRABOffset, the auto-tuning decreased the bad quality significantly, which made it possible to increase the PtxTarget. Increasing the PtxTarget produced very poor quality with fixed CPICHToRefRABOffset of 5.5 dB, which corresponds to 250-mW DL link maximum for CS RT 64 kb/s service. The blocking probability was very high due to a very high rate of arriving calls, which was selected in order to load the system up to the target level.

Table IV shows that the system performance also improved with the auto-tuning turned on in the cases of fixed 3-dB offsets, a level that seem closer to the optimum value. The auto-tuning decreased the bad quality significantly, which made it possible to increase the PtxTarget. Increasing the PtxTarget produced still quite poor quality with fixed CPICHToRefRABOffset of 3 dB, which corresponds to 40-mW DL link maximum for CS RT 64 kb/s service.

TABLE IV
MICRO 46 CELL SCENARIO: RESULTS FOR CS SPEECH AND PS TRAFFIC

Measure	Parameter Setting			
	PtxTarget 33 dBm, fixed offset 3 dB	PtxTarget 33 dBm, DL link maximum tuning	PtxTarget 35.5 dBm, fixed offset 3 dB	PtxTarget 35.5 dBm, DL link maximum tuning
Number of ended RT CS calls	14022	13696	14940	14674
Probability of degraded RT CS BLER	2.6%	2.0%	5.6%	3.8%
RT CS blocking probability	11%	13%	5.3%	6.9%
RT CS throughput kb/s/cell	484	473	516	507
NRT PS through-put kb/s/cell	260	255	506	494
DL Total through-put kb/s/cell	744	728	1023	1001

V. CONCLUSIONS

The suggested feature benefits the improving of inaccurate or even incorrect DL link maxima and PtxTarget values on a per-cell basis. The feature increases the network capacity, especially, in the case when the operator has chosen to set the PtxTarget and DL link maxima values cautiously in order to ensure that required quality criteria are met. DL link maxima that have been set at too low levels result in poor quality of calls in the cell. In such cases, observed poor quality makes the control algorithm increase the DL link maxima values until the quality is at the required level, which means that it may be possible to increase the PtxTarget in small steps. If the acceptable quality cannot be achieved by tuning the DL link maxima, the PtxTarget must be decreased. Another way of finding an optimal PtxTarget would be to use the high load standard deviation of the total transmission power in the cell and, assuming that the total transmission power is normally distributed, set the PtxTarget so that an allowed outage in the total power is achieved.

The conclusion drawn from the results is that the auto-tuning of cell-based downlink link maxima and load targets improve significantly the system performance as measured with throughput particularly in comparison with cautious or incorrect parameter settings. The feature is a promising candidate for the network management system.

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