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Quality-based Auto-tuning of Cell Uplink Load Level Targets in WCDMA

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***Abstract*- The objective of this paper was to validate the feasibility of auto-tuning WCDMA cell uplink load level targets based on Quality of Service. The uplink cell load level was measured with received wideband total power. The quality indicators used were call blocking probability, packet queuing probability and degraded block error ratio probability. The objective was to improve performance and operability of the network with a control software aiming for a specific quality of service. The load level targets in each cell were regularly adjusted with a control method in order to improve performance. The approach was validated using a dynamic WCDMA system simulator. The conducted simulations support the assumption that the uplink 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, which leads to soft capacity gains [1].

The performance of the WCDMA cellular radio network is highly dependent on the amount of interference in the system. High interference reduces cell size and increases the power outage probability of mobile users in uplink. 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).

Holma et al. also present methods for doing power increase estimation [1]. A theoretical uplink (UL) capacity evaluation for 10dB noise rise target or 90% load level can be found in [8]. 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 UL is a trade-off between blocking and dropping. Studies [11] and [12] used the same cost function to evaluate the grade of service (GoS) for different load levels, i.e.:

$$GoS = 10 * DR + BL, \qquad (1)$$

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/ 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.

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

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B. Parameter control

This paper addresses the problem of controlling the uplink planned total received power target, denoted PrxTarget. The PrxTarget is a very critical network parameter and setting it is a trade-off between capacity and coverage/quality. The PrxTarget 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 corresponds to the method presented in [5] pp. 418-420.

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 uplink 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.

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 UL it is the ratio RT calls with degraded BLER to all RT active calls. 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 [5]

The UL admission control interference target (PrxTarget) of a cell is auto-tuned using quality measurements from that specific cell gathered during high uplink load. The PrxTarget 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 blocking of calls. If the dropping and bad quality situation is significantly poorer than allowed levels and poorer than the blocking and queuing situation, the target is lowered. If the bad quality and dropping on the other hand has a lower cost than the cost of queuing plus blocking, which are checked for significance, the target is increased, i.e. auto-tuned in a direction, which increases capacity. Equation (2) shows the criteria used for checking which of the bad quality situation and the lack of capacity situation is poorer:

$$C(DR) + C(BQ) < C(BL) + C(Q) \qquad (2)$$

$$C(DR) = 10 * DRf \qquad (3)$$

$$C(BQ) = 5 * BQf \qquad (4)$$

$$C(BL) = 1 * BLf \qquad (5)$$

$$C(Q) = 0.25 * Qf \qquad (6)$$

In the above equations Q stands for queuing ratio, BQ for bad quality ratio (degraded BLER), 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. UL bad quality preferably includes both UL dropped calls and indication of degraded UL BLER (block error ratio). 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 one) and dropping (weight ten). The call-dropping indicator was not used as a quality criterion in this study, only the degraded BLER, since it is hard to determine an absolute criterion for call dropping. A call that would have been dropped would also normally have a degraded BLER.

The average BLER can be considered degraded if it is above a certain percentage, which is clearly higher than the outer loop BLER-target (e.g. average BLER above 2% in case of 1% BLER-target). An average BLER clearly higher than the BLER-target means that the mobile device/devices suffer from power outage in uplink. In uplink the main bit rate to be monitored for degraded BLER is 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 (degraded BLER) was 2%, allowed level of call blocking was 5% and the allowed level of queuing was 5%. By giving 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
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+/-

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 target. Compare Cost– correspondingly means checking (2) and, if false, decreasing the target. Compare Cost+/– means that the target is increased or decreased if (2) is true or false, respectively. The step size used when tuning the PrxTarget was 0.5 dB. The confidence margins were calculated using binomial confidence intervals.

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 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

Fig. 1. The case 1 deployment of five three-sector and two one-sector macro cell sites in Helsinki center area. Water areas are shown in blue. Average site distance roughly 910 m. Subset of 32-cell scenario in [5] p. 119.

Fig. 1 shows the general view of the simulated network in case 1. Green bars indicate sectors by pointing to the principal direction of antenna pattern. The antenna of the one-sector sites was omni directional, however. The channel multi-path profile was that of ITU Vehicular A [7] with 5-path propagation in case 1. The path gains are shown in Table II. One half of the signal power came along the line of sight and the other half was a sum of powers from four reflected signals. 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, Fig. 1. Short-term fading with 7-dB deviation was added to the process. The fast fading process was that of Jakes [4].

The parameters for cases 2 and 3, which are based on a micro-cell scenario can also be found in table II. An area of 9 km^2 of downtown Helsinki was planned with 46 micro cells in this case. The covered area was the same as in [5] p. 119. 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 difference between these cases is that the traffic mix in case 2 was speech and NRT PS and in case 3 a mix of RT CS 64 kb/s and NRT PS.

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.

TABLE II
NETWORK PARAMETERS

Parameter	Value
Chip rate	3.84 MHz
Frequency	2.0 GHz
Bandwidth	5.0 MHz
Base station maximum transmission power	Macro cell 20 W, micro cell 4 W
Mobile station maximum transmission power	250 mW
CPICH transmission power	Macro cell 1 W, micro cell 0.2 W
Power control dynamic range in UL	65 dB
Base station antenna sector and gain	65°, 17.5 dBi Omni, 11.0 dBi
Mobile station antenna sector and gain	Omni, 0.0 dBi
Uplink system noise	–102.9 dBm
Minimum coupling loss with O-H model	–50 dB
Propagation loss model	Okumura-Hata
Shadow fading deviation	7 dB
Case 1: Multi-path propagation gains	51, 30, 11, 6, 3 %
Case 2 & 3: Multi-path propagation gains	94, 6 %
Mobile station speed	3 km/h
Number of mobile stations	5000/11000/8000 (Case 1/2/3)
Call arrival rate for a mobile station	0.0333 s^-1
Probability of voice service	40/40/0 % (Case 1/2/3)
Probability of circuit-switched service	0/0/10 % (Case 1/2/3)
Probability of packet service	60/60/90 % (Case 1/2/3)
Average voice call length	120 s
Average discontinuous transmission period	3.0 s
Average CS RT 64 kb/s data call length	20 s
Mean number of packets in DL packet call	100
Mean number of packets in UL packet call	1
Mean packet size in uplink packet call	8150
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 %
Admission control transmission power target	Macro cell 10 W, micro cell 2 W
Handover control add window	3 dB (1 dB Case 1)
Handover control drop window	7 dB (3 dB Case 1)
Initial PrxTarget	6 dB
Auto-tuning interval	20 s
Simulation time	600 s

IV. RESULTS AND DISCUSSION

Only uplink was simulated due the fact that uplink auto-tuning methods were validated. For the case 1 macro scenario the soft handover overhead was 28% for the speech traffic and 36% for the packet traffic. The results in Table III show that results with auto-tuning turned on improved the system performance. The UL throughput increased 57% compared to the conservative noise rise target of 4 dB (60% loading), 25% compared to 6 dB PrxTarget (75% loading) and 10% compared to the 8 dB PrxTarget (84% loading). The degradation in RT quality was minor, while the RT blocking improved significantly. 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.

For the case 2 micro scenario with NRT PS and RT speech traffic, the soft handover overhead was 44% for speech traffic and 50% for the NRT packet traffic. The results in Table IV show that the auto-tuning improved the system performance. The UL throughput increased 52% compared to the conservative noise rise target of 4 dB (60% loading), 21% compared to 6 dB PrxTarget (75% loading) and 6% compared to the 8 dB PrxTarget (84% loading). The degradation in RT quality was minor, while the RT blocking improved significantly.

TABLE III
MACRO 17CELL SCENARIO: RESULTS FOR CS SPEECH AND PS TRAFFIC

Measure	PrxTarget Setting			
	4 dB	6 dB	8 dB	Result with cell target load level control
Number of ended RT CS calls	19748	23614	26082	28636
Probability of degraded RT CS BLER	0.3%	0.3%	0.4%	0.7%
RT CS blocking probability	49%	39%	32%	25%
RT CS throughput kb/s/cell	596	712	787	864
NRT PS through-put kb/s/cell	127	191	240	270
UL Total through-put kb/s/cell	723	903	1027	1133

For the case 3 micro scenario with NRT PS and RT CS 64 kb/s traffic the soft handover overhead was 50% for the RT CS traffic and 52% for the NRT packet traffic. The results in Table V show that the auto-tuning improved the system performance. The UL throughput increased 48% compared to the conservative noise rise target of 4 dB (60% loading), 16% compared to 6 dB PrxTarget (75% loading) and 2% compared to the 8 dB PrxTarget (84% loading). The degradation in RT quality compared to lower targets was notable but not problematic, while the RT blocking improved significantly.

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

Measure	PrxTarget Setting			
	4 dB	6 dB	8 dB	Result with cell target load level control
Number of ended RT CS calls	45513	54779	60613	64041
Probability of degraded RT CS BLER	1.0%	1.3%	1.6%	1.8%
RT CS blocking probability	46%	35%	28%	24%
RT CS throughput kb/s/cell	570	686	759	802
NRT PS through-put kb/s/cell	93	152	191	208
UL Total through-put kb/s/cell	663	838	950	1010

TABLE V
MICRO CELL SCENARIO: RESULTS FOR CS AND PS TRAFFIC

Measure	PrxTarget Setting			
	4 dB	6 dB	8 dB	Result with cell target load level control
Number of ended RT CS calls	11501	13160	14095	14193
Probability of degraded RT CS BLER	1.8%	2.7%	3.3%	3.2%
RT CS blocking probability	27%	17%	11%	10%
RT CS throughput kb/s/cell	400	458	490	494
NRT PS through-put kb/s/cell	252	374	457	471
UL Total through-put kb/s/cell	652	831	947	965

V. CONCLUSIONS

This feature benefits the improving of inaccurate or even incorrect PrxTarget values on a per-cell basis. The feature increases the network capacity, especially, in the case when the operator has chosen to set the PrxTarget values cautiously to a low level in order to ensure that required quality criteria are met. A PrxTarget value that has been set at a too high level results in high interference and poor quality of calls in the cell. In such cases, observed poor quality makes the control algorithm reduce the PrxTarget value until the quality is at the required level.

The conclusion drawn from the presented results is that auto-tuning of cell-based uplink interference targets improve significantly the system performance as measured with throughput in comparison to the default parameter settings. The feature is a promising candidate for the network management system.

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