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WCDMA COMMON PILOT POWER CONTROL FOR LOAD AND COVERAGE BALANCING

Kimmo Valkealahti, Albert Höglund, Jyrki Parkkinen, and Ari Hämäläinen

Nokia Research Center, FIN-00045 Nokia Group

Abstract- The paper validates the feasibility of automating the setting of common pilot power in a WCDMA radio network. The pilot automation improves operability of the network and it is implemented with a control software aiming for load and coverage balancing. The control applies measurements of base station total transmission power of neighboring cells and terminal reports of received pilot signal level to determine the pilot qualification. The pilot power of a cell is periodically updated with simple heuristic rules in order to improve the load and coverage balance. The approach was validated using a dynamic WCDMA system simulator with a deployment of macro and micro cells on a city region whose measured propagation characteristics were incorporated into the model. The results showed that the proposed control method balanced load and coverage and improved the air interface performance measured as a function of packet throughput.

I. INTRODUCTION

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 [2]. Moreover, the operating environments vary considerably from indoor cells to large macro cells. Efficient use of limited frequency spectrum in diverse conditions requires careful setting of numerous vital network and cell parameters such as maximum load levels and allocated channel powers. The parameter setting is referred to as radio network planning and optimization. Once a WCDMA network is built and launched, its operation and maintenance largely consists of monitoring the performance or quality characteristics and changing parameter values in order to improve performance. The operability of the network would considerably benefit from automated monitoring and parameter changing. WCDMA network autotuning and advanced monitoring are discussed in [7]. 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.

A. Common pilot power control

This paper addresses the control of the common pilot power whose value is a cell-specific parameter. In the Universal Mobile Telecommunications System, the terminal measures and reports the received level of the pilot energy-per-chip-to-total-wideband-interference-density ratio, or E_c/I_0, for the handover cell selection. The pilot power determines the cell coverage area and the average number of terminals connected to the cell. Increasing or decreasing the pilot power makes the cell larger or smaller. Thus, the adjusting of pilot powers can be applied to balance the cell load among neighboring cells, which reduces the variation of interference, stabilizes the network operation, and facilitates the radio resource management. However, the load balancing must not entail uncovered areas between cells, which can happen if the pilot power of a cell is too low. In an uncovered area, all pilots are too weak for the terminal receiver to decode the signal and call setup is not possible. How low the received power can be depends on the receiver electronics, and the level is thus specific to the terminal. Therefore, the specifications of the Third Generation Partnership Project require that the terminal must be able to decode the pilot from a signal with E_c/I_0 of –20 dB [12]. Quality receivers can cope with ratios several decibels lower than that. Too large coverage is not desirable either as it indicates an unnecessarily high pilot power, consuming the limited power capacity of the cell. The consumption is even compounded if the powers of other common channels are scaled from the pilot power. To summarize, the pilot power control is a compromise between the load balance and the coverage balance.

In the present study, the cell load is measured as the ratio of total transmission power to the target transmission power. The target transmission power is the planned level at which the cell resources are considered to be in optimum use in downlink [7]. The target power depends on the maximum transmission power of the base station and differs among macro cells and micro cells. The cell load is thus commensurate among different cell layers. As the capacity is more limited in downlink than in uplink [2], we see that the measuring of the downlink load only, suffices for our purpose. The load balance of a cell is measured as the difference between the average cell load from the average load in the neighbor cells divided by the standard error of the difference. The standardization makes the measure independent of the number of cell-load measurements. The coverage balance is based on the highest pilot E_c/I_0 levels that the handover-needing terminals report to the network. The coverage balance is measured as the difference of the number of reports with required E_c/I_0 level to the number expected in the case of target coverage divided by the standard error of the difference. The target coverage is the planned average proportion of reports with the required pilot E_c/I_0 level from terminals near the cell border.

The pilot power is controlled with simple heuristic rules. If the load balance or the coverage balance deviates significantly from zero, the pilot power is changed. The load balance has always precedence over the coverage balance in the tested rules. In a real network the rules would be configured according to operator's preferences, however. If the load balance or the coverage balance is significantly higher or lower than zero, the pilot power is decreased or increased, respectively. The interval between pilot power changes should be sufficiently long to collect a significant number of measurements, for instance, hours or days. The cells can update pilots asynchronously. The rule-based control method was selected over a gradient-descent method with cost-function minimization, such as the method of [10], because of the clarity of its configuration and operation. The configuration of cost function with effective weightings of its terms would likely happen through greater amount of trial and error. In [6], a control method is suggested that minimizes the pilot power while providing the coverage for all terminals. The method requires a particular test mobile, however.

B. Network simulator

The pilot control method is verified with an advanced WCDMA radio network simulator developed at Nokia Research Center in Helsinki [3]. The simulator models 32 macro cells and 46 micro cells deployed over an area of Helsinki center. A set of mobile terminals move in the area with constant speed and, with random intervals, make downlink packet-switched calls of variable bit rates. The packet-switched service is selected because packet throughput is a simple and descriptive measure of the air interface performance. Only the downlink is simulated, as the pilot power level does not much affect the uplink performance. The simulator implements many advanced features such as packet scheduler, admission control, closed-loop and outer-loop power controls, soft and hard handover controls, and load control. Previous studies with the simulator are described in [1,8].

C. Summary of results

The pilot power control attained its primary goal of balancing the load between the cells, which also produced improved packet performance. The mean of the macro cell total powers moved closer to the target power and the deviation of power decreased in micro and macro cells. The coverage obtained values close to the target coverage in most of the cells. The improvement of packet performance suggested that the pilot power control benefits performance in congested cells. The results suggested that simple heuristic rules are effective in the pilot power control.

II. METHODS

A. Measuring downlink load

The cell sampled the total downlink transmission power. In order to make the total power of macro cells and micro cells commensurate, the power was divided by the target total power of the cell. Logarithms of the sample values were taken. The cell kept three counters. The first was for the number of samples, the second was for the sum of the sample values, and the third was for the sum of the squared sample values. Denote the counter values of cell i by N_i, S_i, and T_i, respectively. The counters were reset at the point of pilot power adjustment as shown in Table I.

B. Load balance

The sample mean and variance of the load in cell k was obtained with equations

$$m_1 = \frac{S_k}{N_k} \tag{1}$$

and

$$v_1 = \frac{T_k}{N_k} - m_1^2 . \tag{2}$$

The statistics for the load in the neighboring cells were obtained with

$$m_2 = \frac{\sum_i S_i}{\sum_i N_i}, \; i \neq k \tag{3}$$

and

$$v_2 = \frac{\sum_i T_i}{\sum_i N_i} - m_2^2, \; i \neq k . \tag{4}$$

The test statistic of the difference between the own-cell and neighbor-cell loads was obtained with equation

$$t' = \frac{m_1 - m_2}{\sqrt{\frac{v_1}{N_k} + \frac{v_2}{\sum_{i \neq k} N_i}}} . \tag{5}$$

Statistic t' was quantized to three levels of load balance:

$$t = \begin{cases} -1, & t' < -2 \\ 0, & -2 \leq t' \leq 2 \\ 1, & t' > 2 \end{cases} \tag{6}$$

The quantization levels defined that the own-cell load was significantly lower than, not significantly different from, or significantly higher than the average neighbor-cell load.

C. Coverage balance

The terminals in the sector reported the received E_c/I_0 of the pilot. For each reported E_c/I_0, cell-specific counter N_{ecio} was incremented. If E_c/I_0 exceeded –18 dB, counter N_{over} was also incremented. The counters were reset at the point of pilot power adjustment as shown in Table I. The test statistic of the difference between the cell coverage and target coverage C was obtained with equation:

$$c' = \frac{N_{over} - N_{ecio} \cdot C}{\sqrt{N_{ecio} \cdot C \cdot (1 - C)}} . \tag{7}$$

The target was set to $C = 0.98$. As above, statistic c' was quantized to three levels of coverage balance:

$$c = \begin{cases} -1, & c' < -2 \\ 0, & -2 \leq c' \leq 2 . \\ 1, & c' > 2 \end{cases} \tag{8}$$

D. Changing pilot power

The initial pilot power was 1 W in macro cells and 200 mW in micro cells, that is, 5% of the maximum base station power [7, p. 263]. The pilot power control was performed once in a second, which is too frequent for a real network but feasible with the simulator. At the control step, balances t and c were computed and, in the case of a required adjustment, the pilot power of the cell was changed by 0.5 dB (Table I). The pilot power was limited between 3% and 15% of the maximum base station power. After the pilot change, load counters N, S, and T, coverage counters Necio and Nover, or all counters were reset (Table I).

Table 1
Pilot power control.

Load bal. t	Cov. bal. c	Pilot power change and counter reset
–1	–1	Increase pilot and reset all counters
–1	0	Increase pilot and reset load counters
–1	1	Increase pilot and reset load counters
0	–1	Increase pilot and reset coverage counters
0	0	No change and no reset
0	1	Decrease pilot and reset coverage counters
1	–1	Decrease pilot and reset load counters
1	0	Decrease pilot and reset load counters
1	1	Decrease pilot and reset all counters

III. SIMULATION PARAMETERS

Fig. 3 shows the general view of the simulated network. Green bars depict sectors by pointing to the principal direction of antenna pattern, except for sectors with omni directional antennas that are vertically depicted. The channel multipath profile was that of ITU Vehicular A [11] with 5-path propagation. 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. Signals from the same base station propagating along the same path were totally orthogonal, that is, they did not interfere with each other. Thus, the downlink orthogonality factor [2] computed from the path gains was 60%. The propagation loss was calculated using the Okumura-Hata model [9] with average correction factor of –6.2 dB. The shadow fading process conformed to the buildings, streets, and water areas (Fig. 3). Short-term fading with 7-dB deviation was added to the process. The fast fading process was that of Jakes [5]. The simulation step was one frame or 10 ms, at which the transmission powers, received interferences, and signal-to-interference ratios were recalculated for each connection in the downlink. The method of [4] was used to obtain the correctness of received frames from signal-to-interference ratios. The mobile stations were uniformly distributed along the streets of the simulated area and they made new calls according to a Poisson interarrival distribution. The packet sizes of calls were generated according to a Pareto distribution. The call parameters were selected to fill the system up to the target level of the downlink transmission power. The simulation time was 300 seconds.

IV. RESULTS AND DISCUSSION

The results in Table III show that the mean of pilot power, especially in the macro cells, increased with the pilot power control for which a contributory reason can be the pilot power range, which was biased towards increasing the initial power. The standard deviation of the pilot power was high, 60% of its mean, which suggests that the cell load was not well balanced with the fixed pilots. The total base station powers show the effect of load balancing obtained with the pilot control. The mean macro cell total power moved closer to the target of 10 W and the deviation of the power decreased. The decrease of deviation was shown in micro cells as well. Fig. 1 shows that the average load statistic (5) was within the range of insignificance (6) in most of the cells. The control thus attained its primary goal.

Table 2
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
Common pilot power	macro cell 1 W, micro cell 0.2 W
Power control dynamic range in downlink	20 dB
Maximum link power in downlink	1 W
Base station antenna sector and gain	65°, 17.5 dBi Omni, 11.0 dBi
Mobile station antenna sector and gain	Omni, 0.0 dBi
Downlink system noise	–99.9 dBm
Minimum coupling loss	–50 dB
Average antenna height	18 m
Multipath propagation gains	50, 30, 11, 6, 3 %
Mobile station speed	3 km/h
Number of mobile stations	10,000
Call arrival rate for a mobile station	120 h^{-1}
Mean no of packets in downlink packet call	50
Mean packet size in downlink packet call	3.8 kilobits
Packet bit rates	8, 12, 64, 144, 512 kb/s
Outer loop FER target	10 %
Admission control and packet scheduler transmission power target	macro cell 10 W, micro cell 2 W
Handover control add window	1 dB
Handover control drop window	3 dB

Although the pilot powers increased on average, the coverage decreased with the pilot power control. With fixed pilots, the mean share of terminals with insufficient pilot level was better than the target of 2%. With the pilot control, the mean share was somewhat poorer than the target, especially in the micro cells, which is probably due to the control rules, in which the coverage was a secondary measure. However, in general, the average coverage was close to the target of 98% in most of the cells (Fig. 2). If it is required that the average coverage is at the defined target level in all cells, the control rules must be changed, at least, by giving the coverage balance precedence over the load balance.

TABLE III
POWER AND COVERAGE RESULTS

	No pilot control	Pilot control
Macro PtxTotal (std) [W]	9.0 (2.0)	9.4 (1.3)
Micro PtxTotal (std) [W]	1.9 (0.3)	1.9 (0.2)
Macro pilot power (std) [W]	1 (–)	1.6 (0.9)
Micro pilot power (std) [W]	0.2 (–)	0.24 (0.15)
1 - macro coverage [%]	1.6	2.3
1 - micro coverage [%]	1.3	3.5

TABLE IV
PACKET PERFORMANCE RESULTS

	Improvement with pilot control
Total throughput [kbps/cell]	4%
Active session throughput	21%
Allowed bit rate	31%
95th packet delay percentile	5%

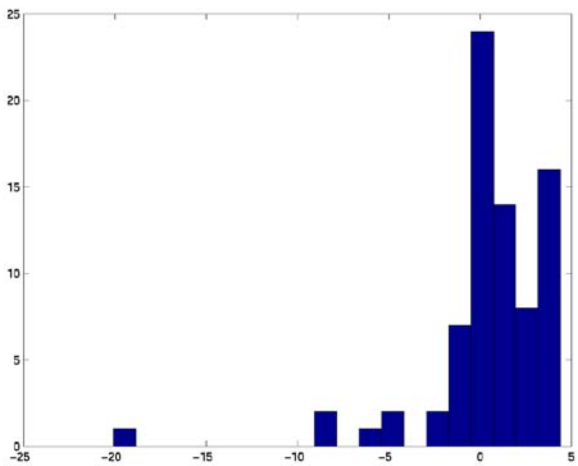

Fig. 1. The frequency (ordinate) of cells having specific average levels of the load statistic (abscissa) obtained with the pilot power control.

The results obtained with the pilot control indicated an improved packet performance, see Table IV. The mean total throughput increased four percent, which is the total number of correctly received bits, with resending of incorrect frames, in all terminals divided by the simulation time and the number of sectors. The mean active session throughput increased 21%, which is the mean per-connection bit rate over the periods of nonempty downlink packet buffer. The mean allowed bit rate increased 31%, which is the mean bit rate that the packet scheduler allocated to downlink connections. The 95^{th} percentile of the packet delay decreased five percent, which is the time from the arrival of packet at the downlink packet buffer to its complete and correct reception. The increased performance is likely linked with the increased total base station powers that the load balancing enabled as the increase in throughput matches with the four-percent increase in the macro cell total powers.

The simulated pure packet traffic unlikely typifies the real traffic in third generation networks. Circuit-switched services, essential but not studied herein, are sensitive to connection quality measured, for instance, with the block error rate. If link powers are allocated proportionally to the pilot power, significant increase of the error rate is possible with low pilot powers, because the link power requirement is more affected by interference levels than the pilot power. Too low allocation of link power can thus cause insufficient received power and erroneous reception, the extent of which requires further study. Setting an adequate lower limit of pilot power may suffice for the solution, however.

The results also corroborated that the fixed setting of the pilot power, by default, to 5% of the maximum base station power is a warranted choice. The coverage was sufficient and the packet performance was close to that obtained with the pilot control. Thus, the pilot power control may benefit performance in congested cells only. However, the load balancing, which was clearly attained, can benefit single cells whose performance is not reflected in the total network performance but which subjectively can be highly significant.

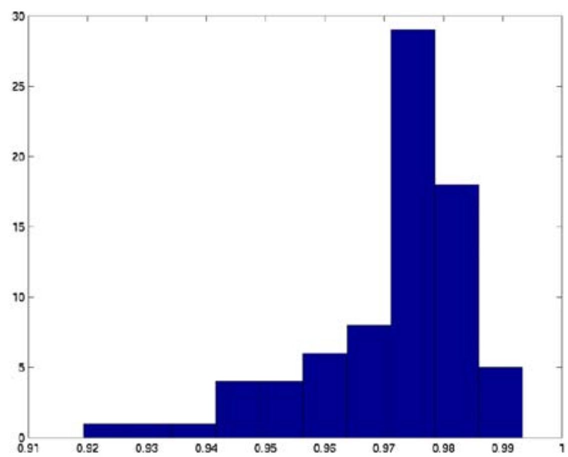

Fig. 2. The frequency (ordinate) of cells having specific average levels of the coverage (abscissa) obtained with the pilot power control.

To conclude, the results suggest that, firstly, the balancing of load among cells and the aiming to a specific coverage level is feasible using simple heuristic rules that control the pilot power. Secondly, the pilot control method improves the air interface performance. Finally, the method is a valid means for improving the network operability with its automation.

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Fig. 3. Deployment of 32 macro cells and 46 micro cells in Helsinki center area. Water areas are shown in blue.