Impact of Pilot Pollution on SHO Performance

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***Abstract*— Soft handovers are an essential part of a WCDMA network functionality. Taking full advantage of SHOs requires careful setting of parameters. In addition, state of the network affects the performance of SHO algorithm. Pilot pollution, i.e., too many hearable pilots, can make it difficult for SHO algorithm to perform properly, and DL transmit power as well as signalling capacity can be wasted for poor decisions and unnecessary active set updates. In addition to simulations, field measurements have been carried out in a pre-commercial WCDMA network, where also the effect of different downtilting scenarios has been studied. The behavior of SHO algorithm has been evaluated in pollution free and pilot polluted areas. The target of the paper is to show how pilot pollution disturbs a UE from making reasonable proposals for active set updates, how pilot pollution problem can be reduced, and network performance improved by increasing antenna downtilt.**

Key words: antenna downtilt, pilot pollution, soft handover, WCDMA

1. INTRODUCTION

Soft handovers (SHO) are an important element in a system using WCDMA (wideband code division multiple access) air interface, such as UMTS (Universal Mobile Terrestrial System). Soft handovers not only enable seamless handover from a cell to another, but also introduce gain for network performance [1]. In a WCDMA network, each cell is sending a pilot signal on P-CPICH (primary common pilot channel). The pilot signal is used to distinguish cells in the network from each others, and it is typically transmitted at constant power. E_c/N_0 (received energy per chip to noise energy ratio) of the pilot signal is used to indicate the quality of the radio channel between UE (user equipment) and the particular cell. SHO algorithm uses E_c/N_0 of each pilot to decide on which cell a UE is connected to. Instead, also RSCP (received signal code power) can be used. Cells are added to active set (AS) when they enter SHO window, i.e., when the difference between the best pilot and measured pilot is small enough. SHO parameter optimization can affect strongly the behavior of the algorithm, but even with optimal parameters SHO algorithm can drift in a false operation.

In optimal scenario, there would be only one hearable pilot in the cell dominance areas, and also pilot from adjacent cell when a UE is moving from a cell to another. Areas in the network are considered as pilot polluted, if there are more pilot signals (or their multipath components) hearable than receiver can process, or none of the pilot signals is dominant [2]. It has been discussed that pilot pollution might have impact on SHO operation [3], but no clear evident of pilot pollution affecting SHO performance have been shown in the literature. Pilot polluted areas can probably never be totally avoided in the network, but by decent radio network planning, the amount of pilot polluted areas can be minimized [4].

Antenna downtilt is typically used to decrease the amount of inter-cell interference in the network by controlling cell coverage areas [5], [6]. The impact of mechanical and electrical antenna downtilt (MDT, EDT) on the network performance is studied in [7], [8], where it was shown that network capacity can be improved by using optimal downtilt angle.

In the paper, the coverage of useful and harmful pilot signals was studied by analyzing hearability of the 1st - 4th pilot signals based on simulations and measurement data. In addition, pilot polluted and pollution free areas are searched from measurements and performance of SHOs is analyzed separately in the areas. In addition, the effect of downtilting on the amount of pilot pollution was examined.

2. SOFT HANDOVERS

In a cellular network, handovers need always to be done in order to ensure continuous transmission on mobiles moving from a coverage area of one cell to another. In a hard handover, connection to the preceding cell is first cut, and then connection to the new cell is established. In addition to hard handovers, in WCDMA system, so called soft handovers can be established. In a soft handover, a radio link to a new Node B can be established before braking the connection to the old one.

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A set of Node Bs that a UE is connected to, is called active set. Typical maximal size of AS is 3, i.e. one mobile can have simultaneous connection to three Node Bs. When a soft handover is established between cells in same base station, it is called softer handover. This enables combining of uplink data in the Node B instead of RNC.

When a UE is in soft/softer handover, two spatially separated cells (in same or separate Node Bs) are receiving the same signal the UE is sending. This introduces diversity between the arriving signals and there might exist some gain called macro-diversity gain in the uplink direction. [9] The gain is proportional to the differences in path losses between the cells participating the SHO. The smaller the difference, the greater the gain. In [10], the effect of SHO in WCDMA uplink direction with different link level differences and different mobile channels have been analyzed. The results show, that SHO gain can be up to 4.5 dB, with slow UE speed and 0 dB level difference. SHO gain decreases below 1 dB when level difference is above 4-6 dB depending on mobile speed. In softer HO, when combining is done in the Node B, the gain should be slightly higher [1]. In [1], also the downlink SHO gain simulation results are presented, and maximum gain of about 3 dB was observed. In downlink direction, link level difference of max. 3 dB results in gain above 1 dB. Since 2-3 simultaneous transmission lines are needed, the gain in downlink direction can also be negative. Therefore, having unfavorable cells in AS can easily overtake the advantage attained with optimal SHO connections and turn total SHO gain to negative.

This clarifies the importance of having optimal set of cells in the active set. The decision of adding and removing cells to/from AS is made based on the measurements a UE performs by SHO algorithm located in the RNC. An example of a typical SHO algorithm is described in more detail in [11].

Setting parameters for SHO algorithm is a difficult but an important optimizing task. i.e. with short hysteresis times fast reaction to network changes can be achieved, but signalling load increases. On the other hand, long hysteresis times can cause delayed additions and removals, and therefore waste power resources and even increase blocking probability [12]. Similar effects can be expected from too small or too wide add/remove hysteresis. Because in soft handover mobiles are connected to more than one cell, the mobiles consume DL transmit capacity, and introduce interference to the network. Therefore, the amount of mobiles in soft handover should be kept reasonable. [1]

3. USING E_C/N_0 LEVELS AND ACTIVE SET TO ANALYZE NETWORK PERFORMANCE

Minimizing interference levels is crucial for maintaining high capacity in WCDMA networks. Using as low DL and UL transmission powers as possible helps in keeping the interference at low level. This can be ensured by staying always connected to the best hearable cell in the network. The hearability of a pilot can be defined by measuring the E_c/N_0 of each pilot signal. Normally SHO algorithm always chooses the strongest hearable pilot signal as the best pilot in the active set. In cell coverage overlapping areas, typically one or two additional pilots can be added to the AS if their level is close enough to the best cell. Parameter settings of SHO algorithm, and delay of active set update affects, of course, how quickly cells can be added to and dropped from AS. Therefore, sometimes the strongest pilot is not always added to the AS. Also sometimes RNC (radio network controller) is not immediately adding to the AS the pilots a UE is proposing in measurement reports. These can be called delayed handovers.

The overall performance of SHO events can be analyzed by comparing the average level of the strongest measured pilot signal to average level of the best pilot to AS. If there is no difference, it can be concluded that SHOs are working perfectly considering the 1st pilot in AS. Sometimes, in heavily pilot polluted areas, SHO algorithm is incapable of making decent decisions, since many pilots are entering and leaving SHO window. If there is a significant difference in the strongest and the 1st pilot, there might be some room for optimizing the handover procedure.

4. SIMULATIONS AND MEASUREMENTS

4.1. Simulation Scenario

The simulations were carried out using static WCDMA simulator, tuned COST-231-Hata propagation model and statistical Monte Carlo analysis with numerous simulation rounds. The used network scenario was similar to the scenario used in the measurements (described in Section 4.3.); site places, antenna heights, antenna characteristics, i.e. were the same. Digital map with resolution of 5 m with morphological and topological information of simulation area was used in order to model the propagation environment. 60 users with 144 kbps circuit switched connection were located in the simulation area so, that the in the center of area the user density was slightly higher. Two downtilting scenarios were applied: first with constant 6° EDT in all cells, and secondly MDT of 5.5° on average was added. Simulated sites are shown in Fig. 1, sites with MDT adjusted are shown in light red.

4.2. Simulation Results

Since simulation-based results of downtilting in a macrocellular network are already rather well known, i.e. [7], [8], the scope of the simulations for this work is mainly to verify how simulations can be used to check the hearability of pilots in, i.e, different antenna downtilting and network loading scenarios.

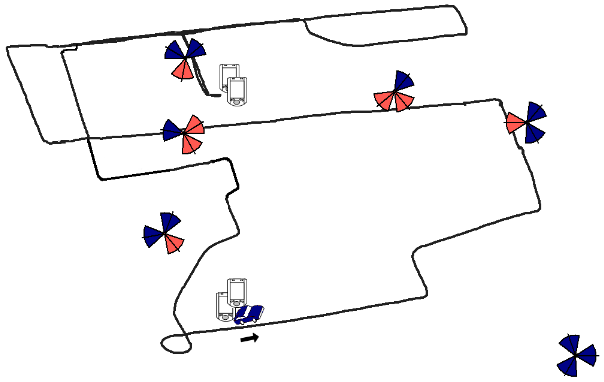

Figure 1. Site places used in simulations and measurements, and measurement route.

Pilot pollution reduction when increasing downtilt in the network is evaluated by CDFs (cumulative distribution function) of the pilot signal levels, shown in Fig. 2. The level of first pilot signal increases in overall about from 1.0 to 1.5 dB. This naturally increases the dominance of the highest pilot signals. The levels of 1st and 2nd pilot signals are decreasing at the level of 1-2 dB, which decreases the amount of interference in the network. Especially the change in the level of 4th pilot signal is having effect on the amount of pilot pollution. The maximum size of AS in the simulations was 3, and therefore the 4th hearable pilot is always introducing interference to the network. Therefore the drop of about 1.5 dB on the average level of 4th pilot is showing improvement on the amount of pilot pollution.

Other relevant simulation results are shown in Table 1. Service probability is slightly decreasing after adding MDT, which comes from coverage limitations in cell edge areas. On the other hand, average downlink transmit power level decreases with over 1 dB, which would have given possibility to serve more users in the coverage area. SHO probability decreases expectedly about 4 %, but the amount of Softer HO connections is increasing slightly, so that the total decrease of soft connections was 3 %.

Table 1. Simulation results.

		EDT	EDT+MDT
Average E_c/N_0 of 1st pilot	[dB]	-4.14	-3.09
Average E_c/N_0 of 2nd pilot	[dB]	-13.27	-15.00
Average E_c/N_0 of 3rd pilot	[dB]	-17.39	-20.79
Average E_c/N_0 of 4th pilot	[dB]	-20.90	-24.37
Service probability	[%]	98.81	98.41
SHO probability	[%]	11.22	7.41
Softer HO probability	[%]	1.93	2.70
SHO + Softer HO probability	[%]	13.15	10.11
DL Throughput	[kbit/s]	495.22	476.62
DL average Tx Power	[dBm]	34.50	33.32

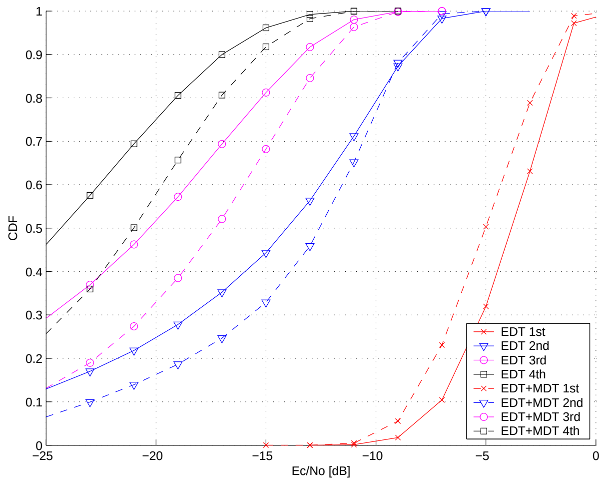

Figure 2. CDFs of simulated 1st-4th CPICH E_c/N_0 levels.

4.3. Measurement Setup

Field measurements were carried out in the center of Tampere city, in a pre-commercial WCDMA network, in macro/microcellular environment. Average antenna height was 25 m and average site spacing 400 m. Measurement area consisted of six 3-sectored base stations, illustrated in Fig. 1. All cells had a constant 6° electrical downtilt. Furthermore, two different downtilt scenarios were used in a part of the cells (marked with red color); without MDT and with additional MDT, denoted as EDT and EDT+MDT, respectively. The measurement route is shown in Fig. 1. The length of the measurement route was about 7 km and measurement results are based on the moving mobiles. The effect of pilot pollution on the performance of SHO algorithm and overall system performance was analyzed by manually searching pollution free and polluted areas from in network area.

4.4. Measurement Results

The results of the pilot measurements are shown in Fig. 3. Dashed lines show levels of the 1st - 4th pilot with EDT, and solid lines show the pilot levels with EDT+MDT. In addition, the averaged values of changes in pilot levels and some other measurement results are shown in Table 2.

With EDT only, average level of the 1st pilot E_c/N_0 is -6.34 dB, which raises by 0.73 dB to -5.61 dB after additional MDT, which clearly improves the hearability of the 1st pilot. Average level of the 2nd and 3rd pilot E_c/N_0s decrease 0.95 dB and 0.69 dB, respectively. Average level of the 4th pilot E_c/N_0 decreases even with 1.4 dB from -20.85 dB to -22.25 dB. This means that all pilots that can not be added to the AS are on average under the level of -22.25 dB. Separate information of SHO and Softer HO probabilities are not available, but adding MDT to the network decreased combined probability of soft+softer handovers by 10 % from 21 %

to 11%. BER (bit error rate) and BLER (block error rate) values, presenting connection quality and power control performance, were both improved; BER by only 0.05 and BLER by 3.18. Improved hearability of 1st pilot, decreased amount of SHO connections together with better connection quality indicate of additional available capacity, especially in downlink direction. Increasing the amount of downtilting is pointing the signal better in cell dominance area, and preventing leagage to adjacent cells. This improves the hearability of the 1st pilot, and also decrease the amount of interference by limiting the hearability of 2nd-4th best pilot, which can then be translated to reduced amount of pilot polluted areas.

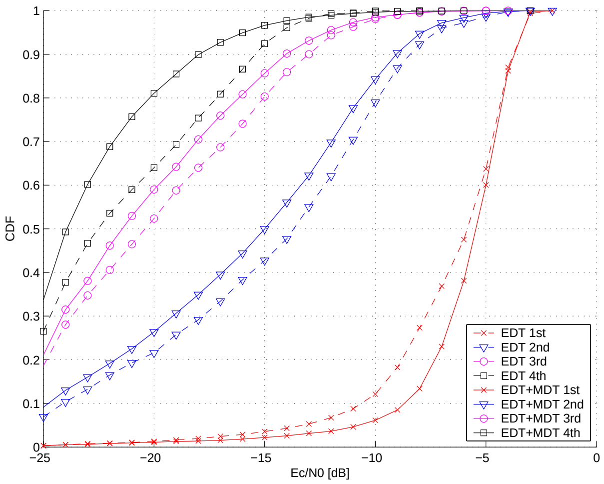

Figure 3. CDFs of measured 1st - 4th CPICH E_c/N_0 levels.

The impact of pilot pollution on the performance of soft handovers was analyzed by comparing the strongest measured pilot and the best pilot added to the active set (best connected pilot). The smaller is the difference, the more optimally are the active set updates made. In Table 3 the results from the whole measurement route, and manually searched pollution free and pilot polluted areas are presented (the results with interferers are shown), in order to see the average difference of E_c/N_0s of the strongest measured and the best connected cells. Average difference in strongest measured and best connected pilot over the whole measurement route is 0.51 dB with EDT only, and 0.33 dB in EDT+MDT scenario. This already shows that there might be some room for optimizing. In pilot polluted areas, with EDT only scenario, the difference is even 0.94 dB, and with additional MDT (EDT+MDT), the difference is still 0.51 dB. In pollution free areas, the difference is rather small in both scenarios; only 0.04 dB with EDT only and 0.21 dB with EDT+MDT. The Reason for increasing difference with additional MDT in pollution free areas could not be found out.

In EDT scenario, in pilot polluted areas, there was on average almost 1 dB better pilot signal available, compared to the one the UE was connected to. This shows how excess amount of pilots reduce the efficiency of SHO algorithm. The BLER values increase in line with the difference in the strongest and the best connected pilot. This indicates how outer loop power control is incapable of compensating poor performance of SHOs, which then affects the overall quality of transmission.

Table 2. Measurement results.

		EDT	EDT+MDT
Average E_c/N_0 of 1st pilot	[dB]	-6.34	-5.61
Average E_c/N_0 of 2nd pilot	[dB]	-14.43	-15.38
Average E_c/N_0 of 3rd pilot	[dB]	-19.31	-20.00
Average E_c/N_0 of 4th pilot	[dB]	-20.85	-22.25
BER	[%]	1.72	1.67
BLER	[%]	8.98	5.80
SHO + Softer HO probability	[%]	21	11

Table 3. Strongest vs. Best connected Pilot Analysis.

		All	Free	Polluted
EDT				
Strongest measured pilot	[dB]	-5.73	-5.44	-6.00
Best pilot in AS	[dB]	-6.24	-5.48	-6.94
$\Delta_{Strongest-Best}$	[dB]	0.51	0.04	0.94
BLER	[%]	6.54	1.16	11.12
EDT+MDT				
Strongest measured pilot	[dB]	-5.27	-4.67	-6.03
Best pilot in AS	[dB]	-5.61	-4.89	-6.54
$\Delta_{Strongest-Best}$	[dB]	0.33	0.21	0.51
BLER	[%]	5.71	2.70	6.55

5. CONCLUSIONS

Pilot pollution in WCDMA radio network was analyzed with simulations and measurements. It was pointed out that pilot pollution can be reduced by using tighter antenna downtilting. By analyzing pollution free and pilot polluted areas separately it was observed that SHOs perform better when there is only a limited amount of pilot signals hearable, providing also better network performance in pollution free areas. As a result of comparison between static simulations and field measurements it can be concluded that although simulations can not estimate the absolute values of network performance, simulations give good indication of network behavior and pilot hearabilities.

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