Automated Up- and Downlink Capacity Balancing in WCDMA networks

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Abstract— **Dynamic optimization of UMTS systems has been gaining a growing interest by the research community. In this context, the current paper concentrates on dynamic automated tuning of RRM parameters to detect whether the uplink or the downlink is the limiting link and force a reconfiguration to balance both and maximize capacity. Modifications of the soft handover algorithm are revealed as a feasible solution to achieve this objective. A three blocks based functional architecture is described to adapt parameters to service mix dynamics and overcome capacity problems. Conducted tests show the feasibility of the approach. Effective adaptation to changes in traffic patterns and significant capacity gains are obtained.**

Keywords - WCDMA optimization, auto-tuning, load balancing

I. INTRODUCTION

Due to the intrinsic characteristics of WCDMA and the great number of services offered by UMTS, its radio channel is much more dynamic compared with, for example, the GSM system. The users scour through the network and constantly change between services with distinct characteristics. These traffic fluctuations can cause the impairment of the network performance and of the quality of service (QoS) in certain sectors. In the worst case a significant degradation of the QoS may be observed and as a result the operator targets are not met. Nowadays, UMTS operators have fixed, and usually uniform, settings for their network parameters. This static configuration is not able to adapt to the changes that occur in the network. A fixed parameter setting then gives a non optimal solution for the network optimization process and thus the utilization of the radio interface is not maximized. Therefore, a research work is needed for automation of the optimization process of UMTS networks to cope with different conditions.

The design of a radio access network is a complex process that can be divided into two main stages. In the first stage, the goals (capacity, coverage and QoS) are defined, the network is dimensioned and the radio planning is executed. The network layout must be designed along with nodes-B configuration. In this process sophisticated planning and optimization tools are used, which resort to complex cost functions to balance different trade-offs. Finally, system parameters, namely the corresponding to the Radio Resource Management (RRM) algorithms, are fixed. In the second stage, after network deployment, network performance and quality characteristics are monitored and possible hard (e.g. antenna tilt) and soft parameters (RRM mechanisms) have to be tuned. This process is manual and should be carried out periodically. The goal of the automated tuning is to adjust dynamically these parameters in a continuous way without human intervention, which is only required in the definition of the reference QoS.

The optimization of mobile networks has been gaining growing interest by the research community. Several authors propose algorithms for the control of a specific network parameter. Since the optimization and tuning of radio planning parameters has been widely studied [1] [2], current efforts are rather concentrating on dynamic auto tuning of RRM parameters (soft parameters). The control of parameters such as handover windows [3], the total received interference target [4], total cell transmission (TX) power target and radio link power maximums [5], E_b/N_0 in the up- and downlink (UL and DL) for data traffic [6] were proposed in several papers and books [7][8]. These studies validate the feasibility of automated optimization of key WCDMA RRM parameters and demonstrate a significant increase in network capacity in comparison with default parameter settings.

Because of services usage and users mobility, the network may evolve from UL to DL limited situations and vice versa. Up to our knowledge, there are no other studies describing a methodology to use RRM auto-tuning to maximize and balance both links capacity in WCDMA networks. Given this, the current paper proposes an Automatic Tuning System (ATS) to detect and correct this situation by changing RRM parameters accordingly. Soft Handover (SHO) is revealed as a feasible solution to balance UL and DL capacity.

Regarding the organization of the paper, after defining the considered functional architecture in Section II, Section III focuses on the problem statement and the solution principle. Section IV describes the scenario that has been studied. Sections V, VI and VII contain a deeper description of the blocks in the proposed ATS along with accompanying results. Finally, the paper is closed by conclusions.

II. FUNCTIONAL ARCHITECTURE.

This section presents the proposed functional architecture for the system. A conceptual representation of ATS is presented in Figure 1. This consists of three main blocks (Control algorithm, Learning & Memory and Monitoring) and two interfaces (UTRAN and reference). The Universal Terrestrial Radio Access Network (UTRAN) provides access to the RRM parameters and measurements which can be grouped into Key Performance Indicators (KPI) to give a better understanding of

the real state of the network. The reference source provides the operator's concept of QoS and network performance.

The UMTS ATS creates a statistical feedback loop between network measurements and RRM parameters. The network is constantly monitored; selected parameters are placed into memory for statistical analysis and compared with the reference source. When any of the cells does not meet the reference criteria, the tuning algorithm is started. Thus, the radio network tuning process becomes an automatic one. Each of the constituting blocks will be explained next in more detail:

- **Monitoring**: A set of input measurements for each cell is constantly monitored and an alarm is triggered when a KPI is not met. In order to obtain a KPI the following process must be carried out:
  - Performance indicators measuring.
  - Data filtering to overcome instantaneous fluctuations.
  - KPIs calculation.

- **Learning & Memory:** This block can be seen as a database that accumulates statistical information concerned with the network performance (memory). It is also responsible for finding out trends and network behavior regarding different traffic and radio aspects (learning). At the end it can extract cell characterization due to the tuning of RRM parameters. This entity can also be used to adjust the rules or the steps of the control algorithm.

- **Control Algorithm:** It receives the alarm from the monitoring block and with the information provided by "Learning & Memory" decides on the actions to take, which may compromise the change of RRM parameters.

In subsequent sections details will be given in the mapping that is proposed for the three ATS blocks for the specific problem of balancing UL and DL capacity.

III. PROBLEM STATEMENT AND SOLUTION PRINCIPLE

Nowadays UMTS operators fix uniformly their network parameters during the planning process and make readjustments considering long-term effects. That static configuration may suit the network conditions and guarantee a perfect balance between UL and DL in certain cases. However, in 3G systems, new data applications, different services usage and users mobility imply important and frequent fluctuations in traffic patterns and as a result UL and DL requirements do not remain constant. Specific RRM settings could favor a particular link at a specific time and thus, variations along time can spoil the network performance.

ATS can cope with this problem if designed with a monitoring subsystem able to trigger an alarm whenever one of the links starts to degrade significantly. On the other hand, the control block should modify RRM parameters so that the network can favor the limiting direction and congestion control mechanisms can be delayed.

SHO constraints are the first set of parameters to be included in the proposed ATS. These parameters are typically adjusted in a static fashion so that they suit the general network conditions. However, the SHO process is not the same in both TX directions. In the UL, selection diversity is used (as long as the two cells do not belong to the same node-B). How
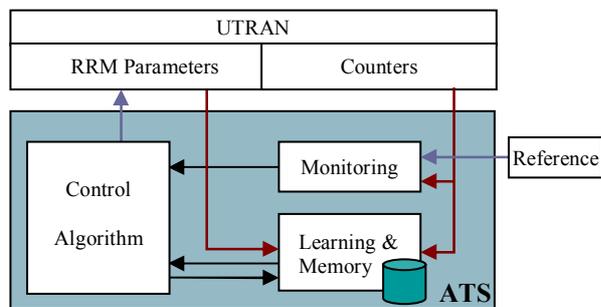

Figure 1. On-line Automated Tuning System

ever, in DL, mobiles receive power from all cells participating in the handover and just see the different signals as multi-path components that can be coherently combined, this provides the benefit of macrodiversity. Although the individual link quality can be improved by this fact, during the SHO process, extra DL resources are needed and so there is a trade-off between the individual link gain and the additional resource consumption. Moreover, there are quite a few parameters that impact on the link that limits the system capacity, particularly on the DL. Some examples are the loss of orthogonality because of the delay spread profile, the maximum power that the operator devotes to a particular DL connection, the assignment of powers in the different cells that form a particular AS, the geographical distribution of UEs, type of services that are mostly used, etc. The first parameter, once it has been characterized, can be considered quite static, the second and third ones are design parameters to be chosen by the operator, but the UEs behavior is not constant, it evolves along time and can make inappropriate certain SHO configurations.

The performance of UMTS SHO algorithm is closely related to the adjustment of different thresholds and hysteresis margins that participate in the algorithm. While the user equipment (UE) is in connected mode, it continuously monitors the primary control pilot channel (P-CPICH) E_c/I_0 of the cells and reports to the network whenever certain conditions on this measure are accomplished. One of the most important parameters is the Addition Window (AddWin), which defines the relative difference of those cells that are to be included in the Active Set (AS) in terms of P-CPICH E_c/I_0. A complete description of the algorithm, thresholds, margins and parameters that participate in it can be found in [9].

Taking these ideas into account, it can be predicted that an AddWin and maximum number of cells in the AS set to a too low value can cause the terminals to connect to a cell which may not be the best option (i.e. the one that would request less power to achieve the E_b/N_0 target). This implies increased UL interference, poor quality and a rise in blocking and congestion. Dropping can also grow because of power outage. On the other hand, too high values would cause a reduction in the DL capacity because of increased TX powers due to many links (eventually insufficient codes could lead to blocking as well). Hence, the control of these parameters is revealed as a feasible design of the ATS to automatically manage this tradeoff.

Next section will describe the scenario that has been used to assess performance gains when ATS is running. Section V, VI and VII will respectively describe the mapping between the different ATS internal blocks and the proposed solution.

IV. SCENARIO

The scenario to be evaluated is a 3GPP based, urban and macrocellular one [10], with an area of 5×5 km^2 and 42 cells in a regular layout. UEs are uniformly scattered. COST231-Hata propagation model for suburban areas is used, considering a 2GHz carrier and radiation patterns from commercial antennas. Two dimensional shadowing model proposed in [11] is employed with a correlation distance of 18m, a standard deviation of 8 dB and a correlation coefficient between base stations of 0.5.Table I shows other important parameters.

Regarding the service mix, two situations are considered. The first one represents a scenario with all UEs of voice type. The second situation has 20% of terminals using a symmetric 64 kbps data service and the remaining 80% corresponds to the voice service. Service features are depicted on Table II. The transition between the two previous situations is simulated and the service mix change is done gradually during the first two-thirds of the observation time. 1100 pedestrian UEs move randomly around the network according to the suburban mobility model defined in [12]

Regarding SHO implementation, measurement reporting can be either event-triggered or periodic in UMTS. The event-triggered option has been chosen, therefore terminals will report to the network each time a P-CPICH signal enters or leaves the different reporting ranges [9]. Moreover, the optional additional time-to-trigger has been set to zero, which means that all events are reported as soon as they occur.

V. ATS: LEARNING STAGE

In an operating network, the process of gathering real data to accumulate statistical information and find and update trends corresponds to the "Learning & Memory" block. By means of simulations this process is approximated. Results could be eventually used as an "Initial Training" previous to the real learning from network data. Thus, in order to evaluate the behavior of both links under different service mix situation, maximum capacity in UL and DL is calculated. This is defined as the situation in which at least one of the cells has a 5% of UEs not reaching the E_b/N_0 target. Figure 2 shows the evolution of capacity for different values of AddWin (in dB) and two possible maximum sizes of the AS, 2 and 3. Several facts are observed. Firstly, the previously announced opposite impact of SHO parameters variations in UL and DL. Whereas the UL increases its capacity with higher values of SHO parameters, the DL worsens it. Variations in the DL are far sharper and an erroneous adjustment can reach capacity reductions of around 30%. Conversely, bad adjustments lead the UL to just a 3% loss, which is logical since the load is evenly distributed. In the central area of the scenario, opening the AS will not give the UEs new interesting cells with lower loads and demanding less power. Finally, note that AddWin tuning shows a higher impact than the maximum AS size selection.

This particular scenario remains UL limited for those cases with a maximum AS size of 3 with an AddWin of 4.5 dB, denoted as configuration (3,4.5), or those cases with a size equal to 2 but windows of 5 dB or less (2,5). Nevertheless, in general, what fixes capacity is the minimum value between UL and DL, and, in particular, the important points are those

TABLE I. SIMULATION PARAMETERS

Minimum required CPICH E_c/I_0		-18 dB
Node-B	Maximum TX power	43 dBm
	Noise power	-104 dBm
UE	Maximum TX power	21 dBm
	Minimum TX power	-44 dBm
	Noise power	-100 dBm

TABLE II. SERVICES FEATURES

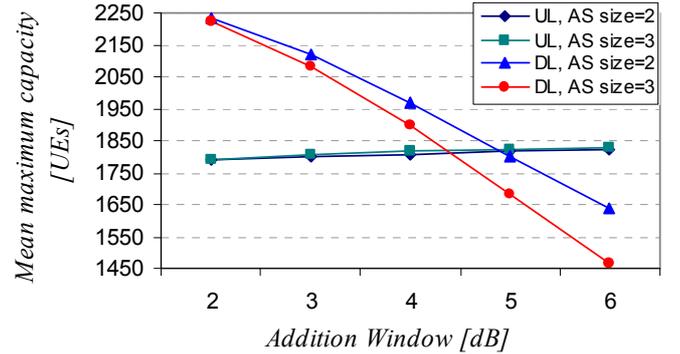| Type of service	UL E_b/N_0 (dB)	DL E_b/N_0 (dB)	Maximum DL power (dBm)
Voice – 12.2 kbps	5.9	6.5	30
Data – 64 kbps	3.5	5.3	30

Figure 2. Maximum Capacity for different configurations of SHO parameters (100% voice UEs)
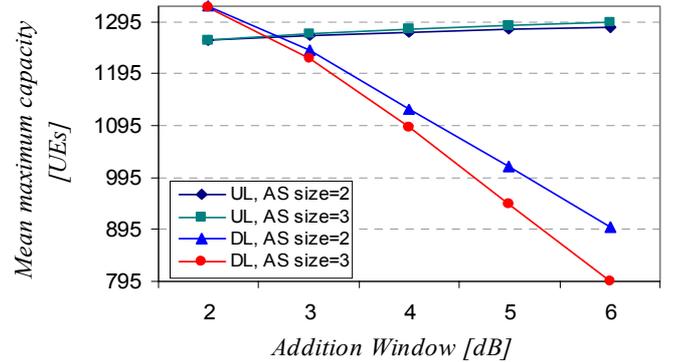

Figure 3. Maximum Capacity for different configurations of SHO parameters (80% voice, 20% data UEs)

in which curves cross (UL and DL remain balanced). Among crossing points, the one with a higher ordinate defines system maximum capacity. According to simulations, a configuration around (2,5) might be a general possibility to be chosen by operators (left maximum crossing point). The righter crossing point implies lower capacity and more signaling (AS size = 3).

For the second traffic pattern, Figure 3 shows that the DL is now the limiting link for all simulated AS configurations except (2,2), moreover, the prior selection (2,5) would not be appropriate any longer. The optimum is now situated around (2,2.7). Given this, detecting the limiting link in real time and automatically tuning SHO parameters could help to maximize the network performance and give an extra capacity margin before congestion control algorithms come into play.

VI. ATS: Monitoring Stage

In order to select appropriate KPIs for the monitoring stage, an initial test was done without implementing ATS. In particular, Figure 4 shows the case in which no tuning is done and SHO parameters are fixed to the optimum value when all UEs are of voice type (2,5).

The pink curve represents the evolution of the DL TX power in the central cell. It can be seen that the maximum power is reached several times at the end of observation time. From the blue curve it can be seen the evolution of the % of UEs reaching the required DL E_b/N_0 also in the central cell. Initially, the cell is able to correctly serve the 100% of UEs that have it in their AS but there is a point in which the network cannot manage so many UEs. Degradation appears once a certain number of UEs commute to the data service and the scenario becomes DL limited as it was previously learnt. The UL adjusted parameters leads the cell into a situation of instability in which most of UEs are in degraded mode. Regarding the UL (not plotted), all UEs reach the required E_b/N_0.

There is a correlation between the variations in the number of UEs with the cell in their AS and the rapid variations of the graph. The downwards trend, however, is motivated by the change in the service mix. Note that degraded UEs appear though the maximum power is not reached. This is because there is a 30 dBm limit in the power that can be devoted for a single connection and a combination of high load factor and propagation loss may imply that a UE cannot meet its requirements. Thus, since the total TX power does not behave as valid KPI, single connections powers evaluations were preferred. Indeed two KPIs are monitored in a cell-by-cell basis:

- **KPI-A:** % of mobiles that require more power than a certain threshold. The comparison reference is a % of the maximum power that can be devoted to one connection. Three percentages have been evaluated. Case-1 considers 80% of the maximum power, case-2 uses 90% and, finally, case-3 employs 100%.

- **KPI-B:** counter of the number of continuous frames in which KPI-A is accomplished for 5% of users (filtering window). Whenever this counter reaches 5, the control block is triggered.

A graph, showing the triggers generated by these KPIs will be shown afterwards, along with complete ATS results.

VII. ATS: Control Stage

Finally, the control block sends an AS reconfiguration order to all the UEs connected to the cell that triggers the mechanism. Note that reconfigured UEs maintain the new parameters until another order is received or the connection finishes. If new mobiles enter the cell after one reconfiguration, they will maintain their original AS, no changes will be applied on them. Therefore a cell with frequent handover (for example with high speed mobiles entering and leaving) will tune SHO parameters often in short periods of time. Also note that, in this work, the study is focused in a scenario that becomes DL limited and thus a (2, 2.7) SHO pattern would be applied after reconfiguration. Conversely, UL limited situa-
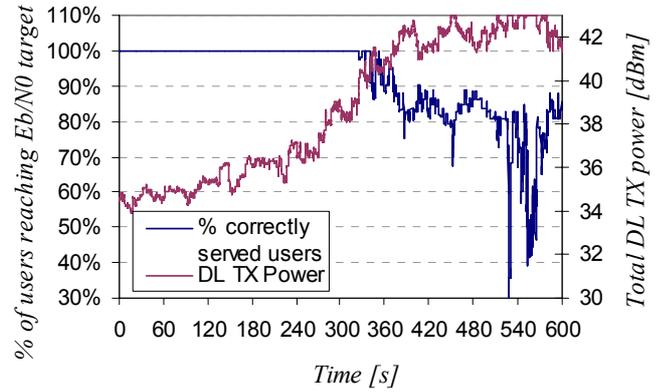

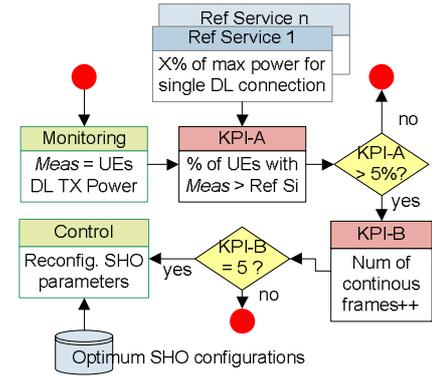**Figure 4. % of UEs reaching Eb/N0 target and DL TX Power**

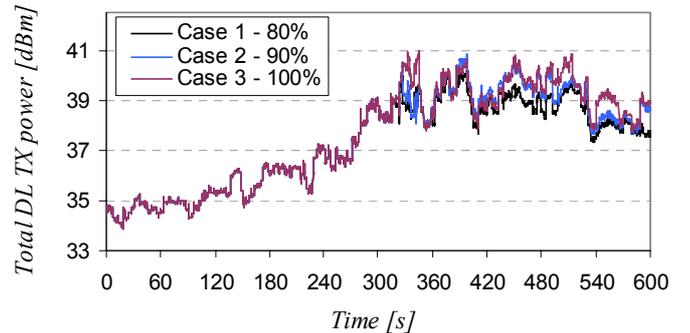**Figure 5. ATS proposal for SHO parameters**

Figure 6. DL TX Power at central cell

tions would imply different reconfigurations (Figure 2). The complete process is described in Figure 5. Note that applied parameters are selected according to the "Learning" stage results, i.e. the optimum configurations (2,5) and (2,2.7).

Figure 6 represents the TX power evolution of central cell during observation time for the three simulated cases. Comparing with Figure 4, the most important difference is that DL TX power is now always kept below 41 dBm. Instability is never reached and a clear margin until the maximum TX power is introduced. Thus, the gains of ATS are obvious.

Graphs show a general upwards trend, coherent with the fact that the service mix evolves to a more demanding situation. However, the trend is not continuous and downwards steps appear each time the observed cell or a nearby one triggers a reconfiguration command. This implies a variation in the number of UEs the cell has to serve and so a reduction in
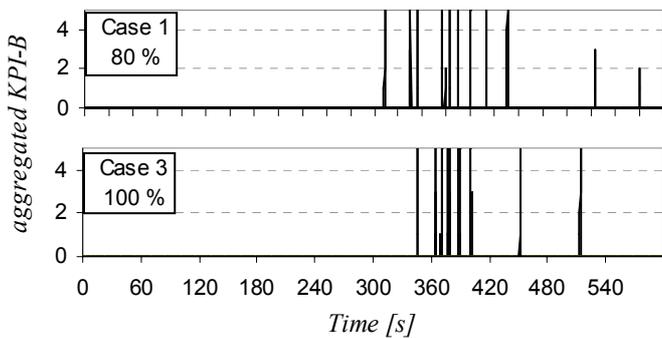
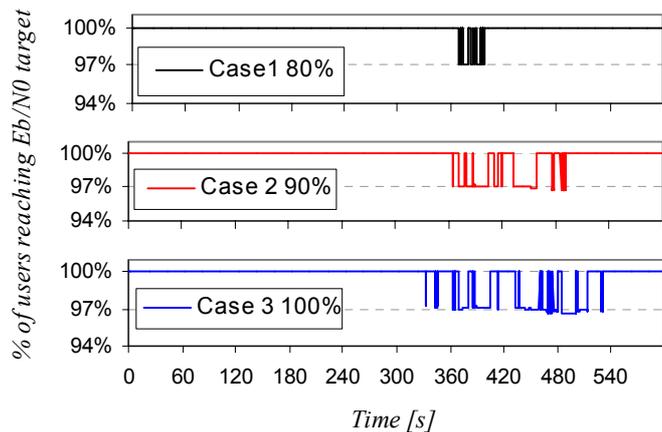**Figure 7. Evolution of KPI-B (aggregated for all cells)**

Figure 8. Evolution of % of UEs reaching E_b/N_0 target

TABLE III. ATS Gains for Different Service Mixes

Data users (%)	Maximum Capacity (simultaneous users)		Capacity gain (%)
	Without ATS	With ATS	
20 %	1014	1270	25.2 %
30 %	852	1115	30.9 %
40 %	730	929	27.3 %
50 %	641	839	30.9 %

the consumption of DL resources. In case 1 (80%), cells trigger "Control" earlier making TX power decrease faster. Nevertheless, all curves report similar values at the end of observation time, so the final result is the same but having different time of response and consequently different number of executed commands. Figure 7 represents the evolution of KPI-B (counter of continuous frames with 5% of users reaching the threshold power), note that all cells are aggregated in the figure. It can be seen, that case-1 (80%) starts triggering the control block before, and commands are slightly more distributed. On the other hand, case-3 (100%) starts triggering later and commands appear concentrated in time and slightly less often. Whereas case-1 executed 17 reconfigurations in the system, case-3 only fulfilled 13.

Figure 8 shows the evolution of the % of UEs reaching their E_b/N_0 target. Whereas, in case 1, central cell almost never shows degraded UEs, this does not occur in case 3, agreeing with previous conclusions. In all cases degradation is always kept below around 3% of UEs, so even case 3 is good enough to guarantee an acceptable performance.

Finally, Table III, quantifies the capacity gains that would be obtained if ATS is applied in different situations. The first table's row corresponds with the previous example, i.e. a 100% voice users situation that evolves to a service mix with 20% of data users. Next rows contain cases with increasing number of data users. The table shows that ATS gains remain quite constant, between 25 and 30%.

VIII. Conclusions

Dynamic optimization of UMTS systems has been gaining a growing interest by the research community. In this context, the current paper concentrates on dynamic automatic tuning of RRM parameters to detect which is the limiting link and force a reconfiguration that favors it. SHO parameters have been revealed as a feasible option to achieve this. A three blocks based auto-tuning architecture has been described to adapt parameters to service mix dynamics and overcome capacity problems. These blocks have been described and tested, showing an effective adaptation to changes in traffic patterns, significant capacity gains are obtained when ATS is running. When DL starts to jeopardize capacity in a cell, a reduction in its resources consumption is executed. This allows a margin in the available power and so, the approach is able to stabilize the network and delay congestion control mechanisms. Three different monitoring cases have been tested showing the feasibility of the approach. The most conservative case reacts faster but generates more reconfigurations. The less conservative also guaranteed network performance but a % of degraded UEs up to 3% was not uncommon during the observation time.

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