Performance Improvement of HSDPA/UMTS Networks through Dynamic Code Tuning

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***Abstract*—This paper concentrates on the dynamic tuning of radio resource management parameters in the context of HSDPA systems coexisting with UMTS Rel'99. In particular, an automatic tuning system is proposed taking into account the close interdependence between the cell throughput and the users channel quality indicators. From these, appropriate performance indicators are derived and a mid-term allocation mechanism is designed to maximize cell throughput while guaranteeing blocking and dropping criteria.**

I. INTRODUCTION

UMTS Rel'5 and Rel'6, among other advances, introduce higher data rates to down- and uplink (DL and UL) through HSDPA (High Speed Downlink Packet Access) and its counterpart HSUPA (High-Speed Uplink Packet Access). These technologies provide a reduction in the cost per megabit through quite a smooth and simple update from pure 3G systems. In fact, many operators are offering some kind of broadband service and the demand for wireless data services is growing faster than even before.

Rel'5 HSDPA has been designed with different performance enhancing features to support theoretical data rates up to 14 Mbps. New and fast mechanisms are introduced into the MAC layer to adapt the data rate to propagation channel conditions, being mainly coding and adaptive modulation, fast hybrid automatic repeat request (H-ARQ) and fast scheduling based on a shorter transmission time interval (TTI) of 2 ms. In addition to this, the H-ARQ mechanism and the scheduler themselves are located in a new MAC sublayer, denoted as MAC-hs and located in the Node-B. This leads to an almost instantaneous execution of H-ARQ and scheduling decisions.

HSDPA also introduces some changes in the UTRAN physical layer. Whereas Rel'99 originally defined three different techniques to enable DL packet data, in practice, dedicated channels (DCH) are the primary means of supporting any significant data transmission. Indeed, one of the novelties that allows HSDPA achieving high data rates is the allocation of multiple codes to a single user. HSDPA defines three new physical channels. First, the High Speed Physical DL Shared Channel (HS-PDSCH) is a DL channel with Spreading Factor (SF) equal to 16 (SF16) carrying the data payload and supporting both time and code multiplexing. Second, the High Speed Dedicated Physical Control Channel (HS-DPCCH) is an UL channel in which each operating HSDPA User Equipment (UE) reports the acknowledgements of the packet received on HS-PDSCH and also the Channel Quality Indicators (CQI). These CQIs can be used by the Node-B scheduler to decide the next UE to serve. And third, the High Speed Shared Control Channel (HS-SCCH) is a fixed rate (SF128) DL channel used to communicate to UEs scheduling and control information. An associated DCH is also needed to carry UL payload and Layer 3 signalling.

Apart from the improvements included in the standards, the Radio Resource Management (RRM) algorithms that are implemented in the vendor equipment are a key factor to the success of HSDPA. Since the design of these algorithms is not defined by 3GPP, several investigations are being carried out to find the best possible implementations. Although scheduling strategies are the main focus of the existent literature (see for example [1; 2]), other aspects are susceptible of study and improvement as it is stated in [3] through lab and field testing.

In the context of HSDPA systems, when a single carrier is shared between Rel'99 and HSDPA itself, some advantages appear (spectrum is more efficiently used, issues associated with upgrading to a multicarrier network are non-existent, also problems with coverage differences among carriers disappear, etc) but the allocation of the resources to be shared has to be efficiently managed, in particular power and OVSF codes. The current work is focused in this second topic. As it is justified in subsequent sections, the optimum code allocation is very dependent on traffic patterns and mobile geographical locations. In this sense, automatic tuning based strategies are revealed as good candidates to track the optimum situation along time. Indeed, the main novelty of this paper is the proposal of a full Automatic Tuning System (ATS) so that the number of codes assigned to HSDPA is dynamically adjusted according to the CQIs reported by the UEs. Thus, a mid-term allocation mechanism is designed to guarantee that HSDPA performs at its most efficient level while guaranteeing blocking and dropping criteria. This is done by using the architecture introduced in [4] and whose 3 blocks are summarized next:

- **Learning & Memory:** Data-base accumulating statistical information concerned with the network performance.
- **Monitoring:** Responsible for measuring a set of parameters, turning them into appropriate Key Performance Indicators (KPIs) and triggering an alarm when certain quality thresholds are not met.
- **Control Algorithm:** It receives the alarm and with the information provided by *Learning & Memory* decides on the actions to take, which may compromise the change of RRM parameters.

Given this, the paper is organized in three main sections, each one describing these blocks in our particular case. Accompanying analysis and results are introduced and after the full proposal is tested, the paper is closed by conclusions.

II. 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. In this work, this process is approximated by means of simulations whose results could be eventually used as an "Initial Training", previous to the real learning from network data. The simulation conditions that have been considered are summarized next.

A. Scenario

The scenario to be evaluated is a 3GPP based, urban and macrocellular one, with an area of 5×5 km^2 and 42 cells in a regular layout. Propagation is modeled according to COST231-Hata model, considering a 2 GHz carrier and radiation patterns from commercial antennas. Regarding shadowing, a correlation distance of 18 m is considered, a standard deviation of 8 dB and a correlation coefficient between base stations of 0.5. The percentage of intracell power generating interference in the DL (orthogonality factor) is equal to 40%.

500 UEs have been spread around the scenario, 50% of them use a high speed packet switched service and are redirected to HSDPA when becoming active. The other 50% remain at Rel'99 and make use of one classical DCH. Regarding HSDPA-capable terminals, category 10 UEs are considered, which support both QPSK and 16-QAM, they can also decode up to 15 simultaneous HS-PDSCH codes with a maximum transport block size of 27952 bits in one TTI with an interval of 1 ms, i.e. consecutive HS-PDSCHs can be decoded.

Since the objective is to determine the maximum HSDPA capacity per cell, traffic buffers are assumed full during the simulation time. The service is considered to be a delay-tolerant and best effort one, so scheduling can be conducted without considering minimum QoS requirements. Rel'99 UEs use a symmetrical 64 kbps data service with an associated TF having a fixed SF32. Both Round Robin and Proportional Fair strategies have been simulated, though trends and conclusions are independent on the algorithm and only changes in absolute values were obtained. Presented Figures show the Round Robin case.

Rel'5 specifications do not stipulate power controlling HS-SCCHs and this decision is left to the infrastructure vendors. Avoiding this would lead to unnecessary power reservation and consequently to poorer throughput of data channels. Simulations consider that these channels are power controlled.

The number of HS-SCCHs is kept to the maximum possible value, i.e. the minimum value between 4 and the number of HS-PDSCHs. Finally, the correspondence between the CQI values and the selected Transport Formats (TFs) was obtained from the AROMA research project, an IST project from the *6th Framework Program of the European Community* [5].

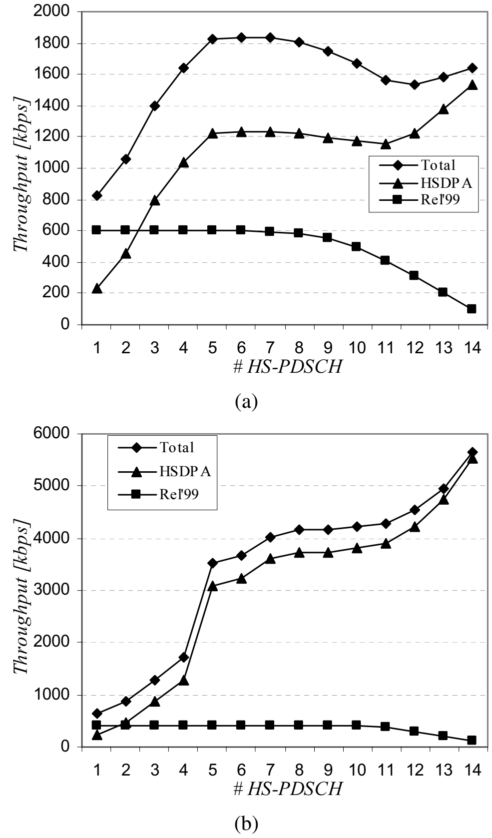


Fig. 1: Cell throughput evolution for different HS-PDSCHs allocations and UEs spatial distribution. (a) UEs close to cell edge. (b) UEs close to Node-B (<150 m)

B. Cell Throughput Analysis with Different Code Allocations

Initially, the impact in the throughput when fixing a certain amount of HS-PDSCHs has been evaluated. Since UEs are not always homogeneously distributed and certain cells can have most of their users concentrated in particular areas, the CQI reports can be very different and so the HSDPA TF and assigned data rates. In order to quantify the impact of these different channel conditions on the cell throughput, results have been obtained for 3 scenarios: UEs uniformly distributed, UEs far from the Node-B and finally UEs close to the Node-B. In particular, Fig. 1 represents the throughput evolution for different codes allocations and for the two last situations, being the uniform one an intermediate case.

As expected, Rel'99 contribution to the cell global throughput is far less important than that of HSDPA, in particular when more than 3 codes are devoted to this technology. But gains depend on the position of UEs, when they are mostly far from the Node-B, there is no benefit in allocating more than a certain amount of codes to HSDPA, 5 in the simulated case. Reported CQIs are low and those extra codes would be hardly used. In fact, assigning more codes would even imply a reduction in the global cell throughput, in this scenario up to 320 kbps. On the other hand, having UEs close to the Node-B (Fig. 1(b)) leads to the rule: the higher the number of HS-PDSCH codes, the better. Nevertheless, in this case, blocking

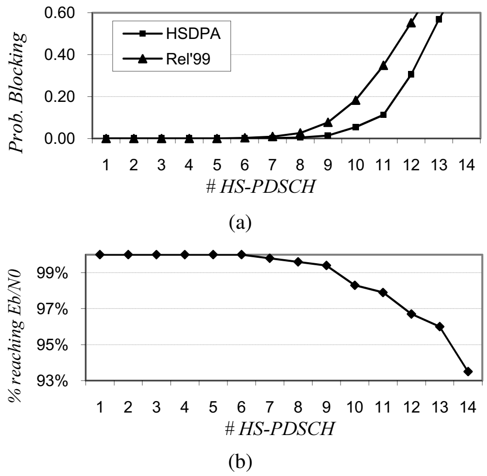


Fig. 2: (a) Blocking probability for Rel'99 and HSPDA. (b) Rel'99 Degradation.

criteria must be considered by the radio planning engineer to upper bound the number of allocable codes. Fig. 2(a) shows the blocking probability for both Rel'99 and HSDPA UEs. A maximum of 8 codes can be allocated to HSDPA to have an average blocking probability below 5% in both technologies. Rel'99 experiences a higher blocking because UEs are more demanding in terms of code tree occupation (SF32 vs. SF256 for HSDPA associated DCHs). The assumed admission control algorithm only takes into account the code tree occupation. No other criteria are introduced to avoid side effects that could hinder the analysis.

On the other hand, Fig. 2(b) shows the evolution of degraded UEs, i.e. those users not reaching the required E_b/N_0. Degradation is indirectly induced by blocking, which affects the normal operation of soft handover since active sets cannot include those cells with all its DCHs occupied. The lack of macrodiversity implies that certain Nodes-B are now forced to transmit 100% of the power required by a UE, which can imply degradation in Rel'99 users and throughput reduction in HSDPA, as seen from Fig. 1(a). To guarantee that degradation does not exceed 2% the maximum number of codes to be considered is 9. The most restrictive of these effects must be considered to limit the maximum number of codes devoted to HSDPA. The last increase in the curve shape is justified by the compensation of extra interference with blocked users. Finally, when UEs are concentrated close to the Node-B, intercell interference is inferior and effects are reduced.

From the previous paragraphs it can be concluded that by making an intelligent allocation based on the RF channel conditions, it is possible to reduce blocking and degradation (eventually dropping) in Rel'99 DCHs while maximizing the cell throughput. Indeed it is only necessary to know the channel status of HSDPA users and so, reported CQI measurements can be used as the first input to consider by a hypothetical ATS. Based on the above, the complete ATS proposal is depicted by the flow diagram in Fig. 3. Along next sections a description of its different steps is given.

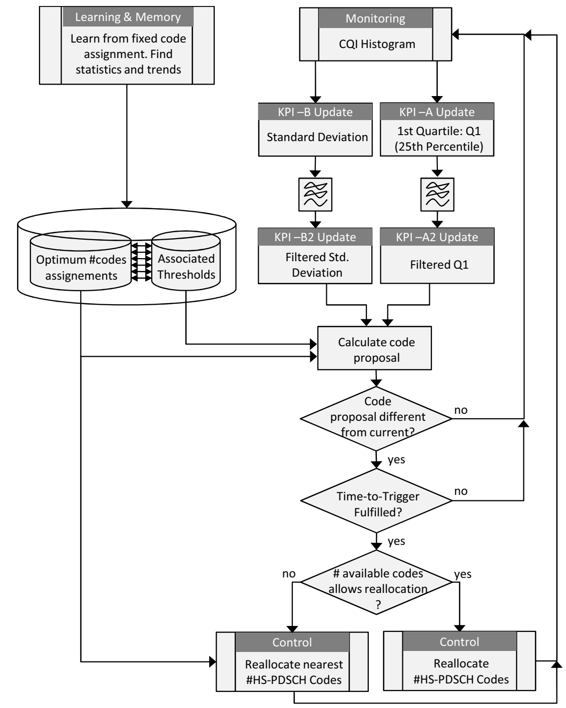


Fig. 3: Complete ATS proposal

III. ATS: Monitoring Stage

Dynamic simulations have been run to study which are the proper KPIs to detect different channel conditions in the links between UEs and their serving nodes-B. An observation time of one hour has been set, divided into 3 distinct parts. Initially users roam around the network at 3 km/h, with a direction which is corrected with a probability of 0.4 by an angle between -45 and 45 deg. In the second third of the simulation, they move towards the cells edge. Finally, in the last third of the observation time, users are directed towards the Node-B, in an area within a radius of 150 m. This behavior is intended to cover a wide range of situations in the sense of reported CQIs.

Fig. 4 represents the temporal evolution of the normalized histogram of reported CQI values, averaged every 500 ms. The three simulation parts can be differentiated. Initially, the histograms show a high standard deviation because UEs are situated homogenously around each particular cell. Besides, their movement does not contribute to generate significant accumulations in specific areas. As users concentrate on cells edges, the standard deviation decreases and also the reported CQI values. Values increase again when users go towards the Node-B.

Since the objective is to detect the channel characteristics of the "majority" of UEs in the cell, KPI-A is defined as the first quartile Q_1 of reported CQIs. This way, it is known that 75% of UEs report better conditions than that threshold. On the other hand, when dispersion is excessive, decisions based on KPI-A can be pessimistic. A high standard deviation σ_{CQI} is indicative that many UEs enjoy a radio channel much better than Q_1. That is why, in order to detect cases with high

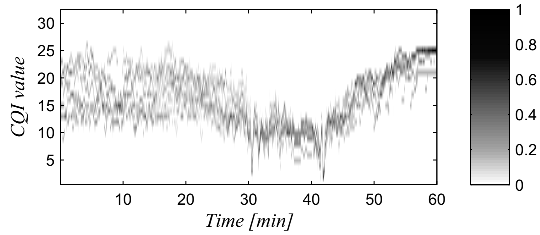


Fig. 4: Evolution of CQI normalized histogram along time.

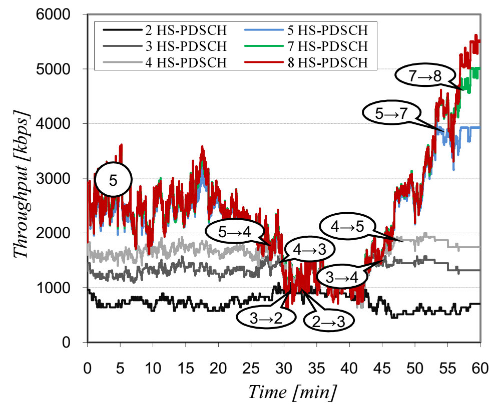


Fig. 5: Averaged throughput evolution for fixed code assignments and optimum commutation points.

differences among link conditions, KPI-B equals σ_{CQI}.

IV. ATS: Control Stage

In order to derive a decision Look-Up-Table (LUT) that relates the KPIs with the number of codes to allocate, an analysis of 3 of the central cells has been done. Several simulations have been run with different static codes allocation. Comparing each possibility with the others, the optimum commutation points have been detected. This is graphically shown by Fig. 5 for one of the cells. Around those points the state of the CQI histogram was analyzed to derive the channel conditions in terms of KPI-A and B.

It can be observed that in certain cases there is no special benefit in increasing the codes assigned to HSDPA. In this sense, the plotted bubbles indicate desirable points to commute from the current code allocation (1st number in the bubble) to a new one (2nd number). At those points the *Control* stage should desirably receive an alarm from the *Monitoring* stage and reallocate codes according to the databases in the *Learning and Memory* block.

From the analysis of these cells a decision LUT has been defined relating the values of Q_1 with the number of codes to apply and the computed value of σ_{CQI}. The standard deviation is considered to be high when it takes a value greater than the 10% of the maximum reportable CQI (=30). An average variation of ± 3 units in CQI values indeed imply diversified radio conditions among UEs. Under these circumstances, several UEs report a CQI fairly far from Q_1 (well over 3 units) and therefore the optimal number of available HSDPA codes should be superior to avoid a too conservative allocation that would lead to a throughput reduction. Given this, the final LUT is shown in in Table I.

Reported CQIs show sharp and fast variations along their general trend and therefore a processing of Q_1 is needed to avoid excessive number of reallocations and ping-pong effect. Making too much codes changes for just a short time is not desirable since they imply extra signalling in the Iub interface. In particular, a FIR filter based running average combined with a classical time-to-trigger were introduced in the *Monitoring* stage to avoid this problem. Both require low computational time and have been configured so that they introduce a delay of 30 s, short enough to detect changes in the generic spatial distribution of UEs inside a cell. Fig. 6 shows Q_1 evolution along time as well as the number of codes set aside for HS-PDSCH after the filtering process.

Fig. 7 contains comparative results when the ATS is running and when a fixed allocation of 8 codes is applied, which was the maximum tolerable value at the *Learning* stage. In particular, Fig. 7(a) represents the blocking probability experienced by the central cell when the static strategy is implemented. Especially in the second third of the simulation, because of UEs being accumulated at the cell edge, and therefore at SHO areas, access requests are increased. The cell however does not have enough resources to support those new petitions and blocking rises dramatically up to values around 30%. On the other hand, the proposed ATS succeeds in keeping blocking equal to zero (no graph needed). Precisely the number of assigned codes clearly descends when users are far away from the Node-B and their reported CQIs worsen. So, in this sense the gains of using a dynamic strategy are obvious.

TABLE I: Look-Up-Table used by the implemented ATS

Q_1	# HS-PDSCH	
	$\sigma_{CQI} < 3$	$\sigma_{CQI} \geq 3$
≤ 7	2	3
≤ 9	3	4
≤ 11	4	5
≤ 17	5	7
≤ 21	7	8
> 21	8	8

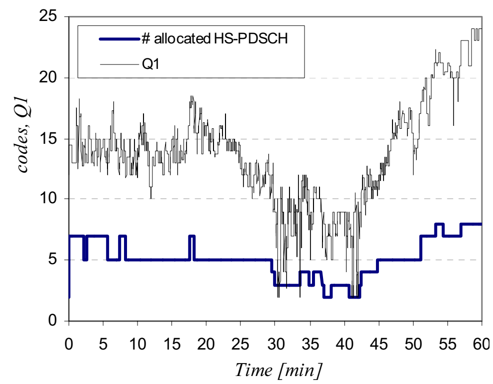
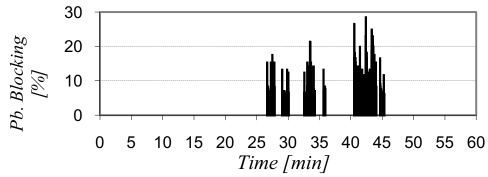
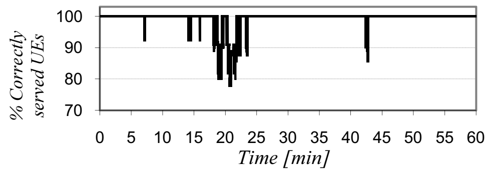


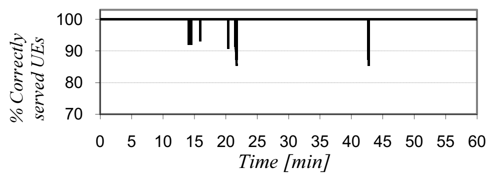
Fig. 6: Q_1 evolution and number of allocated codes at the central cell



(a)



(b)



(c)

Fig. 7: ATS results. Comparison against fixed 8 codes allocation. (a) Blocking probability (8 codes). (b) % Correctly served UEs (8 codes). (c) % Correctly served UEs (ATS)

Regarding the number of UEs that are not reaching their E_b/N_0 target, Fig. 7(b) shows its evolution for the fixed allocation. As it was studied in the *Learning & Memory* stage, the higher the number of codes, the higher the partial blocking and elimination of cells from the AS, which implies a worse interference pattern and a more likely DL degradation. If these values are compared with the ATS running (Fig. 7(c)), it can be concluded that the proposed mechanism also succeeds in reducing the number of degraded UEs.

The ATS is a mid-term mechanism that fits the number of HS-PDSCHs to the channel conditions of the majority of users, however, one UE being especially close to the Node-B could be served with a higher throughput if more codes were devoted to HSDPA, not only 8 codes, but even 9, 10 and so on. Nevertheless, as seen, this would be at the cost of increasing blocking and degradation and thus inducing a globally worse network performance. Given this, it is expected that at certain moments, the throughput obtained with 8 codes is higher than that obtained by the ATS. Nevertheless, the average loss for not using a maximum code policy is of just 18.7 kbps so the throughput can be considered to remain maximized. On the other hand, if the comparison is done with a more conservative static allocation that guarantees blocking and dropping, as for example 5 codes, then the ATS stands out because throughput gains are of 1750 kbps. Thus, the approach succeeds in solving the tradeoff and it does improve throughput while guaranteeing blocking and dropping indicators.

V. Conclusions

Although HSDPA continues evolving through new 3GPP standard definitions, the RRM algorithms to be implemented in the vendor equipment are not defined by the standard and are a key factor to its success and performance improvement. Indeed, the novelty of this paper is the proposal of a dynamic HS-PDSCH code allocation in systems with HSDPA and UMTS Rel'99 coexisting in the same carrier. The objective behind this is to track the optimum value that maximizes throughput while ensuring blocking and dropping constraints.

The basis of the functional architecture is a three-block based structure consisting of learning, monitoring and control phases. From the *Learning & Memory* block it has been observed that the optimum number of codes to be assigned to HSDPA is tightly coupled with the reported CQIs, so the *Monitoring* is done based on the filtered first quartile of the CQI distribution and its standard deviation. By means of an analysis of several cells using different fixed codes allocation a decision LUT was defined to connect these KPIs with the corresponding number of codes to be allocated by the *Control* stage. These KPIs were previously filtered to avoid too frequent reallocations and an excessive ping-pong effect.

Results have revealed that the proposed mechanism allows optimizing the cell global throughput while keeping blocking and degradation below specific thresholds. After these results, that define and confirm the mechanism, a future work consists of studying the generality of the obtained LUT or studying to which extent rules of thumb can be obtained to easily adjust it to any possible scenario.

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