Abstract: Downlink Scheduler Optimization in High-Speed Downlink Packet Access Networks

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High Speed Downlink Packet Access (HSDPA) was standardized by the third generation partnership project (3GPP) to support high speed asymmetric data transfer in mobile networks. The tremendous increase in the achievable spectral efficiency by HSDPA system is attributed to several new technologies that have been incorporated in this system. These technologies include Adaptive Modulation and Coding (AMC), Hybrid Automatic Repeat reQuest (H-ARQ) and Fast Scheduling (FS). Scheduling plays a major role in achieving the desirable data rate in HSDPA networks. It is responsible for allocating the 2 milliseconds Transmissions Time Intervals (TTI) and the 15 available codes (per TTI) to the connected users in a single cell/sector. It can achieve higher data rate by utilizing the channel variation of the connected users. The scheduler also responsible for providing Quality of Service (QoS) for the different classes of services and fairness to all users in the system.

Most of the available work in the area of scheduler design is based on intuition and creativity of the designer. The designer usually selects an important performance measure (in his opinion) and build an algorithm that maximize that measure, and then tries to establish confidence in it using backward analysis or simulation. This, most likely, will result in a suboptimal algorithm at the best, that performs well in some scenarios and poor in the others. This happens especially in systems such as HSDPA, since it uses a very complex set of features such as AMC and H-ARQ, which introduced many new and interrelated tuning parameters that cannot be grasped by a single measure. Another observation is the lack of work on schedulers that dynamically allocate not just the time slots (TTI) but also the 15 codes in each TTI.

The problem in hand is to devise an analytic model and a solution methodology to determine the optimal scheduling policy structure in HSDPA downlink scheduler. The optimal policy is defined as the policy that yields the maximum achievable system throughput while maintaining a reasonable level of fairness between all the users in the system.

The key contributions of this work can be summarized by

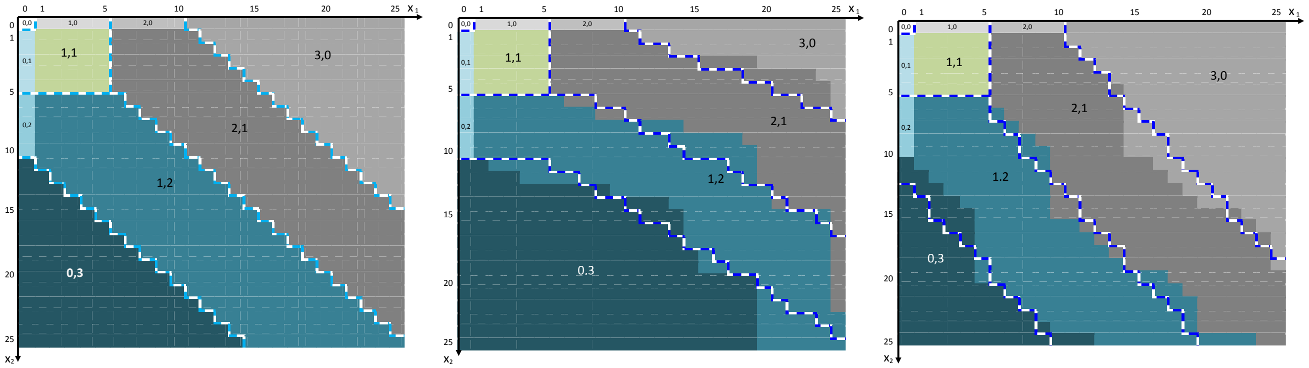
1) A novel approach and a methodology for scheduling in HSDPA system were developed.
2) The HSDPA downlink scheduler was modeled by a Markov Decision Process (MDP), then Dynamic Programming is used to find the optimal code allocation policy in each TTI (refer to [1]).
3) The optimal dynamic allocation policy structure, for 2-user case and using 2-state channel model, was studied and presented in [2].
4) A heuristic approach was developed and used to find the near-optimal heuristic policy for the 2-user case. This work was presented in [3].
5) An optimal policy for code allocation in HSDPA system using Finite-State Markov Channel Model (FSMC) was investigated and the optimal policy structure and the effect of the increased number of channel model states on the optimal policy structure and model accuracy was studied and presented in [4].
6) An extension of the heuristic approach for any finite number of users was derived analytically, using the information about the optimal policy structure and Order Theory, and presented in [5].
7) A performance evaluation was conducted for the optimal policy and the suggested heuristic policy. In addition, we conducted a comparison study of the optimal, heuristic and other well known schedulers such as Round Robin scheduler.
8) An analytic model was developed, using stochastic modeling, to find the average service rate and server share allocation policy for a group of users sharing the same wireless link. This model resulted in a static server share allocation policy and is used as a baseline for the dynamic policies. This work is presented in [6].

THE APPROACH

An analytic model, using stochastic dynamic programming is built to represent the HSDPA scheduler with some realistic assumptions to the rest of the system components. This model is a simplifying abstraction of the real scheduler which estimates system behavior under different conditions and describes the role of various system components in these behaviors. This model can be solved numerically (using value iteration) to obtain the optimal scheduling policy for some given *objective function* in a straight forward manner.

We chose to model the system as a Markov Decision Process. Solving this model is proven to yield the optimal policy for a given reward function. The selection of the reward function is based on the objective that need to be achieved. Different objective functions may result in different optimal policies. Hence, this approach can be considered as a *unified approach* since the same model can be used when solving for different objective function by simply changing the reward associated with the model to reflect the new objective.

In this work, our objective is to maximize system throughput while maintaining fairness between all users in the system. The proposed approach produces an optimal policy in the sense that it maximize cell throughput for a given fairness criteria.



(a) Symmetrical case (b) $p_1 = 0.8$, $p_2 = 0.5$, $q_1 = q_2 = 0.5$ (c) $p_1 = p_2 = 0.5$, $q_1 = 0.8$, $q_2 = 0.5$

Fig. 1. The heuristic policy (dotted line) in comparison to the optimal policy; $c = 5$

It provides an elegant and presentable analytic foundation for scheduling problems and may be used as a benchmarking tool to the existing schedulers.

THE RESULTS

Some of the findings of this work is listed below

1) The optimal policy structure is of a threshold type.
2) The optimal policy can be described as *share the available codes in proportion to the weighted queue length of the connected users*, where, the weight is a function of the differences in the two channel qualities and arrival probabilities.
3) The suggested heuristic policy performance match very closely to the optimal policy.
4) The devised heuristic policy has deterministic polynomial complexity with constant time complexity, i.e., $O(1)$. On the other hand, the calculation of the optimal policy has an exponential time complexity, in the buffer size B, with $O(B^L)$ per one iteration, where L is the number of active users in the system.
5) The suggested heuristic policy was extended to the case with more than two active users. The simulation results showed that the heuristic policy match very well with the optimal one.
6) For more accurate HSDPA model, higher number of channel states in the FSMC model is required. However, increasing the number of channel states will result in increased computational complexity.

An example of the optimal policy structure and the suggested heuristic policy for 2-user case is given in Fig. 1. The figure shows the heuristic policy (the dotted line) superimposed on the optimal policy for different loading (i.e., arrival probability q_i) and channel quality conditions (i.e., probability to be connected p_i). The granularity c is defined as the minimum number of codes that can be assigned to a single user at a time. $c = 5$ means that the 15 codes (per TTI) can be assigned as chunks of 5 codes to the active users in the system. Here, x_i is the queue size of user i, and the numbers in the different regions in the action space represent the code chunks allocated to user1 and user2 respectively (e.g., (3,0) means 3 code chunks allocated to user1 and nothing to user2).

Three selected cases are presented; The symmetrical case (Fig.1(a)) where the two users have the same arrival probability and the same channel quality. Fig.1(b) is the case when $p_1 > p_2$, we can see the shift of the policy in favor of user2 to compensate for that difference and achieve fairness. Fig.1(c) is when $q_1 > q_2$, more arrivals means more load and hence larger buffer size and queuing delay experienced by user1 compared to user2. In this case, the policy is shifted in favor of user1 to compensate for the increased load, again to achieve fairness.

FUTURE WORK

Providing analytic proof for some of the structural properties of the optimal policy is of interest to us at this stage. Using the developed approach to address scheduling in other wireless systems is another area we would like to explore. We also would like to study the performance of existent schedulers in light of the information we gain from studying the optimal policy structure and behavior. The model can also be extended to include retransmission buffers in addition to the transmission buffers. This will generate additional complexity since the arrivals to the retransmission buffers depends on the policy and the channel state in the previous system state.

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