Scheduling Optimization in HSDPA Networks Simulating Maximum Terminal Capabilities

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Abstract — **In HSDPA, a single logical channel is shared amongst multiple contending users. Besides better link utilization, scheduling disciplines seek to achieve fair allocation of this shared resource. However, these two criteria can potentially be in conflict. This paper investigates these two criteria performances in a heavy load scenario using FTP traffic with achievable maximum data rate of 14.4 Mbps, simulating different scheduling algorithms in order to find the best solution for this scenario. Comparison is also made with previous given simulation results with achievable maximum data rate of 3.6 Mbps for three schedulers. Simulation results show that Proportional Fair Time scheduling algorithm provides the best results comparing link utilization and fairness among the users, under heavy load conditions.**

***Keywords* — HSDPA, Scheduling algorithm, Scheduling optimization, Simulation, Terminal Category.**

I. Introduction

HSDPA is a 3.5G wireless system standardized as a set of technological advancements to UMTS in order to improve network capacity and increases the peak data rates up to 14.4 Mbps for downlink packet traffic [1] -[4]. HSDPA utilizes a common downlink shared channel known as high speed downlink shared channel (HS-DSCH), and employs fast link adaptation for downlink data transfer to mobiles, based on adaptive modulation and coding (AMC), hybrid automatic repeat request (HARQ) and a shorter minimum allocation time (transmission time interval, TTI) of 2ms. In addition to these physical layer features, the packet scheduling functionality is moved from the centralized radio network controller (RNC) to the base station (Node B), where it is embedded in a new MAC entity known as MAC-hs.

Packet Scheduling functionality plays a key role in HSDPA. The features included in HSDPA and the new location of the scheduler in the Node-B open new possibilities for the design of this functionality for the evolution of WCDMA. The main goal of the Packet Scheduler is to maximize the network throughput while satisfying the Quality of Service (QoS) requirements of the users.

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In UMTS, the bearers do not set any absolute quality guarantees (such can never be given in a wireless transmission) in terms of data rate for interactive and background traffic classes. The introduction of minimum service guarantees for users is a relevant factor, and it is taken into consideration in the performance evaluation of the different HSDPA schedulers. The service guarantees interact with the notion of fairness and the level of satisfaction among users. Very unfair scheduling mechanisms can lead to the starvation of the least favourable users in highly loaded networks, and as described in [1], the starvation of users could have negative effects on the performance of higher layer protocols, like TCP. These concepts and their effect on the HSDPA performance are thus important for our investigation.

A number of different scheduling algorithms have been proposed to address these issues [2-6], all with their respective advantages and trade-offs. Several simulation experiments were conducted in this paper for evaluating the performance of different algorithms. We evaluate the system performance of different groups of schedulers using CAT 10 UEs (offering up to 14.4 Mbps theoretical bit rate) in a heavy load scenario with FTP traffic in terms of system throughput and fairness. Section II discusses scheduling in HSDPA, and the main performance measures related to scheduling. Section III presents the simulation results of the scheduling algorithms. In our simulations experiments, the performance of CAT 10 UEs is determined under 14 scheduling schemes. The results are given in average throughput and delay and overall cell throughput. Finally, Section IV contains summary of the work done.

II. Scheduling in HSDPA and Performance Measures

The process of scheduling refers to the process of allocation of transmitter time and power (at Node-B) to the randomly time-varying mobile data connections (mobile users, UE). Scheduling decisions control the allocation of resources amongst users, and this allocation determines the overall performance of a system. In HSDPA, the packet scheduler is moved from the Radio Network Controller (RNC) to Node B, with the resulting advantage of fast link adaptation techniques. The idea is to enable scheduling such that, if required, most of the cell capacity may be allocated to one user, when its conditions are favorable. In the optimum scenario, scheduling should be able to track fast fading of users.

In HSDPA, the User Equipment (UE) sends its downlink channel quality feedback to Node B in the form of the Channel Quality Indicator (CQI). The packet scheduling algorithm should take into account the radio channel conditions (based on CQI value), UE capabilities, resource availability, buffer status, and the QoS requirement of different users.

High resource utilization is one of the main aims of scheduling. The best strategy to maximize link utilization in a wireless network is to schedule users who have the best channel condition. But, if Node B always serves users with good channel condition, then users in poor channel condition would be starved. This may cause a degradation of performance of a higher layer protocol, such as TCP. Hence, it is important not to investigate the performance of a scheduling algorithm in terms of only the total system throughput or link utilization.

The throughput at UE depends upon the scheduling scheme employed at Node-B. In [7] the total cell throughput of a HSDPA system having a total of N_u users with a mean bit rate of R_i is given by:

$$T = E\left(\sum_{i=1}^{N_u} R_i\right), \qquad (1)$$

where for Round Robin, R_i is given by:

$$R_i = \frac{1}{N_u}\sum_m k_m \frac{W}{SF}\frac{(N\log 2(M)\tau)_{m,i}}{N_{s,i}} \qquad (2)$$

In (2) W is a chip rate, SF is spreading factor, $N_{s,i}$ is the number of transmissions for user i due to HARQ, M is the modulation order, τ is code rate and k_m varies with the position of UE. For maximum C/I scheduling, the expression for R_i is the same as in (2) but multiplied to the probability that a Transmission Time Interval (TTI) is allocated to user i, for which no simple or closed for formula has been derived.

The performance evaluation of a scheduling algorithm must be based on two metrics:

- Link utilization
- User level fairness – long-term and short-term

Link utilization can be measured by the total system throughput. For ensuring user level fairness, users should be scheduled taking into account their QoS requirements. For a quantitative measure of *long-term fairness*, Jain *et al* [8] have proposed the fairness index by

$$\frac{\left(\sum_{i=1}^{N} x_i\right)^2}{N\sum_{i=1}^{N} x_i^{\,2}}, \qquad x_i \geq 0 \quad \forall i \qquad (3)$$

where x_i is the performance measure of concern for user i, which may be in terms of delay, or throughput, or fraction of demand served, and N is the number of users. In this paper, x_i is calculated based on the fraction of demand served, i.e. R_i/RT_i, where R_i is the average throughput achieved by user i, and RT_i is the maximum bit rate (MBR) requirement of the user. This fairness index lies between 0 and 1; as the variance of x_i values increases, the index approaches to 0.

For short time-scale fairness, the waiting time of MAC-hs PDUs should also be considered while providing long-term fairness. Thus, providing long-term fairness while also considering Node B waiting times is the key insight for aiming at *short-term fairness*.

III. Performance Evaluation

In this section, we evaluate the performance of our proposed scheduling algorithm by means of simulation with the help of Network Simulator ns-2 [9] and its Enhanced UMTS Radio Access Network Extensions (EURANE) [10].

A. Simulation Mode

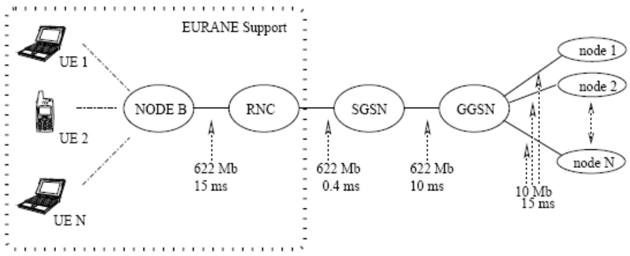

Fig. 1. Topology used in simulation

In this paper we simulate heavy load conditions. Simulation topology and the bandwidth and link delays for each wired link used are shown in Fig. 1. Simulations of the highest possible throughput assigning Terminal Category 10 offering the highest bit rates (theoretical 14.4 Mbps) has been done with previous modification of CQI code.

B. Traffic Model

In simulations as a traffic source FTP traffic generator is used within TCP Agent, which is standard FTP generator of NS-2. This kind of traffic belongs to background class applications. This class presents the most delay latency tolerance since the destination does not expect the data within a certain time. Typical examples of this class are e-mail, file transfer protocol (FTP), short messages (SMS), and multimedia messages (MMS). FTP is one of the most popular and widely used Internet applications besides Hypertext Transfer protocol (HTTP), email, etc. These Internet applications rely on two common protocols, namely, Transmission Control Protocol and the Internet Protocol (TCP/IP), to reliably transport data across heterogeneous networks. QoS requirements of this service class are: one way delay – no limit; bit error rate – between $4*10^{-5}$ and $6*10^{-8}$; delay variation – no limit; use of retransmission mechanism – MAC-hs, RLC; transport layer – TCP.

C. Simulation Experiments

This subsection presents the simulation results of the algorithms using Category 10 terminals (Table 1) offering the highest bit rates (theoretical 14.4 Mbps) Comparison is also made with previous results for three schedulers using Category 5 terminals (Table 1) offering 3.6 Mbps bit rate. Mobiles are considered as pedestrian moving at equal distances from the Node-B (base station).

TABLE 1: HSDPA TERMINAL CAPABILITY CATEGORIES [11]

Cate gory	*Maximum number of parallel codes per HS-DSCH*	*Minimum inter-TTI interval*	*Transport channel bits per TTI*	*Achievable maximum data rate (Mbps)*
1	5	3	7298	1.2
2	5	3	7298	1.2
3	5	2	7298	1.8
4	5	2	7298	1.8
5	**5**	**1**	**7298**	**3.6**
6	5	1	7298	3.6
7	10	1	14411	7.2
8	10	1	14411	7.2
9	15	1	20251	10.2
10	**15**	**1**	**27952**	**14.4**
11	5	2	3630	0.9
12	5	1	3630	1.8

In Fig. 2 and Fig. 3 are presented results for average throughput and average delay for the RR, max C/I and FCDS packet schedulers.

The simulation environment of this results is the same with the one in Fig.1.c,d in [12], except that here is assigned CAT 10 UEs instead of CAT 5 UEs. Average throughput is normally, as expected increased for all three scheduling algorithms. But, what we want to stress from the results is that increasing of the average throughput acts differently at the three scheduling algorithms when the distance from the Node-B is analyzed. For RR scheduler, as mobile users are closer to the Node-B, they will experience more increased throughput, changing the CAT 5 to CAT 10 and users that are at the periphery of the cell will not experience big difference of throughput.

The effect of increasing the achievable maximum data rate from 3.6 to 14.4 is opposite for the mobile users if they use Max C/I scheduler. Users that are closer to the Node-B will not experience big difference at increasing of the throughput, and those that are further from the Node-B will gain more increasing of the throughput. FCDS scheduler has the worst results from increasing the achievable maximum data rate from 3.6 to 14.4 (CAT 5 to CAT 10). Only users closer to the periphery will improve a little their throughput performance.

Increasing the achievable maximum data rate from CAT 5 UEs to CAT 10 UEs, caused better fairness of the users using max C/I scheduler, worst fairness using RR scheduler and approximately the same fairness using FCDS scheduler. Improvement of the fairness of the max C/I schedulers is explained with the better increasing of throughput for the users that are further distanced from the Node-B, and the explanation is vice versa for the RR scheduler.

Average delay of the users has similar attitude comparing the results in Fig.1.d in [12] with the results in Fig. 3. The results of average delay are better with CAT 10 UEs at round robin and max C/I and worse at FCDS scheduler compared with CAT 5. The best results of average delay give the RR scheduler. Average delay is not satisfying a part of UEs that are using FCDS and max C/I.

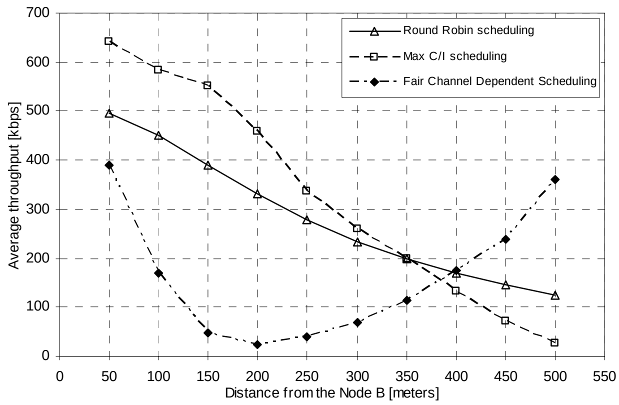

Fig. 2. Average throughput of the simulated mobile users

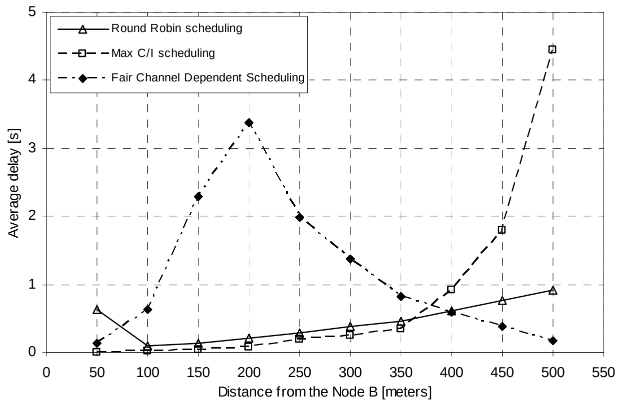

Fig. 3. Average delay of the simulated mobile users

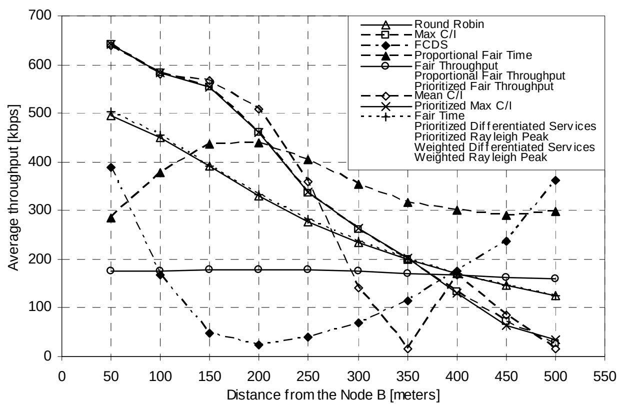

Fig. 4. Average throughput of all 14 packet schedulers using CAT 10 UEs

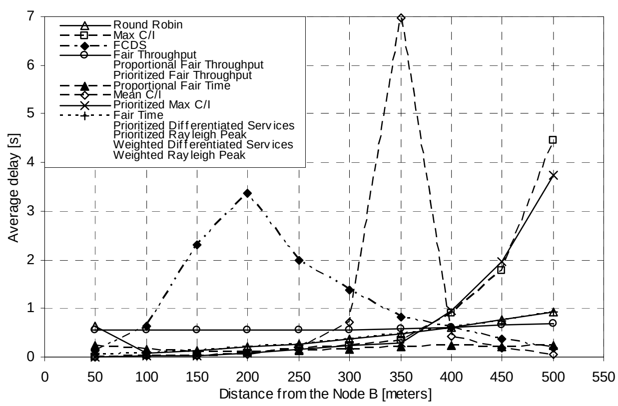

Fig. 5. Average delay of all 14 packet schedulers using CAT 10 UEs

D. Performances of all 14 scheduling algorithms using CAT 10 UEs

Three groups of scheduling algorithms which have similar average throughput results are detected in Fig. 4: Round Robin, Fair Time, Weighted Rayleigh Peak, Prioritized Differentiated Services, Prioritized Rayleigh Peak, Weighted Differentiated Services scheduling; max C/I, prioritized max C/I scheduling; Fair Throughput, Proportional Fair Throughput, Prioritized Fair Throughput scheduling.

The first group where there are 6 scheduling algorithms produces fair time management and division within users, but doesn't care about the users with low CQI. The users near the edge of the cell have low average throughput. The second group with two scheduling algorithms (max C/I and prioritized max C/I) and mean C/I gives huge amount of network resources for those UEs placed closer to Node-B, but users from further parts are not satisfied. Because of its lack of fairness, these three scheduling algorithms cannot be used in real HSDPA networks. The third group of fair throughput algorithms gives the best results of fairness of the users, but overall cell throughput together with FCDS, as can bee seen in Fig. 6 isn't so optimal.

Fig. 5 presents the results of the average delay of all 14 simulated scheduling algorithms for the simulated scenario. The worst results in average delay have FCDS, mean C/I, max C/I and Prioritized max C/I scheduling algorithms, because approximately half of the users that are further from the Node B using these algorithms have very high average delay values. The best results in average delay, considering all 20 users gives the Proportional Fair Time scheduling algorithm. The curve of this algorithm, as we can see in Fig. 5 has the most stable low average delay results for all simulated users.

Simulations results show that Proportional Fair Time is the best solutions for the simulated environment with achievable maximum data rate of 14.4 Mbps (CAT 10 UEs), giving the best cell resources utilization. Using this scheduling algorithm, all users in the cell can feel equal. Finally, the overall cell throughput is utilized optimally using Proportional Fair Time scheduling algorithm, as can be seen in Fig. 6. Proportional Fair Time scheduling attempts to give all users/flows the same probability of being scheduled while keeping attention to the instantaneous quality received by using a *Relative Instantaneous Channel Quality* (RICQ) defined as the ratio between current and average user SIR. With this method users are scheduled only during constructive fades, thereby raising both the overall cell throughput and the user data rates while keeping fairness among users. The flow having the higher RICQ value is scheduled first.

IV. Conclusion

In this paper, we have evaluated many scheduling techniques in a heavy load scenario in a single-service case using achievable maximum data rate of 14.4 Mbps (CAT 10 UEs).

In the first case, we have addressed a comparison study between higher and lower terminal capabilities (CAT 10 and CAT 5 UEs) for three schedulers simulated in previous papers and have analyzed the difference.

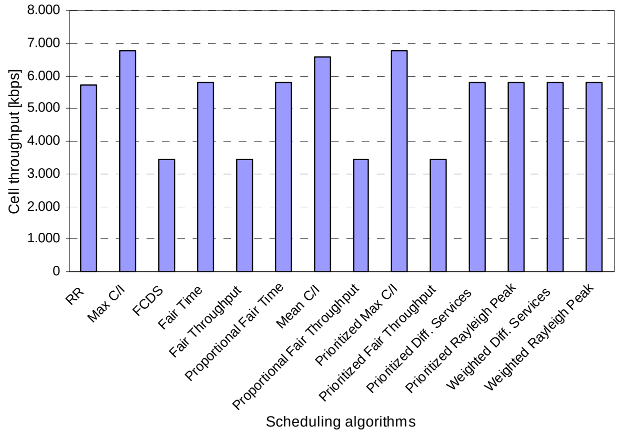

Fig. 6. Overall cell throughput for different Scheduling Algorithms

Furthermore, we have also tested different HSDPA scheduling algorithms and recommended the most efficient scheduling technique for achievable maximum data rate of 14.4 Mbps (CAT 10 UEs) in a heavily loaded scenario in a pedestrian environment, using non-real time service (FTP traffic). We conclude that the Proportional Fair Time scheduling algorithm ensures fairness among users in the given scenario, according to their QoS requirements, while seeking to maximize link utilization.

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