# Measuring quality of experience of Internet Access over HSDPA

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**Abstract** High-Speed Downlink Packet Access (HSDPA) is being introduced by mobile operators as a solution both for increasing the downlink throughput and for achieving a more efficient usage of the radio resources. This work analyses the quality of experience of HSDPA users, based on experiments and measurements over a commercial network. The effect of multiple users sharing the overall capacity of the cell is explicitly evaluated. The results show that the HSDPA user experience for Internet access is satisfactory and in some cases comparable to that achievable over fixed access technologies such as ADSL. In addition, we explore the impact of TCP configuration on the HSDPA performance and suggest suitable parameter values.

## 1 Introduction

UMTS (Universal Mobile Telecommunication System) networks based on 3GPP Release 99 specifications provide a maximum downlink throughput for packet-switched (PS) services of 384 kbit/s. From the user point of view, this bit rate may provide an acceptable quality of experience for Internet applications such as web browsing and e-mail, although lower than in fixed access technologies (e.g. ADSL or cable).

From the operator's perspective, however, the way UMTS Rel 99 PS services are provided over the radio interface is far from efficient. The reason is that these services are supported over dedicated radio channels (despite shared channels were defined in the specifications). This limits the maximum number of PS users that can be simultaneously served by an UMTS cell, especially at 384 kbit/s (5 or 6 users at most). In addition to that, considering the high burstiness of many Internet applications, dedicated radio channels are often underutilized.

Fortunately, 3GPP Release 5 specifications introduce the HSDPA (High-Speed Downlink Packet Access) technology [1]. Besides increasing the downlink throughput, a key aspect of HSDPA is the use of the High-Speed Downlink Shared Channel (HS-DSCH). This new channel allows for a better utilization of radio resources for packet data services, especially when considering applications that generate intermittent traffic. However, the fact that the HS-DSCH channel is a shared resource requires considering the impact of multiple users simultaneously competing for the channel capacity.

The performance of HSDPA has been investigated in the last years. Most of the studies, however, rely on analytical models or simulation techniques [2], in general following a theoretical approach. As the number of HSDPA networks in operation grows and users start utilizing them, there is a lack of knowledge about the real performance provided by this technology. Some recent papers present results based on measurements in laboratory [3], in scenarios that clearly differ from the real conditions found in a live network. A few studies based on measurements on commercial HSDPA networks have been published [4, 5]. These studies, however, focus on measurements related to one HSDPA user only, without taking into account the influence of other simultaneous users sharing the capacity of the cell. While this aspect can be neglected in early network deployments, as the number of users increases it should definitely be taken into account.

One of the main contributions of our work is the realization of measurements in a scenario with multiple HSDPA users simultaneously accessing to the same cell. The results led us to investigate the impact of the TCP configuration parameters on the observed performance.

The rest of the paper is organised as follows. Section 2 introduces the main aspects that influence the performance of HSDPA networks. Section 3 describes the measurement scenario and the experiments carried out. Sections 4 and 5 present and discuss the results of the measurements with multiple HSDPA users. Section 6 analyzes the performance improvement that can be achieved by tuning some TCP configuration parameters. Conclusions and plans for future work are given in section 7.

## 2 HSDPA performance issues

HSDPA technology represents the first of a number of enhancements that increase the bit rates offered through 3GPP radio access networks. More specifically, it focuses on increasing the downlink throughput for packet based services, while at the same time providing a more efficient usage of radio resources than in UMTS Release 99. The fist goal is achieved by combining several advanced capabilities including AMC (Adaptive Modulation and Coding), HARQ (Hybrid-ARQ), and fast scheduling mechanisms. The second goal is based on using a common channel, HS-DSCH (High-Speed Downlink Shared Channel), shared among the HSDPA users of the cell.

The maximum downlink throughput achievable by one HSDPA user depends on several issues. Propagation conditions limit the efficiency of AMC and H-ARQ mechanisms. The downlink bit rate is also limited by the terminal category, which determines the modulation scheme and the maximum number of simultaneous OVSF (Orthogonal Variable Spreading Factor) codes that the terminal can use. Currently, most operators support terminals of category 12 (1.8 Mbit/s) and category 6 (3.6 Mbit/s), although other categories (e.g. category 8 with 7.2 Mbit/s) providing higher speeds are expected soon. These bit rates are defined at physical layer, without considering the overhead of the protocol stack above the radio layer. In any case, note that these bit rates surpass the maximum of 384 kbit/s offered with dedicated channels in UMTS Release 99.

Another limiting factor to consider is the number of OVSF codes allocated to the HS-DSCH channel in the cell. The HDSPA specifications allow assigning up to 15 codes to HS-DSCH. However, the number of available codes depends on whether the HSDPA service is offered over a dedicated 5 MHz WCDMA carrier or over an existing carrier providing conventional UMTS services as well. The later option is adequate for early phases of HSDPA deployment, provided that the overall traffic load in the cell is low. In this case, the overall capacity of the cell is distributed between UMTS and HSDPA services, with a number of OSVF codes reserved for each traffic type. Currently, many cells in operation are shared by UMTS and HSDPA services, typically with only 5 OSVF codes allocated to HS-DSCH. As HSDPA gains popularity, a dedicated carrier for HSDPA traffic may be more appropriate, particularly in areas with high traffic load (e.g. business areas). This solution allows up to 15 OVSF codes for the HS-DSCH channel.

As the number of users concurrently using the HS-DSCH channel increase, the maximum throughput achievable by each one decreases. Initial users did not observe this effect, because there were few HSDPA terminals in operation and the probability of having other competing users in the same cell was low. However, as the total number of HSDPA subscribers increases, this probability becomes higher and the capacity sharing effect must be taken into account.

Another relevant issue when evaluating the performance of HSDPA for Internet access is the behaviour of TCP. It is a well-known fact that the performance of TCP connections worsens over wireless networks. This is true also for HSDPA, as discussed in section 6.

## 3 Measurement scenario

In order to evaluate the performance of HSDPA in a real network, the measurement scenario depicted in Fig. 1 was arranged. The measurements were performed in one of the teaching laboratories at Universidad Politécnica de Madrid, which is in the coverage area of an HSDPA/UMTS macro cell located in the university campus. The cell has five OVSF codes allocated for HSDPA and a backhaul link formed by 3 E1 lines using IMA (Inverse Multiplexing over ATM). We were not able to exclude other users in the same cell during our experiments. However, in normal conditions this particular cell is lightly loaded, so during the test periods most of the traffic was generated by our terminals. Additionally, note that our goal was to assess the user experience during normal network operation, not the maximum performance achievable in ideal conditions. In future tests, we plan to repeat the measurements in other cells with heavier load values and compare the results obtained.

A total of 28 students distributed into two shifts participated in the measurements campaign. The measurements were performed from 11:00 to 14:00, and repeated during five days, from Monday to Friday.

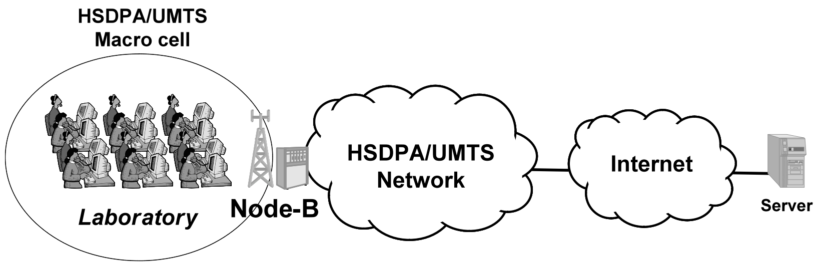


**Fig. 1** Measurement scenario.

To perform the measurements, each student had a desktop computer with a Category 6 (3.6 Mbit/s) HSDPA modem. The students performed several basic experiments including web navigation sessions, web-based on-line speed tests, and file downloads.

## 4 Web navigation experiments

The first experiment consisted in a five minute web navigation session. In order to quantitatively evaluate the HSDPA performance, a basic throughput measurement software was running in the laboratory desktops. Fig. 2 shows the probability density function (PDF) and the complementary cumulative distribution function (CDF) for the downlink peak rate observed in the experiments.

The download peak rate was between 128 kbit/s and 1750 kbit/s, with an average value of 870 kbit/s. The complementary CDF graph indicates that 85% of the users got a download peak rate above 550 kbit/s. These values correspond to net bit rates measured at application level. Taking into account the overhead added by the protocol stack, the non-optimum indoor propagation conditions at the laboratory, and, of course, the high number of HSDPA users simultaneously active in the cell (up to 14), the results obtained are satisfactory.

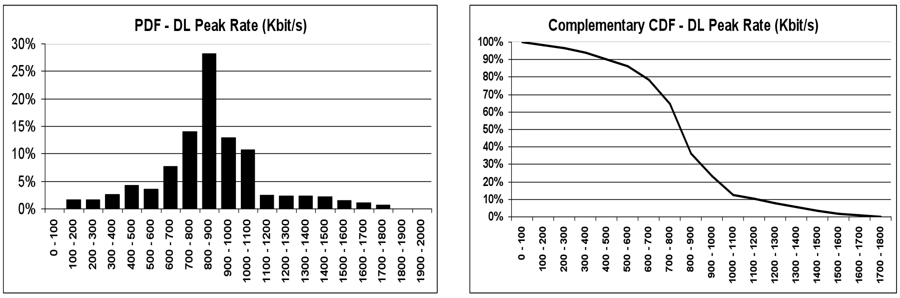


**Fig. 2** Downlink peak rate results for web navigation experiments

In order to make a subjective evaluation of performance, the students rated the quality of the HSDPA service between 1 and 5, resulting in an average score 3.4. For comparison purposes, the same experiment was performed using the fixed broadband access infrastructure of the laboratory, giving an average score of 4.3.

## 5 File transfer experiments

In a second set of experiments, we used a well-known Spanish web portal that offers an on-line speed test application. Residential users with broadband Internet access lines utilize this type of test applications to get an indication of the access speed actually provided by their ISP (which often is well below the maximum speed values advertised by the provider.) The speed test normally consists in exchanging a number of web pages (or files) with different sizes between the user and the server in both directions. In our case, students performed the speed test over HSDPA with the results shown in Fig. 3.

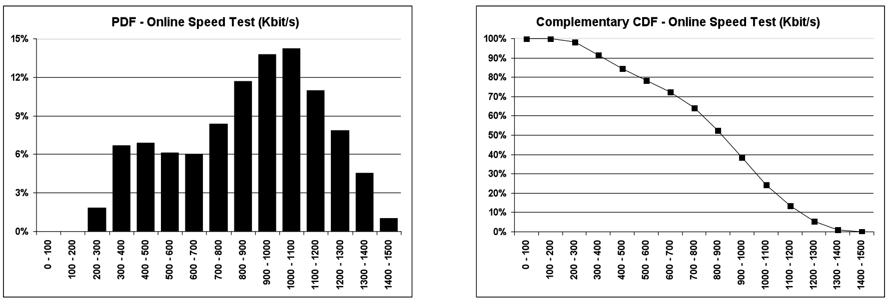


**Fig. 3** Results for on-line speed tests

Downlink speed values ranged from 234 kbit/s to 1338 kbit/s, with an average value of 826 kbit/s. 85% of the users got values above 560 kbit/s. These measurements are comparable to those achievable with an ADSL access of 1 Mbit/s. Once again, it is worth pointing out the satisfactory results considering the relatively large number of HSDPA users in the cell.

Additional experiments consisted in downloading a number of files from a FTP (File Transfer Protocol) server. Three different file sizes were considered: 100 kbyte, 1Mbyte, and 10 Mbyte. For comparison purposes, the same experiments were performed previously for a single HSDPA user in the cell. The results are summarized in Fig. 4.

Starting with the single user case (Fig. 4, left), the average download throughput was between 465 kbit/s and 1734 kbit/s, depending on the size of the file. Note that the results are considerably better for large file sizes. This aspect will be analyzed in section 6.

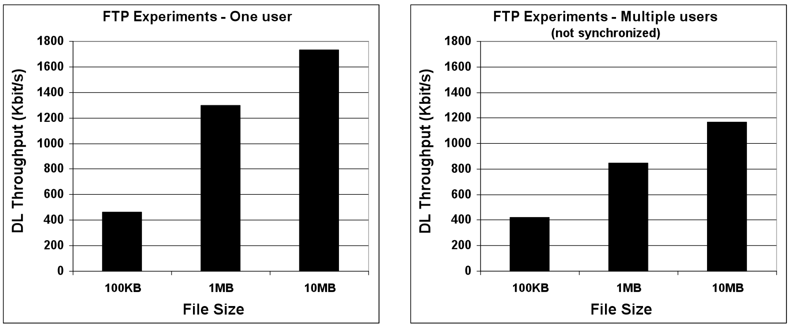


**Fig. 4** Summary of results for file transfer experiments

For the scenario with multiple users (Fig. 4, right), the average download throughput was between 422 kbit/s and 1165 kbit/s. When interpreting these results, it is necessary to observe that the experiments were not synchronized. That is, students performed freely the file downloads without taking into account how many of them were simultaneously connected to the FTP server. While this approach does not allow to accurately interpret the effect of the capacity sharing in the HS-DSCH, it has the advantage of being more in line with the actual traffic that could be observed in a real network, where the user behaviours are independent.

Additional experiments with synchronized file downloads were performed. The results, shown in Fig. 5, provide an indication of the minimum throughput a user can obtain in the worst case when several users are downloading files simultaneously.

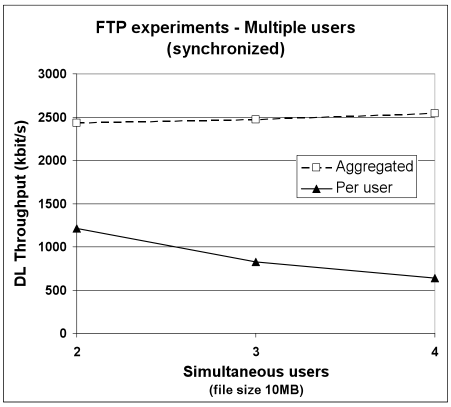


**Fig. 5** Results for synchronized file transfer experiments

## 6 TCP configuration

As mentioned in section 2, the degradation of TCP over wireless networks is a well known issue. On the one hand, packet losses in the radio path are misinterpreted as congestion by TCP, causing a temporal reduction of throughput. On the other hand, the relatively large delays in the wireless link have a direct influence on the duration of slow start and congestion recovery phases. While HSDPA includes a number of features aimed to reduce both packet loss and delay, both effects are still present and negatively affect the performance of TCP.

A number of solutions have been proposed to cope with this type of impairments in wireless networks, and therefore may be applied to HSDPA: modified TCP stacks, performance enhancing proxies, cross-layering mechanisms and TCP parameter tuning. In our experiments, we opted for the last approach as it simply requires adjusting the TCP configuration settings of the operating system in the user desktop computers.

Among the different TCP configuration parameters, we focused on the TCP receive window size and the selective acknowledgement (SACK) option. In the first case, the idea is to use large window sizes in order to allow filling the “pipe” during long transfers. The reasoning behind this is that while delay in HSDPA is lower than in previous systems (GPRS or UMTS Rel 99), this reduction is compensated with higher bit rates, making the overall bandwidth-delay product (BDP) or “pipe size” bigger. Using large window sizes makes it advisable to activate the SACK option in order to avoid retransmitting large amounts of packets in the event of packet losses.

To evaluate the impact of the TCP configuration on the HSDPA performance, we repeated the FTP experiments for the single user case varying the receive window size, with the SACK option on and off. The results are summarized in Fig. 6 for the following window sizes: 17, 64, 128, and 256 kbyte.

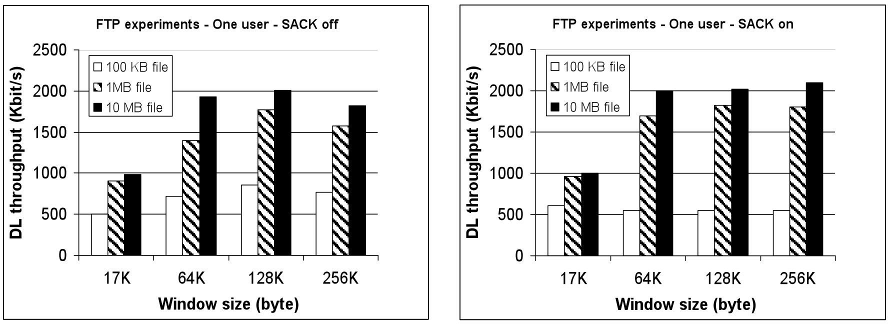


**Fig. 6** Impact of TCP receive window size and SACK option in FTP downloads

The smallest window size, 17 kbyte, is clearly insufficient for the bandwidth-delay product of the HDSPA connection and therefore gives low throughput values. Nevertheless, it should be noted that there are still many computers that use this TCP receive window size. In fact, this was the default TCP configuration found in the laboratory computers where the experiments were performed. More recent versions of operating systems use larger window sizes, typically 64 kbyte. The graphs show that a 64 kbyte window provides a much better performance, close to the optimum. Larger window sizes, such as 128 or 256 kbyte, provide marginal improvements only, or may even cause a degradation of throughput due to retransmissions. This effect is corrected by activating the SACK option, as shown in Fig. 6. For example, in our experiments with 1 Mbyte file and SACK off, the maximum throughput is obtained for the 128 kbyte window. Doubling the window size to 256 kbyte results in a lower throughput, but turning on the SACK option this effect is corrected.

The performance improvement obtained by increasing the window size is more noticeable for the larger file sizes: 1 and 10 Mbyte. For small files, using large TCP windows and SACK does not seem to provide a performance improvement. The explanation is that for small files the TCP connection setup hand-shake procedure and the slow start mechanism prevent the full use of the capacity available in the HSDPA link. In other words, the connection may finish without having reached the maximum achievable throughput.

This observation is relevant for the web navigation experiments as well. Recent studies report a typical web page size of around 130 kbyte [6], which is close to the smallest file size considered in our experiments. Therefore, we can conclude that for web navigation, if the user is browsing pages in different servers the moderated size of the web pages themselves does not permit to fully exploit the high bit rates provided by HSDPA. However, there is a growing trend in using web navigation programs for downloading files or reading e-mail messages with attachments. In those cases, the downloaded objects may be considerably bigger (1 Mbyte or more), therefore making large TCP receive windows and SACKs highly recommendable.

Finally, the students repeated the on-line speed test experiments using different window sizes and turning on and off the SACK option. The results are shown in Fig. 7.

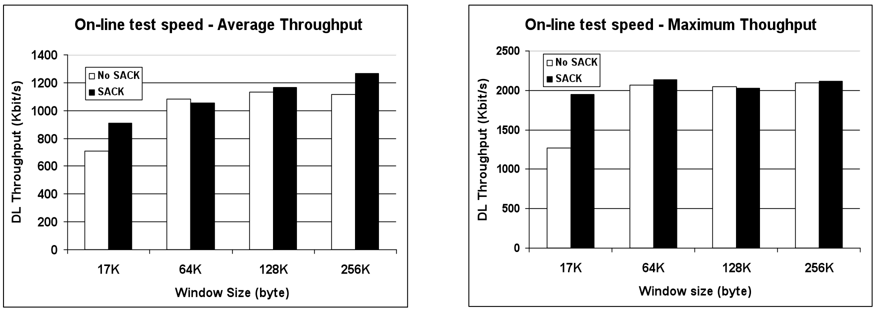


**Fig. 7** Impact of TCP receive window size and SACK option in on-line speed tests

The best combination of TCP parameter settings in our experiments is a receive window of 256 kbyte with the SACK option active. This configuration gave an average downlink throughput of 1270 kbit/s. This represents an improvement of around 80% compared with the worst case, corresponding to a receive window size of 17 kbyte without SACKs. As indicated above, a 64 kbyte window gives reasonably good throughput values.

## 7 Summary and conclusion

This work evaluates the quality of experience of Internet access over HSDPA based on measurements made in a commercial network. A main contribution is the realization of measurements in a scenario with multiple HSDPA users simultaneously accessing to the same cell. Several experiments were performed, including web navigation and file transfer with different file sizes, with up to 14 simultaneous users. Despite the high variability of the results, overall the experiments showed that performance and user-perceived quality are quite satisfactory. For example, in one of the experiments reported above we measured downlink throughput values between 234 kbit/s and 1338 kbit/s, with an average value of 826 kbit/s. In this particular case 85% of the users got throughput values above 560 kbit/s. Other experiments described in the paper produced similar results.

Another set of experiments focused on evaluating the performance impact of the TCP receive window size and the Selective ACK option. The results prove that, for file sizes above 1 Mbyte, large receive window sizes (64 kbyte or more) with SACK lead to higher download throughputs (up to 80% increase in some experiments).

Future work currently under consideration includes repeating the experiments in several cells with different background traffic load, measuring delay and jitter, and experiments with HSDPA category 8 devices. Taking into account the operators' plans for the imminent introduction of HSUPA (High Speed Uplink Packet Access) in their networks, we also consider extending the measurements to that technology.

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