HSDPA fairness analysis in the transport network

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Abstract

This paper analyses fairness of HSDPA resource sharing which is basically influenced by HSDPA flow control, the radio scheduler, and to some extent TCP. The presented and applied bounded fairness formula makes comparison of different network scenarios possible and expressive. Fairness is evaluated based on two different types of performance measures: RLC throughput providing system level fairness of bottleneck link resource sharing, and object bitrate facilitating the measurement of application level fairness. Before evaluating system level fairness, an aggregation on the time scale is performed. Several scenarios are examined by means of these measures with variable number of users and file sizes. Both measures are needed because what is fair on system level, not necessarily fair on application level, and vica versa.

1 Introduction

This work was originally motivated by the idea of finding a quantitative measure for objective fairness comparison in HSDPA. Fair and effective bandwidth sharing is essential in the Transport Network (TN) because it is often deployed as a low-cost, low-bandwidth network through financial reasons. Therefore, its available narrow resources should be distributed efficiently and as fairly as possible to grant each user an equal bandwidth share.

The notion of fairness has been defined several ways in the literature. In [1] standard definitions of fairness are reviewed, compared and generalized. One of the most common ones is max-min or bottleneck optimality criterion. An other proposition is the notion of proportional fairness which suggests allocating more bandwidth to shorter flows in many scenarios [4]. For a quantitative comparison of bandwidth allocation fairness for different algorithms, the concept of the fairness index [2] can be applied, which is defined as a function of variability of throughput across connections. In [3] the authors define new fairness measures that are better suited for measuring fairness in wireless networks. In [4] the author reviews engineering solutions and economic models for fair allocation of network bandwidth to elastic flows. In [5] the authors study TCP synchronization and fairness over high-speed networks.

In this paper we analyse the fairness of HSDPA by defining and evaluating application level and TN level fairness measures in different scenarios.

2 HSDPA and its Flow Control

An enhancement of third generation (3G) mobile networks is HSDPA (High Speed Downlink Packet Access) which increases the download data rate. HSDPA services do not possess a fixed amount of bandwidth on the Iub interface – the link between the Radio Network Controller (RNC) and the base station (Node B) – but use of resources not exploited by other services is possible. That is why a Flow Control [6](FC) algorithm is needed on the Iub interface to control the maximum amount of data to be sent by each flow taking into account the capacity which is available on the radio interface (Uu) and the Iub interface. Henceforth, the Iub interface is considered which is the TN itself. In order to support high bitrate the system has been extended with a new transport channel, the high-speed downlink shared channel (HS-DSCH) To support HSDPA with

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minimum impact on the existing radio interface protocol architecture, a new MAC sub-layer, MAC-hs, has been introduced for HS-DSCH transmission which is implemented in Node B and in the User Equipment (UE).

HSDPA FC is implemented in the RNC and Node B; thus it has its impact on the Iub interface. The algorithm assures that the Iub interface is maximally utilized when Iub interface is limiting HSDPA bandwidth. FC keeps the Iub congestion level low avoiding high frame loss ratio, and long delays caused by long buffer build-up within long buffers in the TN. The TN should be considered as a black box since it may be deployed in many ways. Low Iub congestion grade is necessary for good end-user TCP performance. FC has an important role if Iub interface is limiting HSDPA. If the air-interface (Uu) is limiting, the algorithm takes care of relatively minor tasks.

An important requirement concerning the FC algorithm is to share Iub resources among users fairly. Considering HSDPA fairness two different cases should be distinguished; when the Uu interface is limiting and the case Iub is. In the first case, resources of the TN are much greater than the maximal Uu resources. E.g. the Uu interface has 15 Mbps bitrate and the TN is fiber optic cable based. In this case, fairness of resource sharing depends on the Radio Scheduler algorithms, and the FC's only responsibility is to keep the fairness the Scheduler provided. If the Iub interface is limiting, the TN represents the bottleneck capacity, therefore, resources of Uu cannot be maximally utilized. In this case it is the FC's duty to make sure that the Iub resources are distributed among users in a fair way.

3 System description and fairness measures

The system under study corresponds to a simplified 3G architecture. Simulations are performed on the Iub interface. This link has a bottleneck capacity of C kbps. The model also implements RNC, Node B and UE functionality and contains TCP, IP, RLC and HSDPA FC. The simulation tool we used is a hierarchical, modular, Java based network traffic simulator. Simulations have been performed using different network scenarios. Capacity (C) of the Iub bottleneck, the number of users in the network, the reading time between two consecutive downloads (t_r) and the size of files to be downloaded (S_f) can be set.

A quantitative measure is needed to study HSDPA FC which evaluates suitably how equal share of available resources each user gets. Let bw_{nk} denote the k^{th} bandwidth sample at time point n. N is the total number of time points and K_n is the number of samples at the time point n. Let us define fairness as the average ($\overline{\alpha}$) of

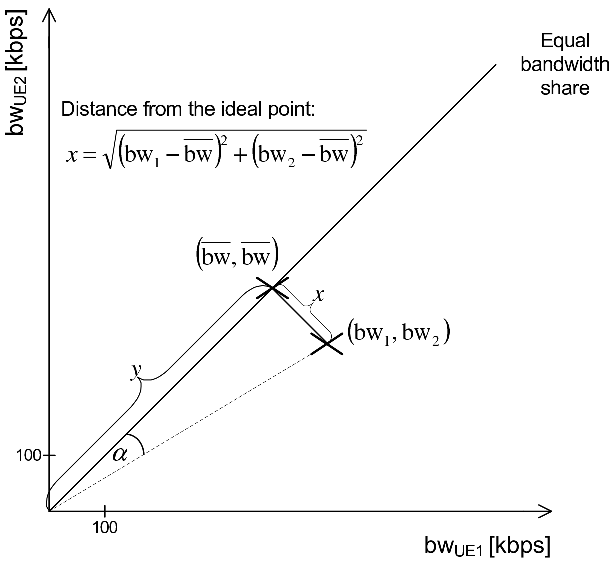

Figure 1: Fairness interpretation for two users

each time point's bandwidth allocation viewing angle ($\tan\alpha = \frac{x}{y}$[1]) (see Fig. 1):

$$\overline{\alpha} = \frac{\sum_{\forall t} \arctan \frac{x}{y}}{t} = \frac{\sum_{n=1}^{N} \arctan\left(\frac{1}{\overline{\mathrm{bw}}_n} \cdot \sqrt{\sum_{k=1}^{K_n} (\mathrm{bw}_{nk} - \overline{\mathrm{bw}}_n)^2 / K_n}\right)}{N} \tag{1}$$

[1]Such α always exists because $\overrightarrow{x}$ is perpendicular to the line of equal bandwidth share in every dimension ≥ 2.

where $\overline{\mathrm{bw}}_n = \left(\sum_{k=1}^{K_n} \mathrm{bw}_{nk}\right)/K_n$. (1) has its minimum value at zero. This value means that the resource sharing is absolutely fair. The value of (1) is always less than 90°. Because this formula is bounded it makes comparison of different scenarios possible.

4 Fairness evaluation

Application level and system level fairness are distinguished. Fairness of bandwidth sharing will be examined by means of two different types of data: User data throughput measured in downlink direction on RLC level and application level object bitrate. In order to evaluate fairness, the following four steps are performed:

Data collection: The output of the simulator is preprocessed and converted to the appropriate format using AWK scripts. In case of measuring RLC throughput one sample per 100 ms arrives from the simulator. Regarding the object bitrate, a sample arrives whenever a user has finished downloading a file. This sample contains the average download data rate during the download of the corresponding file.

Session identification is performed in each user's throughput data series, so that download sessions are detected. Our download session definition is the following: If the gap between two positive throughput values is longer than 2 seconds then they are in separate sessions. The 0 throughput value is substituted by a minus ('$-$') sign if this value is out of a session, otherwise it remains zero. The minus sign means that the user has finished a download and has not started an other one yet so no data on throughput is available at the moment. Zero value means that there is requested data to be downloaded but the user has got 0 bitrate currently. For application level object bitrate no session identification is needed.

Aggregation of data is done on the time scale. Throughput values belonging to the same user within a given time interval are averaged. Consequently, multiple samples are aggregated into a single sample which has the average value of those samples. E.g., if the time interval is 1 sec, every 10 samples are aggregated into one sample which will be the average of these 10 samples.

Calculating fairness measures means the evaluation of the formula described in more detail in Section 3.

5 Simulation results

Two different cases have been considered. In the first case a fixed number of users with equal data download demand (i.e., S_f is equal for all users) is downloading files. The initial download start time of each user is random. In the second case, we distinguish users with high (greedy users) and low (e.g.: web surfers) download demand. It has been examined whether the bandwidth sharing was fair, and if not, which flows had been preferred. Case $C = 1.5$ Mbps and $C = 0.75$ Mbps have been examined with the presence of 2, 5, 10 users downloading 10 MB or 100 kB files periodically. t_r was fixed in 2 seconds for each of these scenarios. In

Users	$C = 1.5$Mbps $S_f = 100$kB	$C = 0.75$Mbps $S_f = 100$kB	$C = 1.5$Mbps $S_f = 1$MB
2	2.85° (4.55°)	3.1° (6.79°)	3.9° (1.66°)
5	10.48° (10.48°)	10.4° (7.8°)	10.29° (3.21°)
10	12.77° (10.65°)	11.27° (5.69°)	7.3° (1.14°)

Table 1: Fairness – equal download demand

Users	$C = 1.5$Mbps $S_{f1,2} = 100$kB, 1MB	$C = 0.75$Mbps $S_{f1,2} = 100$kB, 1MB
1 – 9	6.85° (1.65°)	8.31° (0.19°)
5 – 5	11.02° (7.83°)	9.05° (2.31°)
9 – 1	13.77° (10.97°)	11.2° (3.75°)

Table 2: Different download demand

Tab. 1 we can see the throughput fairness values by calculating (1), and in brackets the application level results. In Tab. 2 values in case of different download file size are shown. The notation 1 – 9 means that there is one user downloading 100 kB files and there are 9 to download 1 MB files.

In accordance with Tab. 1, dependency on S_f and C is not so relevant (e.g. first row of Tab. 1). On system level the number of users has significant impact on fairness. At two users the bottleneck link resource sharing is fair. The more users participate in the system the more unfair the FC is. One reason for that is the fact that there are more flows contending for resources, therefore, there will be more conflicting periods. Considering application level measures number of users has also its effect on fairness but it is not as remarkable as in case of system level (See last column in Tab. 1). In Tab. 2 we can see that different download demand does not influence system level fairness significantly. However, many 'web users' against one 'greedy user' will receive the least fair service, the greedy one being preferred.

Both of these measures are needed because what is fair on RLC level, not necessarily fair on application level (e.g.: $C = 0.75\,\text{Mbps}$, 2 users, in Tab. 1), and vica versa (e.g.: row one, $C = 0.75$Mbps, in Tab. 2). In order to have a full picture of how fair the resource sharing is, calculations should be performed using both measures.

In HSDPA, fairness is determined mostly by HSDPA FC not by the TCP. In case of TCP, the bandwidth of a flow is proportional to $\frac{\mathrm{cwnd}}{\mathrm{RTT}}$. The rate adaptation of a TCP flow to the available bandwidth is done by the increased/decreased Round Trip Time (RTT) or by decreasing/increasing the Congestion Window (cwnd) based on the arrived acknowledgements. HSDPA does not work efficiently with TCP exclusively. After frame losses the RLC layer retransmits the lost data, because RLC works in acknowledged mode. In case of congestion, packet loss may occur and retransmissions even further increase the congestion level diminishing the chance of a successful retry. Meanwhile TCP is not informed about the congestion at all, and can not react on it properly. All in all, this would result much less efficiency than the prevention of congestion by means of FC on the Iub interface. Moreover, because TCP would not practically detect packet losses, the only thing it could become aware of is the augmentation of RTT. This notion would not be beneficial, because in HSDPA due to delay sensitive traffic the RTT should not be high ($\lesssim 100\,\text{ms}$). At the presence of HSDPA FC, neither the loss detection of TCP nor the RTT control is really used. The increment of cwnd is stopped by its maximum value, so TCP has fully open congestion window. Fairness is influenced by HSDPA FC, except for the Slow Start phase of TCP. As a consequence, HSDPA FC is the most influential factor in fairness.

6 Conclusion

Fairness of HSDPA Iub-resource sharing have been studied. This is mainly influenced by HSDPA FC and to some extent TCP. The presented and applied bounded fairness formula makes possible the comparison of different scenarios. Two types of simulation output have been used for fairness evaluation: user data throughput measured in the downlink on RLC level that the fairness of bottleneck link resource sharing is based on, and object bitrate for application level fairness. Several scenarios have been analysed by means of these measures with variable number of users and file size. Both measures are needed because what is fair on RLC level, not necessarily fair on application level, and vica versa.

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