High Speed Downlink Packet Access: WCDMA Evolution

Troels Emil Kolding, Klaus Ingemann Pedersen, Jeroen Wigard, Frank Frederiksen
& Preben Elgaard Mogensen, Nokia Networks

This article gives an overview of the high speed downlink packet access (HSDPA) concept; a new feature which is coming to the Release 5 specifications of the 3GPP WCDMA/UTRA-FDD standard. To support an evolution towards more sophisticated network and multimedia services, the main target of HSDPA is to increase user peak data rates, quality of service, and to generally improve spectral efficiency for downlink asymmetrical and bursty packet data services. This is accomplished by introducing a fast and complex channel control mechanism based on a short and fixed packet transmission time interval (TTI), adaptive modulation and coding (AMC), and fast physical layer (L1) hybrid ARQ. To facilitate fast scheduling with a per-TTI resolution in coherence with the instantaneous air interface load, the HSDPA-related MAC functionality is moved to the Node-B. The HSDPA concept facilitates peak data rates exceeding 2 Mbps (theoretically up to and exceeding 10 Mbps), and the cell throughput gain over previous UTRA-FDD releases has been evaluated to be in the order of 50-100% or even more, highly dependent on factors such as the radio environment and the service provision strategy of the network operator.

Introduction

Data services are anticipated to have an enourmous rate of growth over the next years (the so-called data tornado) and will likely become the dominating source of traffic load in 3G mobile cellular networks. Example applications to supplement speech services include multiplayer games, instant messaging, online shopping, face-to-face videoconferences, movies, music, as well as personal/public database access. As more sophisticated services evolve, a major challenge of cellular systems design is to achieve a high system capacity and simultaneously facilitate a mixture of diverse services with very different quality of service (QoS) requirements. Various traffic classes exhibit very different traffic symmetry and bandwidth requirements. For example, two-way speech services (conversational class) require strict adherence to channel symmetry and very tight latency, while Internet download services (background class) are often asymmetrical and are tolerant to latency. The streaming class, on the other hand, typically exhibits tight latency requirements with most of the traffic carried in the downlink direction.

Already in Release 99 of the WCDMA/UTRA specifications, there exist several types of downlink radio bearers to facilitate efficient transportation of the different service classes. The forward access channel (FACH) is a common channel offering low latency. However, as it does not apply fast closed loop power control it exhibits limited spectral efficiency and is in practice limited to carrying only small data amounts. The dedicated channel (DCH) is the "basic" ra-dio-bearer in WCDMA/UTRA and supports all traffic classes due to high parameter flexibility. The data rate is updated by means of variable spreading factor (VSF) while the block error rate (BLER) is controlled by inner and outer loop power control mechanisms. However, the power and hardware efficiency of the DCH is limited for bursty and high data rate services since channel reconfiguration is a rather slow process (in the range of 500 ms). Hence, for certain Internet services with high maximum bit rate allocation the DCH channel utilization can be rather low. To enhance trunking efficiency, the downlink shared channel (DSCH) provides the possibility to time-multiplex different users (as opposed to code multiplexing) [1]. The benefit of the DSCH over the DCH is a fast channel reconfiguration time and packet scheduling procedure (in the order of 10 ms intervals). The efficiency of the DSCH can be significantly higher than for the DCH for bursty high data rate traffic [2].

The HSDPA concept can be seen as a continued evolution of the DSCH and the radio bearer is thus denoted the high speed DSCH (HS-DSCH) [3]. As will be explained in the following sections, the HSDPA concept introduces several adaptation and control mechanisms in order to enhance peak data rates, spectral efficiency, as well as QoS control for bursty and downlink asymmetrical packet data [4]. In this paper, issues of importance to radio resource management (RRM) are discussed and UE capability implications are introduced. Next, the potential performance of the HSDPA concept is evaluated for different environments before the paper is concluded with a short discussion of further HSDPA enhancements proposed for future 3GPP standard releases. At the time of this writing, the Release 5 specifications have not yet been frozen so the specific details may be subject to change.

Concept Description

The fundamental characteristics of the HS-DSCH and the DSCH are compared in Table 1. On the HS-DSCH, two fundamental CDMA features, namely variable spreading factor (VSF) and fast power control, have been deactivated and replaced by AMC, short packet size, multi-code operation, and fast L1 hybrid ARQ (HARQ). While being more complicated, the replacement of fast power control with fast AMC yields a power efficiency gain due to an elimination of the inherent power control overhead. Specifically, the spreading factor (SF) has been fixed to 16, which gives a good data rate resolution with reasonable complexity. In order to increase the link adaptation rate and efficiency of the AMC, the packet duration has been reduced from normally 10 or 20 ms down to a fixed duration of 2 ms. To achieve low delays in the link control, the MAC functionality for the HS-DSCH has been moved from the RNC to the Node-B. This is a noticeable architectural change compared to the Release 99 architecture.

Feature	DSCH	HS-DSCH
Variable spreading factor (VSF)	Yes (4-256)	No (16)
Fast power control	Yes	No
Adaptive modulation and coding (AMC)	No	Yes
Fast L1 HARQ	No	Yes
Multi-code operation	Yes	Yes, extended
Transmission time interval (TTI)	10 or 20 ms	2 ms
Location of MAC	RNC	Node-B

Table 1 *Comparison of fundamental propeties of DSCH and HS-DSCH.*

This leads to significant software and hardware changes compared to the existing Release 99 Node-B implementation. For the HS-DSCH, only hard handover is supported as of the Release 5 specifications.

Modulation and coding options in HSDPA

To substitute the functionality of fast power control and VSF, the modulation, coding, and multi-code part of HSDPA must cover a wide dynamic range corresponding to the channel quality variations experienced at the UE (including fast as well as distance-dependent variations). The means of adaptation are the code rate, the modulation scheme, the number of multi-codes employed, as well as the transmit power per code. The HS-DSCH encoding scheme is based on the Release 99 rate-1/3 Turbo encoder but adds rate matching with puncturing and repetition to obtain a high resolution on the effective code rate (approximately from 1/6 to 1/1). To facilitate very high peak data rates, the HSDPA concept adds 16QAM on top of the existing QPSK scheme available in Release 99. The combination of 16QAM and e.g. rate-¾ channel encoding enables a peak data rate of 712 kbps per code (SF=16). Higher robustness is available with a QPSK rate-¼ scheme but at the penalty of having only a 119 kbps data rate per code. A modulation and coding combination is sometimes denoted a transport format and resource combination (TFRC). Five example TFRCs available on the HS-DSCH are shown in Table 2. Given sufficiently good channel conditions, a single user may simultaneously receive up to 15 parallel multi-codes leading to very high peak data rates up to 10.8 Mbps. This is the maximum peak data rate supported by the HSDPA concept, which can only be achieved in very favourable environments or with advanced transmission and reception technologies. It will be shown in a later section that the HSDPA concept defines a number of UE capability classes, and that only the high-end UE classes will support the very high data rates.

The dynamic range of the AMC for a single code is illustrated in Figure 1 showing the available user data rate versus the instantaneous (per-TTI) E_s/N_0. The curve includes the gain from fast HARQ based on chase combining which significantly improves the throughput at low E_s/N_0 values.

TFRC	Modulation	Eff. Code Rate	Data rate (1 code)	Data rate (5 codes)	Data rate (15 codes)
1	QPSK	¼	119 kbps	0.6 Mbps	1.8 Mbps
2	QPSK	½	237 kbps	1.2 Mbps	3.6 Mbps
3	QPSK	¾	356 kbps	1.8 Mbps	5.3 Mbps
4	16QAM	½	477 kbps	2.4 Mbps	7.2 Mbps
5	16QAM	¾	712 kbps	3.6 Mbps	10.8 Mbps

Table 2 *Example transport format and resource combinations and corresponding user data rates at layer 1 (including overhead). More options for TFRCs are given in [1,3].*

The E_s/N_0 range from where the throughput of TFRC1 is larger than 32 kbps to where the data rate of TFRC5 saturates to the maximum throughput of 712 kbps is on the order of 20 dB. As is also shown in Figure 1, the AMC curve becomes smoother when using multiple codes, i.e. multi-code operation provides increased granularity of the AMC. Further, multi-code operation enhances the dynamic range of AMC by the number of available codes. Hence, the total dynamic range of for instance AMC with 15 multi-codes is on the order of 32 dB. If all the code rate resolution available to HSDPA is utilized this will also lead to a smoother AMC curve than presented in Figure 1, which only includes the five example schemes of Table 2.

L1 retransmission techniques

The HARQ protocol selected for HSDPA is stop and wait (SAW). In SAW, the transmitter persists on the transmission of the current block until it has been successfully received by the UE. In order to avoid waiting times for acknowledgements, N parallel SAW-ARQ processes may be set for the UE, so that different processes transmit in separate TTIs. The value for N may maximally be 8 but in practice, the delay between the original and the first retransmission is expected to be on the order of 8-12 ms. The control of the L1 HARQ is located in the MAC-hs, so that the storage of unacknowledged data packets and the following scheduling
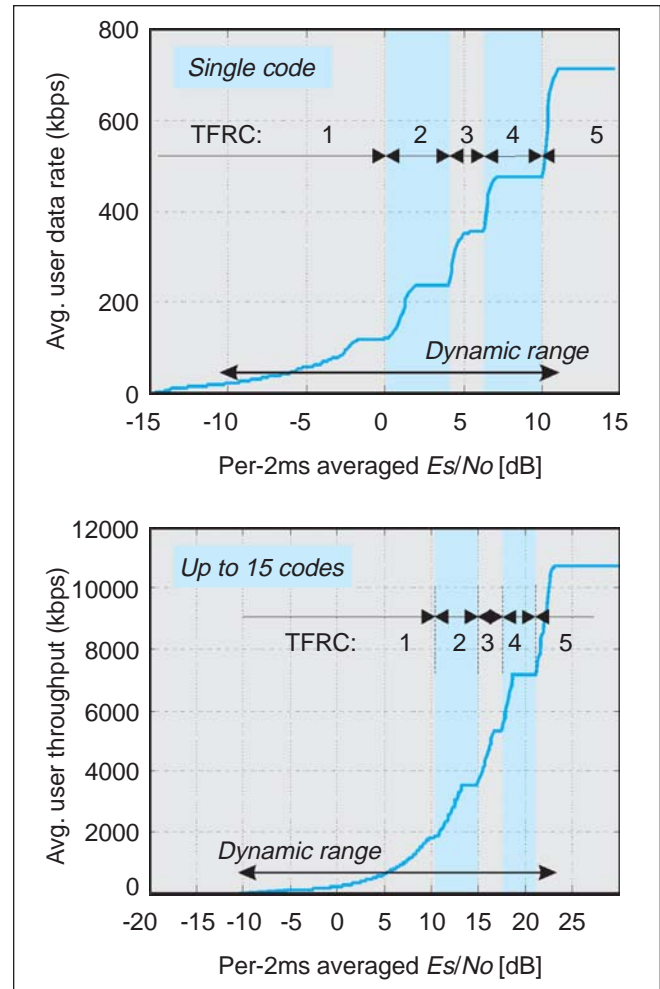
Figure 1 Dynamic range of the HSDPA AMC.
Simulation assumptions: RAKE receiver,
ITU Pedestrian-A profile, 3km/h.
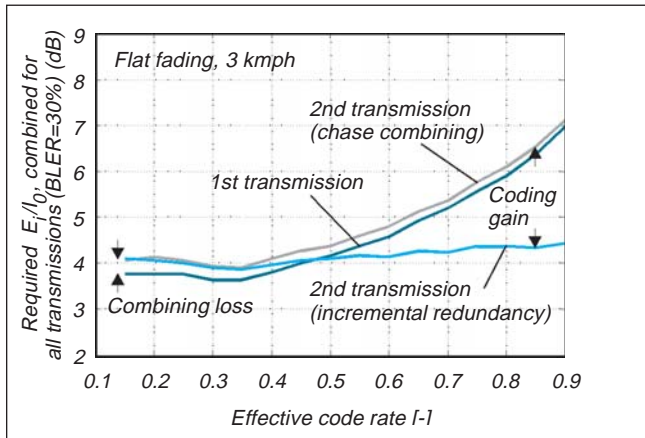
Figure 2 Performance of different retransmission strategies.

of retransmissions does not involve the RNC. Hence, Iub signaling is avoided and the resulting retransmission delay of HSDPA becomes much lower than for conventional RNC retransmissions. The HSDPA retransmission procedure is thus several orders of magnitude faster than the conventional RNC based ARQ implementation and enables the use of advanced retransmission strategies with lower delay jittering and higher spectral efficiency, even for delay sensitive services like streaming.

The HSDPA concept supports both the incremental redundancy (IR) and chase combining (CC) retransmission strategies. The basic idea of the CC scheme is to transmit an identical version of an erroneously detected data packet and then for the decoder to combine the received copies weighted by the SNR prior to decoding. With the IR scheme, additional redundant information is incrementally transmitted if the decoding fails on the first attempt. The performance of CC and IR schemes are compared in the curves of Figure 2 showing the information bit energy to interference ratio (E_i/I_0) required to obtain a BLER of 30%. E_i/I_0 values are given as a function of the effective Turbo encoding rate. The curve labeled "1st transmission" shows the required E_i/I_0 if successful detection is to be accomplished in a single transmission with a probability of 30%. The curves labeled "2nd transmission" indicate the required E_i/I_0 calculated as the linear sum of the E_i/I_0 of the two individual transmissions, still at a 30% probability of correctly detecting the packet. As can be seen for the case of chase combining, a slight combining loss must be expected (loss slightly higher if lower BLER target is set after second transmission). This loss is mainly attributed to the combining operation itself, which is based on the combining of soft information values. As can be noticed for a code rate of 3/4, there is a large advantage of applying IR since the resulting code rate after the second transmission is close to optimum (1/3 which is the base encoder rate). For code rates of ½ or lower, IR does not provide a significant gain over chase combining since almost all code information has been sent in the first transmission. The disadvantage of IR over CC is the much higher memory requirements for the UE. The possibility to utilize IR for a certain TFRC and multi-code combination is defined by the UE capability class. Depending on the data rate compared to the UE capability as well as the code rate of the first transmission, aspects of both the CC and the IR schemes will be utilized in the retransmissions. When 16QAM is used as the modulation scheme, two of the four bits constructing the received symbols will have a higher probability of error than the other two bits. In order to compensate for this effect it is

possible to use constellation re-arrangement for retransmissions, which provides a swapping of the bit streams in a way that all bits experience the same average level of error probability after the retransmission combining.

Retransmission utilization for a user depends on whether the channel quality is generally in the lower or the upper end of the AMC dynamic range and if it exceeds this dynamic range. For optimal spectral efficiency and a simple round-robin scheduling scheme (without consideration of hardware and code utilization issues), users located at the cell edge will experience an average first transmission BLER around 30-60%, while users located in the vicinity of the Node-B will operate with a first transmission BLER around 10-20%. The reason for the higher BLER at the cell edge is that a user in bad conditions will more often be in a condition where even the most robust TFRC cannot be received without error in the 1st transmission.

Spectral and code efficiency
Before reaching the pole capacity, a synchronous WCDMA system may be capacity limited due to either a power shortage or a code shortage. One of the major benefits of the HSDPA concept is the ability to make a tradeoff among power and code efficiency to accommodate the current state of the cell. This aspect is illustrated in Figure 3, where the five example TFRCs are plotted in a diagram showing both their power efficiency (measured as allowed noise power to user bit energy ratio for a BLER of 10%, e.g. I_0/E_i) and their respective code efficiency (measured as supported data rate per code). If the Node-B has relatively more power resources than code resources available (code limited), the link adaptation algorithm will optimize for a more code efficient TFRC while a more robust TFRC with more multi-codes will be used when the Node-B is mainly power limited.

Link adaptation and support channels
The overall concept of the HS-DSCH link adaptation (LA) is illustrated in Figure 4. The Node-B tracks the radio channel quality in the downlink direction by monitoring the transmit power on the downlink associated DCH (adjusted via control commands available on the uplink associated DCH). The UE can also be requested to regularly send a specific channel quality indicator (CQI) on the uplink high speed
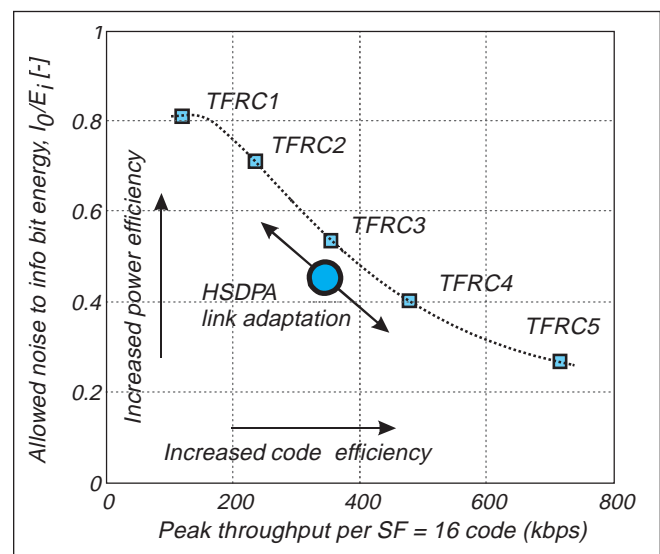
Figure 3 Power and code effciency for different TFRCs.
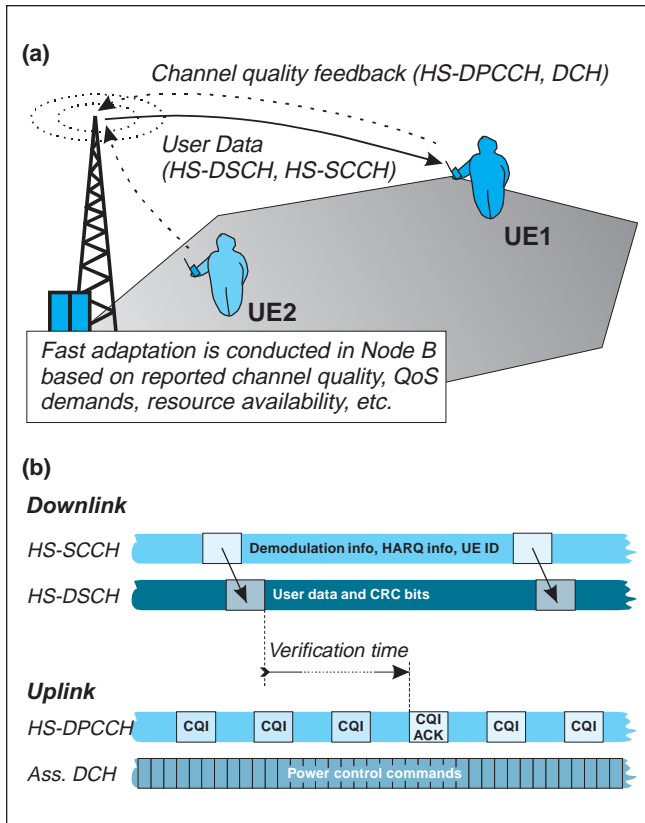
Figure 4 The general HSDPA operating principle is shown in (a) and inter-channel operation is illustrated in (b).

dedicated physical control channel (HS-DPCCH). The CQI is an indicator of the TFRC and multi-code number currently supported by the UE (e.g. the supported data rate). The feedback cycle of the HS-DPCCH CQI can be set as a network parameter in predefined steps from 2 ms to infinite time (i.e. disabled). The power of the HS-DPCCH is set as an offset compared to the uplink dedicated physical control channel (DPCCH) and to guarantee full cell-coverage a CQI repetition scheme can be used. For the Node-B to know if a transmitted packet was detected correctly or wrongly in the receiver end, the UE is required to send a CRC-based ACK/NACK response on the HS-DPCCH. It is up to the Node-B (and thus the manufacturer/operator) to decide whether it will base its link adaptation strategy primarily on the associated DCH power control commands, the HS-DPCCH information, or a combination of the two.

Depending on packet prioritization and resource availability, the Node-B then schedules data to the users on the HS-DSCH. In this sense, two users may be both time and/or code multiplexed to better utilize the available resources under the constraint of having different UE capability classes. Prior to sending data on the HS-DSCH, the Node-B sends a detailed demodulation message to the active users via the high speed shared control channel (HS-SCCH). This information describes the employed TFRC, the multi-code set, as well as the H-ARQ process control and is transmitted 2 slots in advance of the HS-DSCH. The UE being active on the HS-DSCH must be capable of receiving up to four parallel HS-SCCHs in order to determine if data is being transmitted to the UE in the following time period. Masking the CRC field on the HS-SCCH with a unique UE ID facilitates the UE identification process. The power of the HS-SCCH is controlled by the Node-B and it may have a time-variant

power. The HS-DSCH contains user data as well as a single 24-bit CRC field that is calculated over all the transmitted multi-codes (i.e. one logical transport channel maps into several physical channels). This approach yields a Turbo coding gain for larger data rates where the encoding block size increases.

UE Capabilities

With the introduction of the HSDPA concept into the Release 5 specifications, a new generation of UE capability classes will be introduced. Five main parameters are used to define the physical layer UE capability level [5]:

- ✦ Maximum number of HS-DSCH multi-codes that the UE can simultaneously receive. At least five multi-codes must be supported in order to facilitate efficient multi-code operation.
- ✦ Minimum inter-TTI interval, which defines the distance from the beginning of a TTI to the beginning of the next TTI that can be assigned to the same UE. E.g. if the allowed interval is 2 ms, this means that the UE can receive HS-DSCH packets every 2 ms.
- ✦ Maximum number of HS-DSCH transport channel bits that can be received within a single TTI.
- ✦ The maximum number of soft channel bits over all the HARQ processes.
- ✦ If the UE supports 16QAM (e.g. code efficiency limitation).

Further, parameters are specified for informing the network what is the total L2 buffer capability (MAC and RLC) in the UE. Examples of UE capability classes proposed in 3GPP are listed in Table 3, but more combinations are possible [5]. Note that a 'low-end' HSDPA UE will support a maximum of 5 simultaneous HS-DSCH codes, and the minimum distance between the starting points of two successive data packets is 3 TTIs (i.e. 6 ms). Such a UE will support a maximum of 7300 bits in each TTI and thus belong to the 1.2 Mbps class. Another important difference is the amount of soft channel bits defined for each UE class. The number of soft channel bits will impact the UE receiver performance when HARQ is employed. A UE with a low number of soft channel bits will not be able to support IR for the highest peak data rates and its performance will thus be slightly lower than for a UE supporting a larger number of soft channel bits.

Architecture Issues and RRM

It is entirely up to the network operator to choose a policy for weighting the different offered services, the subscription

Reference combination	1.2 Mbps class	3.6 Mbps class	7 Mbps class	10 Mbps class
RLC and MAC-hs parameters				
Total RLC AM and MAC-hs buffer size (kbytes)	50	50	100	150
Maximum number of AM RLC entities	6	6	8	8
PHY parameters				
FDD HS-DSCH category	1	5	7	9
Maximum number of bits of HS-DSCH codes received	5	5	10	15
Minimum inter-TTI interval	3 (6 ms)	1 (2 ms)	1 (2 ms)	1 (2 ms)
Maximum number of bits of an HS-DSCH transport block received within an HS-DSCH TTI	7300	7300	14600	20432
Total number of soft channel bits	19200	57600	115200	172800

Table 3 Example of HS-DSCH UE capability classes [5]. All example catagories support 16QAM.

classes, etc. This weighting applies to both the priority in the network among other services/users but also to the service quality targets; e.g. in terms of guaranteed data rates, minimum delays, etc. One example is to use a paradigm of having different QoS classes; e.g. the premium, gold, and silver subscription division [6]. The RRM algorithms are responsible for best utilization of the available system resources to meet the service policies adopted by the network provider as well as maximizing the system capacity. Specifically, the RRM algorithms are responsible for implementing a hardware and power resource sharing between the different channel types, so that a Node-B can convey traffic over e.g. the DCHs, DSCH, and HS-DSCH at the same time. The admission control (AC) functionality is critical to obtaining the best tradeoff among capacity and single-service quality. Guaranteeing a negotiated QoS level calls for an efficient and QoS-aware AC mechanism, which adjusts its user admission criterion according to the service requirements of the currently active users as well as the pending new user.

The cell specific power and code resource allocation among different channel types is negotiated in the RNC on a rather slow basis compared to the TTI for the HS-DSCH (using cell reconfiguration messages). The power and code resources reserved for HS-DSCH and HS-SCCH are subsequently reported to the Node-B (MAC-hs) over the open Iub interface [7]. If no power constraints are specified, the Node-B can use all excess power not needed for other traffic for the HS-DSCH. The number of channelization codes for HS-DSCH (SF=16) and HS-SCCH (SF=128) are explicitly dictated by the RNC, while the MAC-hs has the freedom to freely distribute the power between the user data and the control channels. The packet scheduling (PS) is responsible for conducting the scheduling of the users, which have been directed to the HS-DSCH. The complicated scheduling operation must consider UE capability issues (e.g. use of code multiplexing), QoS requirements and priority, pending re-transmissions, user's current channel quality, etc. Subsequently, the link adaptation process and the SAW channel selection process are conducted. As the HS-DSCH offers per-TTI bit rate modification and time/code multiplexing between different users, the MAC-hs, containing the HSDPA PS, link adaptation, and HARQ entities, has been moved to the Node-B. This is illustrated in Figure 5.

Packet scheduling

The high scheduling rate combined with the large AMC dynamic range available with the HSDPA concept, makes it possible to conduct the packet scheduling according to the radio conditions as well as the data amounts to be transmitted to the different users. Hence, the HSDPA concept opens for Waterfilling based packet scheduling strategies for optimized cell throughput/fairness strategies, see e.g. [8,9]. The PS methodologies can generally be characterized by:

Scheduling period/frequency: The period over which users are scheduled ahead in time. If short, the PS may utilize fast channel variations and track fast fading for low-mobility users. Shorter periods call for higher computational complexity in the Node-B.

Serve order: The order in which users are served; e.g. random order (round robin) or according to channel quality (C/I or throughput based). More advanced order mechanisms require higher computational processing at the Node-B.

Allocation method: The criterion for allocating resources; e.g. same data amount or same power/code/time resources for all queued users per allocation interval.

Some general packet scheduling methods and their characteristics have been compared in Table 4. The fair throughput (FT) scheduler serves users in a random order and according to the same data amount. In theory, all users currently active in the system will therefore experience the same delay and throughput. With the fair resource (FR) scheduler, users receive equal resources in random order and will thus experience different data rates according to their average channel quality. With the C/I PS method (also denoted the thoughput or TP method), the user with the best channel quality is served until the queue is emptied. This leads to a very different service experience among users and to the potential situation where a certain poor-quality user will experience excessive service delays. The scheduling rate for these packet schedulers is assumed to be slow such that fast channel variations are not incorporated (averaging still may be faster than shadowing variations, though). An available option with the HSDPA concept is to make very fast scheduling, which tracks the fast fading variations. Ultimately, users are only scheduled when they are experiencing constructive fading; thereby improving both the user throughput and cell throughput for time-shared channels. The Max C/I or throughput (M-TP) method is the most drastic method, which only serves the best user during the current TTI; e.g. the user who can sustain the highest throughput. Compared to the TP scheduler, this scheduler is fairer to the users since a single user's fading variations typically exceed or are on the order of the average C/I difference between different user locations in the cell. However, the outage of this method is still significant. To obtain a fairer scheduling method, it is possible to define and calculate a relative instantaneous channel quality (RICQ) measure as a selection and prioritization metric. The RICQ measure is often identical to the ratio of the user's instantaneous throughput and the user's average served throughput [9]. In calculation, it utilizes the CQI information as well as the link quality estimation algorithms, which are located in the Node-B. This fast scheduling method is referred to as the proportional fair resource (P-FR) scheduling method as illustrated in Table 4. The proportional scheduling method results in all users getting approximately an equal probability of becoming active even though they may experience very different average channel quality.

The above-mentioned schedulers are "prototype" packet schedulers, which use different means to utilize and distribute excess capacity of the network. They basically yield a very different tradeoff between user fairness and cell capacity. Prioritization based on either QoS constraints or different subscription classes (e.g. premium, gold, and silver users) will in general override the scheduling principles depicted in Table 4 and the scheduling will then only be applied to groups of users/services encompassing the highest
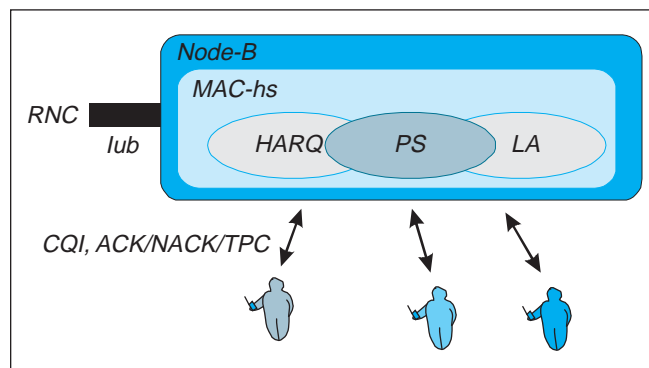

Figure 5 HSDPA RRM entities in the Node-B.

PS method	Scheduling rate	Serve order	Allocation method
Fair throughput (FT)	Slow	Round robin in random order	Resources according to same data amount (up to max. allocation time)
Fair time (FR)	Slow	Round robin in random order	Same resources (time, code, or power) and uneven data amount
C/I or throughput (TP)	Slow	Based on highest average C/I (fast enough to track shadowing)	Same resources (time, code, or power) and uneven data amount
Proportional fair resource (P-FR)	Fast	Based on highest relative instantaneous channel quality (tracks fast fading)	Same resources (time, code, or power) and uneven data amount
Max C/I or throughput (M-TP)	Fast	Based on highest instantaneous channel quality (tracks fast fading)	Same resources (time, code, or power) and uneven data amount

Table 4 *Comparison of different simplified packet scheduling methods [9, 11].*

priority level. When QoS requirements dominate the scheduling strategy, the differentiation between different PS strategies becomes less significant and the capacity gain of the most aggressive schedulers reduces (while becoming more fair).

Performance

The performance of the HS-DSCH depends on a large number of aspects, such as (i) channel conditions including othercell interference and time dispersion, (ii) UE demodulation performance and capability, (iii) nature and accuracy of RRM algorithms, and (iv) hardware imperfections. The throughput performance for a single link employing link adaptation is shown for different channel profiles and average I_{or}/I_{oc} values in Figure 6 versus the code power allocation. In the estimation of the UE channel quality (E_s/N_o) at the Node-B some error must be expected. In these simulations, a lognormally distributed error with a standard deviation of 1 dB and a 2 ms AMC delay have been assumed. In general, the HARQ mechanism makes the LA very robust towards channel estimation errors and scheduling delays. With fast L1 HARQ, the degradation in throughput due to channel estimation errors is approximately halved compared to an AMC system without HARQ [11].

Two different network scenarios are considered for analysis at cell level. This first case (Macrocell/Veh-A) is a macrocell outdoor environment where an ITU Vehicular-A channel profile is assumed (e.g. significant time dispersion). The second case (Microcell/Ped-A) is a microcell outdoor-indoor environment characterized by a favorable I_{or}/I_{oc} distribution due to better cell isolation as well as an ITU Pedestrian-A profile (e.g. limited time dispersion). The I_{or}/I_{oc} distributions are averaged over fast fading and are from [10]. Other simulation assumptions are listed in Table 5.

The fair resource and proportional fair resource schedulers are often considered in conjunction with HSDPA and these have

| Parameter	Setting
HSDPA power	75% of Node-B power
Common channel power	20% of Node-B power
HSDPA code allocation	15 (SF=16)
HSDPA cell coverage	90%
Number of users	32
UE velocity	3 kmph
TFRC resolution	See Table 2
Download request	400 kbit for all users
Node-B PCDE*	-36 dB (SF=256)

Table 5 *Simulation Assumptions*
* Simple AWGN model for Node-B hardware imperfections adjusted to Release 5 level of peak code domain error (PCDE).
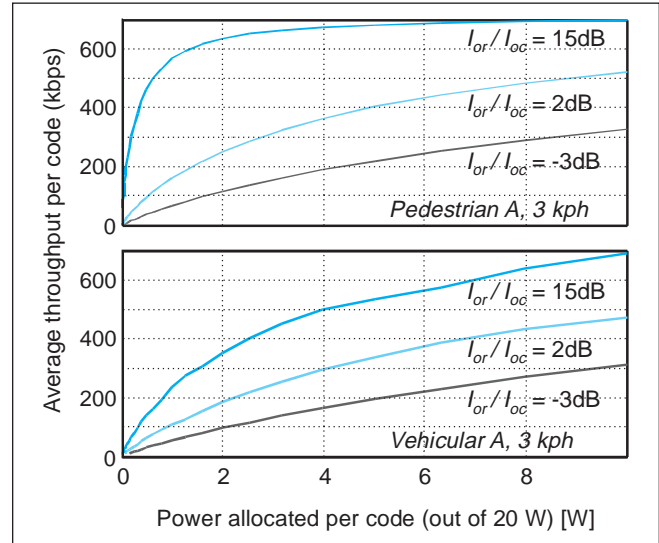
Figure 6 Code throughput versus code power allocation.

been evaluated under the assumptions listed in Table 4. Only one user prioritization class is considered and the packet scheduler operation is not limited by QoS constraints. As TCP and other higher layer protocols are not considered in the evaluation, we attempt a "best effort" type simulation assuming no degradation from e.g. slow start effects. The average cell capacity for the different packet scheduling methodologies are compared in Figure 7 also including reference numbers for Release
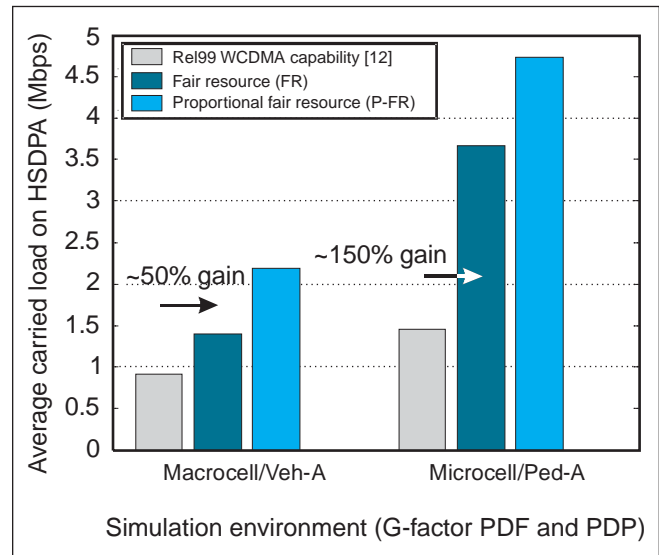
Figure 7 Average cell throughput for different scheduling types.

99 WCDMA obtained from [11]. It is noted that the performance improvement of fast scheduling over slow scheduling is significant for this simulation case with near-optimum conditions. For the macrocell environment the gain in cell throughput is on the order of 56%. For the microcell environment, users are already experiencing very good channel conditions and during good fading conditions they exceed the dynamic range of the AMC. For this reason, the fast scheduling gain reduces to approximately 29%. The available cell throughput for the microcell case exceeds 3.5 Mbps and 4.5 Mbps for the FR and P-FR schedulers respectively. For the interference limited macrocell scenario, the FR throughput is approximately 1.4Mbps. Compared to the numbers for Release 99 performance (denoted by "Rel99 WCDMA"), the cell throughput gain of HS-DSCH exceeds 50% in macrocell and thus significantly more with advanced packet scheduling or in favorable scenarios where the DCH/DSCH becomes code limited [11].

Continued Evolution

HSDPA provides a significant cell capacity gain for packet data traffic in WCDMA and is thus an important part of the continuous 3G evolution. Since the HSDPA concept offers improved code efficiency and dynamic range in user data rates, it can utilize improvements in detector performance foreseen in the future. Hence, it may be viewed as an enabler for more advanced communication techniques, including equalizers, multi-user or multi-code interference cancellation, as well as advanced multiple input multiple output (MIMO) techniques. The HSDPA concept can be introduced gradually in the network with incremental introduction of advanced packet scheduling and link enhancement strategies. The performance and cost/complexity issues of further improvements will be considered within future 3GPP standardization framework to further evolve the WCDMA concept.

References

[1] 3GPP TS25.211, "Physical Channels and Mapping of Transport Channels onto Physical Channels (FDD)", version 4.4.0.

[2] K. W. Helmersson and G. Bark, "Performance of Downlink Shared Channels in WCDMA Radio Networks", Proc. IEEE Vehicular Technology Conference (VTC), vol. 4, pp. 2690-2694, Spring 2001.

[3] 3GPP TS25.855, "High Speed Downlink Packet Access; Overall UTRAN Description", version 5.0.0.

[4] 3GPP TS25.308, "UTRA High Speed Downlink Packet Access (HSDPA); Overall description; Stage 2", version 5.2.0.

[5] 3GPP TS25.306, "UE radio access capabilities definition", version 5.2.0.

[6] Y. Guo, H. Chaskar, "Class-Based Quality of Service over Air Interface in 4G Mobile Networks", IEEE Communications Magazine, 40 (3), pp. 132-137, March 2002.

[7] 3GPP TS25.877, "High Speed Downlink Packet Access: Iub/Iur protocol aspects ", version 5.0.0.

[8] J.M. Holtzman, "CDMA Forward Link Waterfilling Power Control", Proc. IEEE Vehicular Technology Conference, pp. 1663-1667, September 2000.

[9] J.M. Holtzman, "Asymptotic Analysis of Proportional Fair Algorithm", Proc. IEEE Personal Indoor Mobile Radio Communications (PIMRC), pp. F33-F37, September, 2001.

[10] J. R. Fonollosa, M. Heikkilä, J. P. Kermoal, X. Mestre, A. Pagès, A. Pollard, L. Schumacher, A. Wiesel, and J. Ylitalo, "Adaptive Modulation Schemes for MIMO HSDPA", IST Mobile Summit, Thessaloniki, Greece, pp. 78-82, June 2002.

[11] H. Holma and A. Toskala, WCDMA for UMTS, 3rd edition, Wiley, 2002.

Troels Emil Kolding accomplished his M.Sc.E.E. and Ph.D. studies in Aalborg University, Denmark, in 1996 and 1999, respectively. For a two-year period, he worked as associate research professor at Aalborg University, leading a UMTS front-end design project. Since 2001, he is wireless networks specialist with Nokia Networks, Denmark, working on high-speed data concepts for CDMA cellular networks.

Klaus Ingemann Pedersen received his M.Sc.E.E. and Ph.D. degrees in 1996 and 2000 from Aalborg University, Denmark. He is currently with Nokia Networks in Aalborg, Denmark. His current research interests include radio resource management for WCDMA systems, adaptive antenna array systems, and spatial radio propagation modeling.

Jeroen Wigard received his M.Sc.E.E. in electrical engineering from Delft University of Technology in 1995 and his Ph.D. in 1999 from Aalborg University, Denmark. He worked in 1995 and 1999 as assistant research professor at Center for PersonKommunikation (CPK), Aalborg University on GSM system issues. Since 2000, he is with Nokia Networks in Aalborg. His current research interests include packet data performance, TCP, and RRM issues in WCDMA.

Frank Frederiksen received his M.Sc.E.E. in telecommunications from Aalborg University in 1994. From 1994 to 2000, he has been working at Center for PersonKommunikation (CPK), Aalborg University as a research engineer developing measurement systems for DECT/GSM/W-CDMA. Since 2000, he has been working for Nokia on evaluation of high-speed data services for W-CDMA.

Preben Elgaard Mogensen received the M.Sc.E.E. and Ph.D. degrees, in 1988 and 1996, from Aalborg University Denmark. He is currently part time Research Professor at Center for Personkommunikation (CPK), Aalborg University, where he is heading the Cellular Systems research group (CSYS). He is also manager of the 3G Radio Systems Research team of Nokia Networks in Aalborg, Denmark.