WCDMA evolved—High-speed packet-data services

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Compared to second-generation systems, one of the most important aspects of third-generation mobile systems is enhanced packet-data access. WCDMA Release 99 provides data rates of 384 kbit/s for wide area coverage and up to 2 Mbit/s for hot-spot areas, which is sufficient for most existing packet-data applications. However, as the use of packet-data services increases and new services are introduced, greater capacity will be required. WCDMA Release 5 extends the specification with, among other things, a new downlink transport channel that enhances support for interactive, background, and to some extent, streaming services, yielding a considerable increase in capacity compared to Release 99. It also significantly reduces delay and provides peak data rates of up to 14 Mbit/s. This enhancement, which commonly goes under the abbreviation, HSDPA, is the first step of evolving WCDMA to provide even more outstanding performance.

The authors describe the basic principles used by this enhancement and how they are incorporated into the specification and products. They also explain the associated system and end-user benefits.

High-speed downlink shared channel

WCDMA Release 5 extends the WCDMA specification with a new downlink transport channel, called high-speed downlink shared channel. With shared channel transmission, a certain amount of the channelization codes and transmission power in a cell are considered a common resource that is dynamically shared among users, primarily in the time domain. Shared-channel transmission makes more efficient use of available code resources in WCDMA. HSDPA also supports new features that rely on, and are tightly coupled to, the rapid adaptation of transmission parameters to instantaneous radio conditions:

- Fast link adaptation—instead of compensating for varying downlink radio conditions by means of power control, the transmission power is kept constant. Fast rate adjustment is used to adapt to the varying radio conditions. Commonly referred to as link adaptation, this method is more efficient than power control for services that tolerate short-term variations in the data rate. To further increase capacity and data rates, spectral-efficient 16-quadrature amplitude modulation (16QAM) can be used, channel conditions permitting.
- Fast hybrid-ARQ with soft-combining—the terminal (user equipment, UE), can rapidly request retransmission of erroneously received data, substantially reducing delay and increasing capacity (compared to Release 99). Prior to decoding, the terminal combines information from the original transmission with that of later retransmissions. This practice, called soft-combining, increases capacity and robustness.
- Fast channel-dependent scheduling—The scheduler determines to which terminal the shared channel transmission

BOX A, TERMS AND ABBREVIATIONS

3GPP	Third-generation Partnership Project
16QAM	16-quadrature amplitude modulation
ARQ	Automatic repeat request
CIR	Carrier-to-interference ratio
DCH	Dedicated channel
G-RAKE	Generalized RAKE
HSDPA	High-speed downlink packet access
HS-DSCH	High-speed downlink shared channel
HS-SCCH	High-speed shared control channel
MAC	Medium access control
PDCP	Packet data convergence protocol
PF	Proportional-fair (scheduler)
QPSK	Quadrature phase-shift keying
RAB	Radio access bearer
RAN	Radio access network
RBS	Radio base station
RLC	Radio link control
RNC	Radio network controller
RR	Round-robin (scheduler)
RRC	Radio resource control
RTP	Real-time protocol
SGSN	Serving GPRS support node
TCP	Transmission control protocol
TTI	Transmission time interval
UDP	User datagram protocol
UE	User equipment (mobile handset or terminal)
UMTS	Universal mobile telecommunications system
WCDMA	Wideband code-division multiple access

should be directed at any given moment. The term channel-dependent scheduling signifies that the scheduler considers instantaneous radio-channel conditions. This greatly increases capacity and makes better use of resources. The basic idea is to exploit short-term variations in radio conditions by transmitting to terminals with favorable instantaneous channel conditions.

Architecture

An important objective of the HSDPA design has been to retain the functional split introduced in Release 99 between layers and nodes. Moreover, a minimum of architectural changes ensures a smooth upgrade and enables operation in environments where not every cell supports the new functionality. Nonetheless, given that the key features are rapid adaptation to changes in the radio environment and fast retransmission of data, it follows that the corresponding functionality should be placed close to the air interface. In other words, the introduction of HSDPA mainly affects the radio base station (RBS, also called Node B), in particular, through the addition of a new medium access control sub-layer (MAC-hs). The architecture retains the radio network controller (RNC) functionality of Release 99.

By switching channels in the RNC, the system can easily handle terminal movement from a cell that supports HSDPA to one that does not. That is, by switching the terminal from the high-speed downlink shared channel (HS-DSCH) to a dedicated channel (DCH) in a non-enhanced cell, the system ensures uninterrupted service, albeit at a lower data rate. Conversely, when the terminal enters a cell that supports HSDPA, the system can switch it from a dedicated channel to the HS-DSCH.

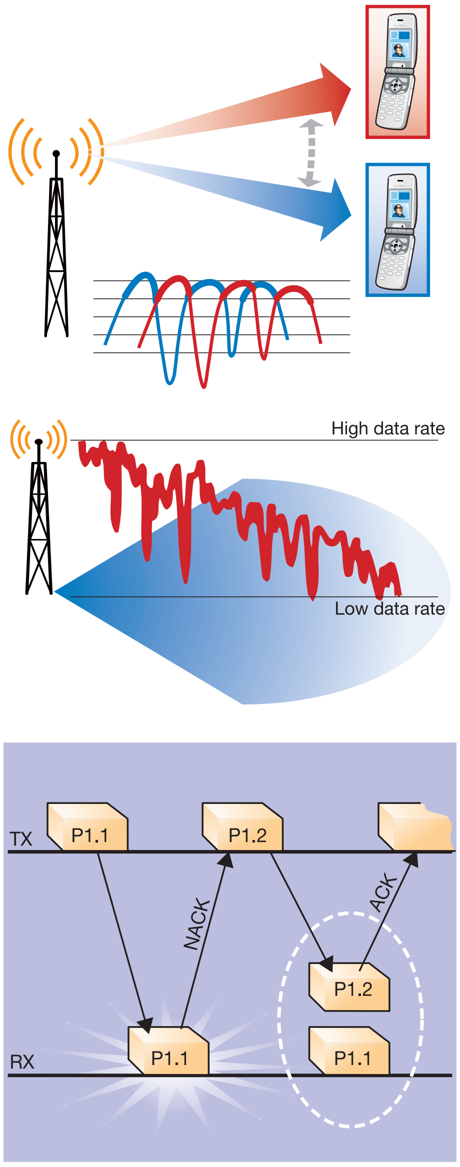


Figure 1
Basic principles employed by HSDPA.

Channel structure

The shared code resource onto which the HS-DSCH is mapped consists of up to 15 codes with the spreading factor fixed to 16. The number of HS-DSCH codes in each cell is configured, or slowly adapted, by the RNC, according to the number of resources needed for packet-data services on HS-DSCH and other services, such as voice.

The channels introduced with HSDPA share the same carrier as other channels—for example, dedicated channels for voice services. Hence, operators need not allocate additional spectrum to introduce HSDPA services. This translates into efficient use of spectrum and flexible allocation of resources between services using HS-DSCH (for instance, packet-data applications) and DCH (for instance, voice).

Channelization codes from the shared code resource are dynamically allocated by the RBS every 2 ms. The use of a short transmission time interval (TTI) reduces overall delay and improves the tracking of channel variations, which are exploited by link adaptation and channel-dependent scheduling. Time sharing is the primary means of shar-

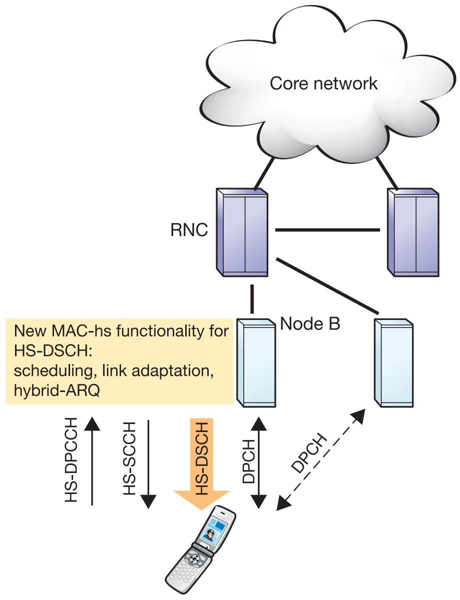


Figure 2
New MAC-hs functionality introduced in the RBS (Node B).

ing common code resources among users. A limited form of sharing in the code domain is also made possible by employing different subsets of the complete HS-DSCH channelization code set for different users. Although sharing in the time domain is preferable, sharing in the code domain is useful for

- providing efficient support of small payloads, for instance when the transmitted data does not require the full set of HS-DSCH codes configured in the cell; or
- supporting terminals that cannot despread the full set of codes.

A new downlink control channel, the high-speed shared control channel (HS-SCCH), carries control information from the MAC-hs in the RBS to the scheduled terminal. The control information required for each 2 ms TTI includes the identity of the terminal, hybrid-ARQ-related information, and the parameters of the HS-DSCH transport format selected by the link-adaptation mechanism. Since the HS-DSCH is shared mainly in the time domain, and since only the currently scheduled terminal needs to receive the HS-SCCH, there is typically only one such channel (more, if code domain-sharing is used) configured in each cell. Release 5 mandates that all HS-DSCH-enabled terminals must monitor up to four HS-SCCHs.

In addition, a new uplink control channel, called the high-speed dedicated physical control channel (HS-DPCCH), must be set up for each terminal that uses high-speed services. The terminal uses this channel to request the retransmission of erroneously received transport blocks and to report measured downlink channel quality to the RBS.

Finally, terminals that use high-speed services must always have a set of dedicated uplink and downlink channels for uplink traffic and downlink services not carried on the HS-DSCH. The dedicated uplink and downlink channels use soft-handover as implemented in Release 99, while HS-DSCH, HS-SCCH and HS-DPCCH do not. Implementing soft handover (which by definition implies multiple RBSs) for the high-speed channels is not feasible, since fast channel-dependent scheduling is handled by a single RBS. Furthermore, the potential gains from soft handover are limited, since most of these gains are exploited by fast channel-dependent scheduling.

Scheduling

The scheduler, which is part of the MAC-hs in the RBS, is a key element that determines the overall behavior of the system. For each TTI, it determines which terminal (or terminals) the HS-DSCH should be transmitted to, and in collaboration with the link-adaptation mechanism, at what data rate. A significant increase in capacity can be obtained if, instead of allocating radio resources sequentially (round-robin scheduling), the scheduler employs channel-dependent scheduling—that is, the scheduler prioritizes transmissions to terminals with favorable instantaneous channel conditions. By prioritizing these users, the network experiences mostly good conditions. The effect is greater diversity at the system level, hence the term multi-user diversity. As load in the cell increases, the number of terminals queued for scheduling increases. This, in turn, raises the probability of scheduling terminals with good channel quality. Ordinarily, this results in a high carrier-to-interference ratio for the scheduled terminal. Even so, traffic priorities can be taken into account, for example to prioritize streaming services ahead of background services.

When we discuss and compare scheduling algorithms, we need to distinguish between two kinds of variations in service quality:

- rapid variations in service quality; and
- long-term variations in service quality.

Rapid variations in service quality are due,

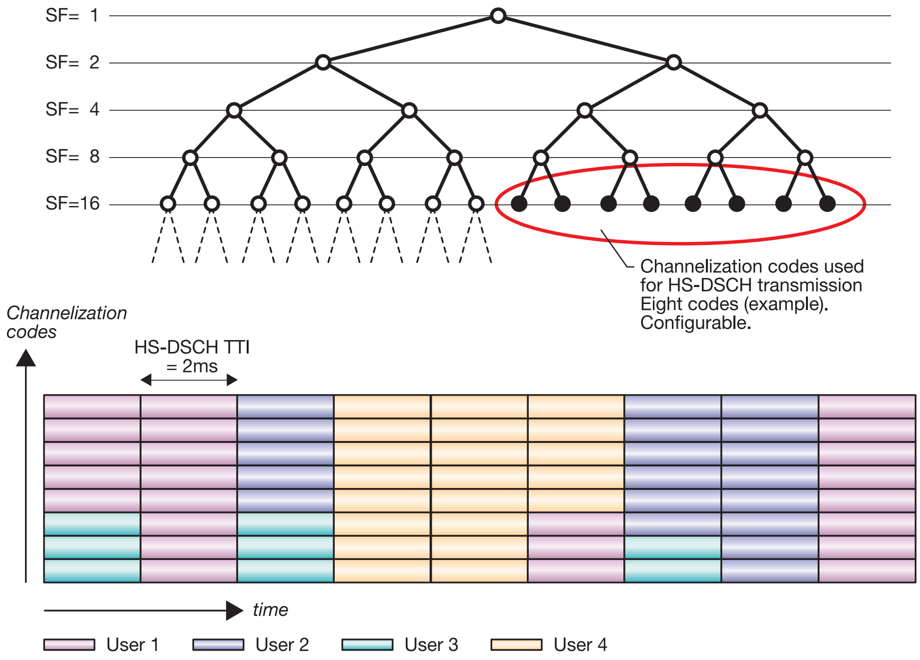


Figure 3
HS-DSCH code and time structures.

for example, to multipath fading and variations in the interference level. For many packet-data applications, relatively large short-term variations in service quality are acceptable or go unnoticed.

Long-term variations in service quality are due, for example, to distance between the terminal and RBS. These variations must often be restricted.

A practical scheduling strategy exploits the short-term variations while maintaining some degree of long-term fairness between users. In principle, system throughput decreases the more fairness is enforced. Therefore, a trade-off must be reached. Typically, the higher the system load, the greater the discrepancies between different scheduling strategies.

Channel-dependent schedulers must estimate the instantaneous radio conditions of the terminal. Therefore, each terminal that uses high-speed services transmits regular channel quality reports to the RBS via the HS-DPCCH. The scheduler might also use other information available in the RBS to assess terminal radio conditions.

Link adaptation and higher-order modulation

As mentioned above, higher-order modulation and link adaptation can be combined to maximize the instantaneous use of the fading radio channel. The HS-DSCH does not employ fast power control to compensate for channel variations. Instead, to maximize user throughput in the downlink, it adjusts the data rate to match the instantaneous radio conditions and the available transmission power in the RBS. After serving common and dedicated channels, it is thus possible to assign the remaining cell power to the HS-DSCH, resulting in more efficient use of cell power. In contrast to the HS-DSCH, the dedicated channels are designed to maintain a constant data rate by means of fast power control. With only power-controlled channels it is difficult to exploit the total cell power. However, by using fast link adaptation for services that can tolerate some jitter in the data rate, it is possible to operate close to the maximum cell power while still providing a constant data rate for some services through dedicated channels. Figure 4 illustrates power allocation with and without HSDPA.

Since the TTI for the HS-DSCH is relatively short (2 ms), and scheduling and link adaptation decisions are taken for each TTI, the link-adaptation function can track rapid variations in the channel. The system adjusts the data rate by

- varying the effective code rate; and
- changing the modulation scheme.

Besides QPSK, the HS-DSCH can use 16QAM to provide greater data rates. Higher-order modulation, such as 16QAM,

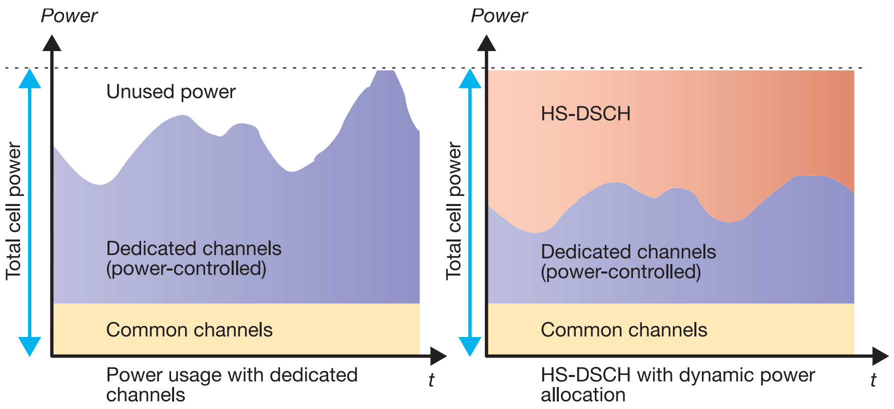


Figure 4
Power utilization with and without HSDPA.

makes more efficient use of bandwidth than QPSK but requires greater received energy per bit. Consequently, 16QAM is mainly useful in bandwidth-limited scenarios and not in power-limited scenarios. Bandwidth-limited scenarios are primarily encountered in low-dispersive environments close to the base station.

Hybrid-ARQ with soft-combining

The hybrid-ARQ mechanism allows the terminal to rapidly request retransmission of erroneously received transport blocks, essentially fine-tuning the effective code-rate and compensating for errors made by the link-adaptation mechanism. The terminal attempts to decode each transport block it receives, reporting to the RBS its success or failure 5 ms after the reception of the transport block. The hybrid-ARQ mechanism in the RBS can thus rapidly respond to retransmission requests. During retransmission, the terminal employs soft-combining—that is, it combines soft information from previous transmission attempts with the current transmission (retransmission) to increase the probability of successful decoding.

The RBS controls the set of coded bits used for retransmission, taking into account available memory in the terminal. The retransmission might consist of the same set of coded bits as the initial transmission (Chase combining) or a different set of coded bits that represents the same information (incremental redundancy). Incremental redundancy can provide better performance than Chase combining in some situations, but uses more buffer memory in the terminal.

System and end-user application performance

The enhancements of HSDPA can be grouped into two categories:

- improved application performance—shorter round-trip times obtained from short TTI and fast retransmissions improve interaction with TCP and enhance the performance of end-user applications. Increased bit rates also benefit application performance; and
- increased system throughput—higher-order modulation, fast scheduling, and fast link adaptation yield greater maximum system throughput.

Both a multi-cell radio network simulator and a protocol simulator were used to investigate the principal behavior and to estimate gains in performance and system capacity. A radio network demonstrator was used to further assess performance and evaluate end-user applications in real-time.

Principle behavior

HSDPA increases capacity in several ways. Link adaptation maximizes channel utilization and enables the base station to operate close to maximum cell power; fast channel-dependent scheduling yields multi-user diversity; and 16QAM yields higher bit rates. Depending on the deployment scenario, the combined gain in capacity is assessed to be two to three times that of DCH. End-user service quality, in terms of the packet bit rate, benefits primarily from shorter delays, thanks to fast hybrid-ARQ and short TTI, but also from increased bit rates.

Figure 5 schematically illustrates the gains in packet bit rate and system throughput obtained from the introduction of HSDPA in any system. However, the performance of end-user applications depends on the type of service and behavior of higher layer application protocols. For instance, TCP, which is commonly used for packet-data services, was originally designed for wired networks and includes slow-start and congestion-avoidance mechanisms that strongly influence performance. A fair assessment of the overall performance of a particular service must include these mechanisms.

Web pages often consist of several small objects, and as a consequence the slow-start mechanism in TCP has a big impact on download times. This is especially true of HTTP v1.0, in which a separate TCP connection is used for each object. For web-browsing services, the perceived data rates are thus often limited by TCP and not the air interface. TCP transmission consists of sudden bursts of traffic followed by relatively long idle periods. Thus, system load from a user who is browsing the web is relatively light. The main end-user benefit of HSDPA for small objects transported via TCP is reduced round-trip time thanks to hybrid-ARQ and short TTI. Figure 5 illustrates the relatively constant gain in performance over a wide range of load. Simulations indicate that the use of HSDPA when loads are low yields two or three times the capacity of the corresponding Release 99 system.

In contrast to web browsing, the slow-start mechanism in TCP has little or no impact on the time it takes to download a large file. Instead, the perceived performance is largely determined by the data rate of the radio link. A single user downloading a large file can occupy a significant amount of the total cell capacity. Consequently, system load has a big impact on the perceived performance when end-users download large files. Simulations show that in a lightly loaded system, HSDPA can reduce the time it takes to download large files by a factor of 20.

As discussed above, a channel-dependent scheduler exploits short-term variations in radio quality to increase system throughput. Generally speaking, a certain degree of long-term fairness in service quality is desirable. However, since system throughput decreases the more fairness is enforced, a trade-off must be reached between fairness and system throughput. Traffic characteristics have a significant influence on the trade-off between system throughput and service quality. Figure 6 shows the approximate behavior in two dissimilar traffic scenarios. In the first, it is assumed that users always have data to transmit; the second scenario represents a more realistic, web-browsing situation. Three different schedulers are considered:

- round-robin (RR) scheduler, where channel conditions are not taken into account;
- proportional-fair (PF) scheduler, where short-term channel variations are exploited while maintaining the long-term average user data rate; and
- maximum-CIR scheduler, where the user with the best instantaneous channel quality in absolute terms is scheduled.

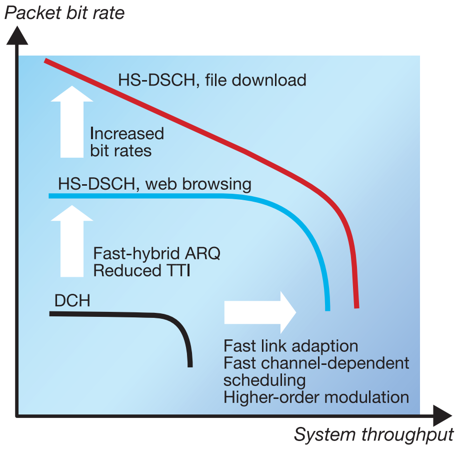


Figure 5
Performance enhancements attributed to HSDPA.

Compared to the round-robin scheduler, the proportional-fair scheduler provides equitable throughput for continuous data. The maximum-CIR scheduler gives high throughput to a few users, but fails to provide any throughput to the majority of users. The behavior for the packet-data model is quite different: compared to the maximum-CIR scheduler, the proportional-fairness scheduler provides only a slight improvement in throughput for some users. Users with favorable long-term channel quality can transmit packets rapidly with the maximum-CIR scheduler, giving more time to users with less favorable long-time averages. The traffic model thus introduces a certain degree of fairness. The proportional-fairness and maximum-CIR schedulers give almost the same throughput to users with less favorable long-time averages, while the maximum-CIR scheduler provides better system throughput. The proportional-fairness scheduler, on the other hand, exhibits similar behavior in both traffic scenarios, which can be an important advantage for mixed traffic. In conclusion, when designing the scheduler, the anticipated traffic situation must be carefully considered.

Radio network demonstrator

To evaluate and demonstrate the benefits of evolved WCDMA, Ericsson has developed a radio network emulator, called *Rasmus*, which models the major radio network functions and radio protocols of WCDMA to a detailed level. For example, by importing

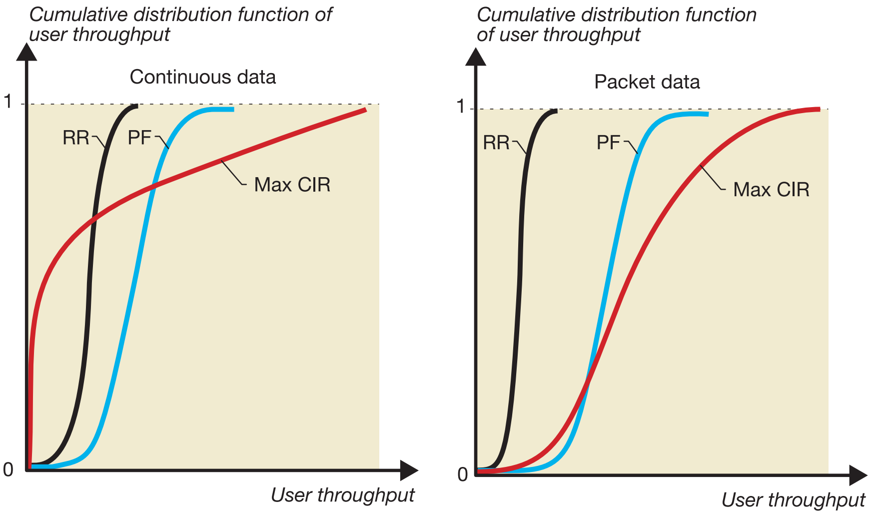
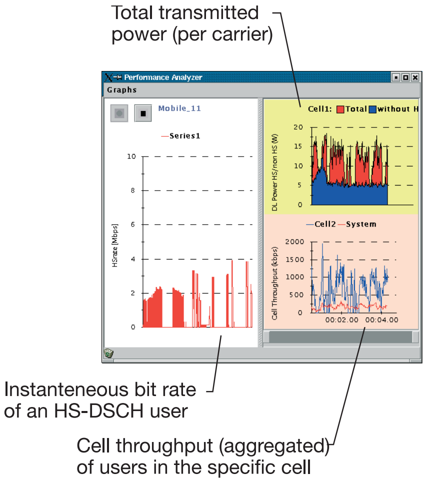


Figure 6
Approximate behavior of three schedulers for two traffic scenarios. The cumulative distribution function of user throughput is plotted.

Figure 7
Example of performance monitoring. *Rasmus* can monitor specific users and make aggregated measurements of a cell or system. The measurement frequency ranges from 0.67 ms (one WCDMA slot) to 1 second. *Rasmus* can also report statistics per user session.



path-gain maps from cell-planning tools, *Rasmus* can emulate real radio networks and yield system capacity figures for different scenarios. Likewise, when connected to standard IP clients, *Rasmus* can evaluate, in real-time, commercial end-user applications for small and medium-sized networks.

Rasmus emulates a WCDMA Release 5 network composed of a (simple) core network, an RNC, several RBSs, and several users. The radio protocols employed in WCDMA are modeled to a high degree of detail. Multiple users can be simulated and system capacity and end-user performance assessed under different assumptions. Optionally, an application server and clients can be connected to *Rasmus* via standard Ethernet. With this setup, it is possible to demonstrate real-time services for some users in the simulated network. Additional, simulated users provide the background load. The application server and clients are mainly useful for obtaining "hands-on" experience of different applications from the end-user viewpoint and are not necessary for evaluating capacity.

Thanks to *Rasmus*, it is possible to monitor behavior at the user, cell, or system level (Figure 7). *Rasmus* can also be used to trace specific RLC and RRC protocol messages, and to monitor data that is not otherwise easily accessible—for example, instantaneous receive and transmit power per slot, and path loss for different users.

The propagation model includes distance-dependent path loss, shadow fading, and multipath fading, where path loss and shadow fading are defined by pre-calculated, two-dimensional maps. The delay spread, which gives rise to multipath fading, is computed along the lines of the COST259 channel model. A user who is close to the site will thus experience less delay spread than a user who is at the edge of the cell. The available traffic models include voice, video streaming using RTP/UDP, and web browsing and file download using TCP.

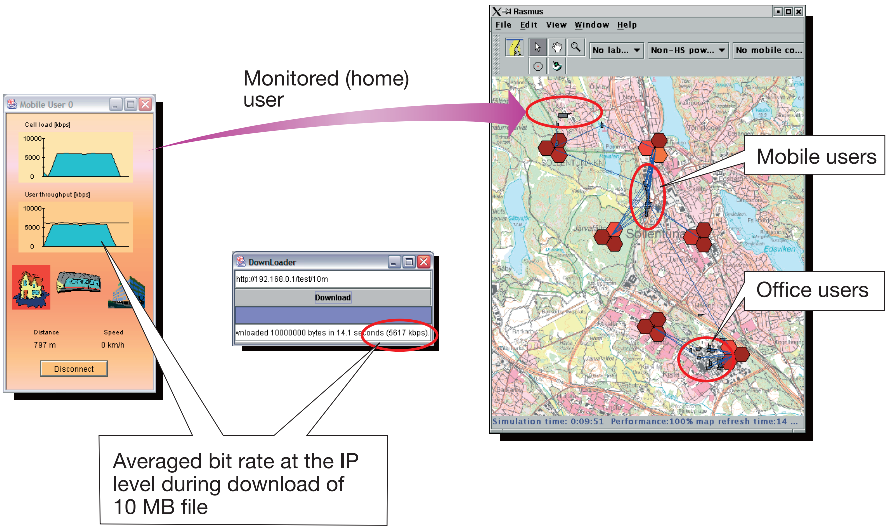
Users can be distributed over the coverage area according to several models. Moreover, users can be stationary or moving according to either stochastic or predefined mobility patterns. It is thus easy to evaluate different scenarios, such as fast-moving users on a highway, stationary users at home, or groups of users who form an area with heavy traffic load.

Figure 8 shows an example of a large file download, where the user has connected to a file server using the HS-DSCH in the downlink, and a 64 kbit/s DCH in the uplink. In this example, 10 codes were allocated to the HS-DSCH. The stationary user is located about 800 meters from the closest site; the background traffic, which consists of voice, is light. For this scenario, the user throughput on the IP level is about 6 Mbit/s.

To illustrate efficient sharing of multiple services, a case has been simulated with voice and video streaming services using the DCH, and web-browsing services using the HS-DSCH. Figure 9 shows that power not used by the DCH or common channels is allocated to the HS-DSCH. Note that the total transmit power is fairly constant.

Deploying HSDPA-capable networks

HSDPA will first be used where the WCDMA radio access network (RAN) has been deployed. This means that it will make use of existing infrastructure in all parts of the network. Operators will be especially interested in seeing how the upgrade affects large installations of RBSs. In addition, HSDPA-enabled terminals must be power-efficient and affordable, and deployment must not have a detrimental affect on Release 99 performance.



wnloaded 10000000 bytes in 14.1 seconds (5617 kbps)

Simulation time: 0:09:51 Performance:100% map refresh time:14 ...

Figure 8
Example of high-bit-rate transfer during file download.

Initially, high-speed services will be offered in a small part of the network, for example, in areas with heavy traffic, such as city centers, office areas and airports. End-users who enter the area where HSDPA is offered should gain a significant increase in throughput. When users enter or leave the area, their ongoing calls can be switched transparently between the HS-DSCH and any of the channels in Release 99 using WCDMA channel-switching and handover mechanisms. Operators can thus gradually evolve the network as demand for increased capacity and throughput grows and the population of HSDPA-enabled terminals increases.

Infrastructure

To enable the use of HSDPA in the network, the RBS hardware must be upgraded to support the new baseband and MAC-hs processing. RBS 3000 can be upgraded by modifying the baseband hardware and by remotely loading new RBS software. To rationalize network management, the RBS can be dimensioned to allow unrestricted traffic mixes—for example, mainly DCH traffic during the day, and mainly HS-DSCH traffic in the evening. A large part of the new RBS software relates to MAC-hs functionality and the scheduler. Given the increase in capacity in the RBS, operators might eventually also have to expand transport capacity. This can be done in a straightforward manner using statistical dimensioning—interactive traffic uses “remaining” transport capacity—to limit the initial cost of deployment.

The software in the RNC must also be upgraded to support HSDPA, but no hardware modifications are foreseen.

The impact on the core network from the introduction of HSDPA should be minor. The higher bit rates provided by HSDPA signify that the radio access bearers (RAB) must be modified and re-dimensioned to cope with larger data volumes. Operators who want to offer higher maximum bit rates to some users will be glad to know that the Ericsson SGSN already supports subscriber-based quality-of-service differentiation.

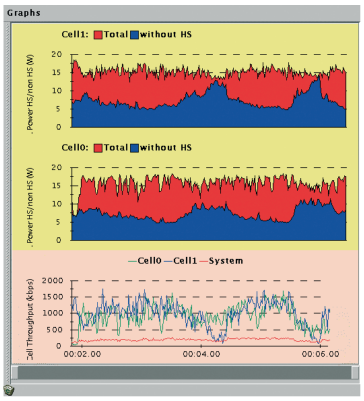
The flexibility of HSDPA allows a multitude of deployment strategies. One concern with this is that terminal support of the required mechanisms might become uncoordinated, thereby slowing rollout. However, the definition of 12 terminal categories partly sidesteps this issue. A phased introduction will further ease multi-vendor coordination. The initial phase will support the lower terminal classes, using QPSK and basic radio resource management functions. Later phases will support 16QAM and enhanced radio resource management. The upgrade in later phases will be made in software via standard, remote procedures. Each step of development enables operators to upgrade the network to match demand—testimony that the Ericsson RAN has been designed with a strong focus on future expansions.

User equipment

Compared to a Release 99 terminal, an HS-DSCH-enabled terminal must contain processing for the hybrid-ARQ operation, multi-code processing, HS-SCCH reception, and HS-DPCCH signaling. Moreover, to handle faster data rates, it must fulfill more stringent requirements for fast turbo decoder processing. To accommodate low-end and high-end implementations, 12 terminal categories have been defined (Table 1) with peak rates ranging from 912 kbit/s up to 14 Mbit/s. All but two of these terminal categories require the terminal to receive 16QAM symbols.

The idea behind the categories is to allow different levels of terminal complexity. Categories 11 and 12, for example, solely offer QPSK operation. By the same token, other terminal categories support the same peak rate but define different hybrid-ARQ buffer sizes.

Figure 9
Efficient sharing of resources between DCH and HS-DSCH. The top two graphs show the carrier power of two cells where voice and streaming services are carried on DCH (blue), and a web-browsing service on HS-DSCH (red). The HS-DSCH traffic makes use of the carrier power not used by DCH and CCCH. The bottom graph shows the throughput of the two cells and system.



Another differentiator is the inter-TTI interval, which determines how often the terminal can be scheduled. For example, if the inter-TTI is 3, then the terminal can be scheduled, at most, every third TTI. To some extent, a large inter-TTI alleviates the processing load imposed on the terminal.

A key aspect of the HSDPA design philosophy is rapid retransmission. The terminal is therefore required to process HS-DSCH bits within 5 ms and transmit acknowledge (ACK) or negative acknowledge (NACK) on the uplink HS-DPCCH. Support for hybrid-ARQ with soft-combining is mandatory for all terminal categories, and depending on the category, as many as 172,800 soft channel bits must be buffered. The amount of buffering required in the digital baseband, and the need for high-speed baseband processing, are the main design challenges for terminals that support high-speed data rates.

Reception of up to four HS-SCCHs, as mandated by 3GPP specifications, requires additional baseband processing compared to Release 99. However, the associated increase in complexity is moderate, although a power-efficient design is desirable.

In highly dispersive radio environments, the main factor limiting performance is self-interference from multipath propagation, which limits the obtainable carrier-to-interference ratio and reduces the number of occasions for which 16QAM can be used. In time-dispersive scenarios, performance (capacity) losses can be partially compensated for using advanced receivers that suppress self-interference. One such receiver is the G-RAKE, which employs the same structure as the RAKE receiver

TABLE 1 TWELVE CATEGORIES OF HS-DSCH-CAPABLE TERMINALS.

Category	Maximum number of supported HS-DSCH codes	Minimum inter-TTI interval	Number of soft values in terminal's hybrid ARQ buffer	L1 peak rate [Mbit/s]	Modulation schemes
Category 1	5	3	19,200	1.2	16QAM, QPSK
Category 2	5	3	28,800	1.2	16QAM, QPSK
Category 3	5	2	28,800	1.8	16QAM, QPSK
Category 4	5	2	38,400	1.8	16QAM, QPSK
Category 5	5	1	57,600	3.6	16QAM, QPSK
Category 6	5	1	67,200	3.6	16QAM, QPSK
Category 7	10	1	115,200	7.3	16QAM, QPSK
Category 8	10	1	134,400	7.3	16QAM, QPSK
Category 9	15	1	172,800	10.0	16QAM, QPSK
Category 10	15	1	172,800	14.0	16QAM, QPSK
Category 11	5	2	14,400	0.9	QPSK
Category 12	5	1	28,800	1.8	QPSK

and is therefore easily incorporated into current RAKE implementations. The use of link adaptation gives terminal manufacturers incentive to implement more advanced receivers, since they support higher end-user data rates than standard receivers. This is in contrast to power-controlled channels, where the use of an advanced receiver in the terminal mainly benefits the system in terms of reducing average transmitted power.

In summary, the functionality required in an HSDPA-enabled terminal is based to a large extent on existing Release 99 functionality. This simplifies and speeds up terminal development. Furthermore, there is an incentive for terminal manufacturers to produce advanced receiver structures that fully exploit the data rates made possible by HSDPA services. This also benefits DCH services in terms of lower average transmit power in the RBS.

Conclusion

The evolution of WCDMA, most notably the inclusion of HSDPA in Release 5 of the specifications, significantly improves the support of best-effort packet data.

The basic design principles behind the HS-DSCH and their enhancements to performance have been evaluated and estimated through simulations and found to improve the performance of end-user applications and system capacity.

The modular architecture of Ericsson's line of WCDMA products facilitates a successive increase in performance and allows operators to satisfy customer demands in a cost-effective manner.