

BASIC CONCEPTS OF HSPA

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White Paper

HSPA is a vital part of WCDMA evolution and provides improved end-user experience as well as cost-efficient mobile/wireless broadband.

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1 Executive summary

WCDMA is evolving to enable higher bit-rates and throughput. The first step is to improve the downlink by introducing High Speed Downlink Packet Access (HSDPA). The second step is to improve the uplink by introducing Enhanced Uplink. Together these two technologies are known as High Speed Packet Access (HSPA).

HSPA improves the end-user experience by:

- increasing peak data rates to 14 Mbit/s in the downlink and 5.8 Mbit/s in the uplink
- reducing latency
- providing up to five times more system capacity in the downlink and up to twice as much system capacity in the uplink, reducing the production cost per bit

These capabilities will benefit operators by providing higher performance, and improving end-user experience for web access, file download/upload, voice over IP (VoIP) and streaming services.

HSPA makes mobile/wireless broadband a reality.

2 Introduction

One of the most important aspects of third-generation (3G) mobile systems is enhanced packet data access. WCDMA 3GPP Release 99 provides data rates of 384 kbit/s for wide-area coverage. However, as the use of packet data services increases and new services are introduced, higher speed and greater capacity are required – at a lower production cost.

WCDMA 3GPP Release 5 extends the specification with, among other things, a new downlink transport channel that enhances support for high-performance packet data applications. The production cost per bit will be reduced since the enhanced downlink provides a considerable increase in capacity compared with Release 99. It also significantly reduces latency and provides peak data rates of up to 14 Mbit/s. This enhancement, which commonly goes under the abbreviation HSDPA (High Speed Downlink Packet Access), is the first step in the evolution of WCDMA performance.

Although a lot of traffic is downlink oriented, there are still quite a number of applications that will benefit from an improved uplink. These include the sending of large e-mail attachments, pictures, video clips, blogs etc. WCDMA 3GPP Release 6 introduces, among other things, a new transport channel in the uplink. This Enhanced Uplink – also known as HSUPA (High Speed Uplink Packet Access) – provides higher throughputs, reduced latency and increased capacity. A peak data rate of up to 5.8 Mbit/s can be provided with Enhanced Uplink.

Together HSDPA and Enhanced Uplink are known as High Speed Packet Access (HSPA). The first part of this paper describes the benefits of these enhancements for operators and end-users. The second part describes the basic principles of HSDPA and Enhanced Uplink.

3 Operator and end-user benefits

The primary benefit of HSPA is improved end-user experience. In practice, this means shorter download and upload times as a result of higher bit-rates and reduced latency compared to WCDMA 3GPP Release 99. HSPA also benefits operators by reducing the production cost per bit through greater system capacity. In other words, more users can be served with higher bit-rates at a lower production cost.

3.1 Improved end-user experience

As with any telecommunications technology, end-user performance with HSPA depends on the type of service and the behavior of higher-layer application protocols. For instance, TCP (Transmission Control Protocol), 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.

For web browsing services, for example, the perceived data rates are often limited by TCP and not the air interface. TCP transmission consists of sudden bursts of traffic followed by relatively long idle periods. Hence, system load from a user browsing the web is relatively light. The main end-user benefit of HSPA for small objects transported via TCP is reduced round-trip time, thanks to fast hybrid-ARQ (Automatic Repeat reQuest) and short TTI (Transmission Time Interval). Fast hybrid-ARQ and TTI are further discussed in Chapter 4.

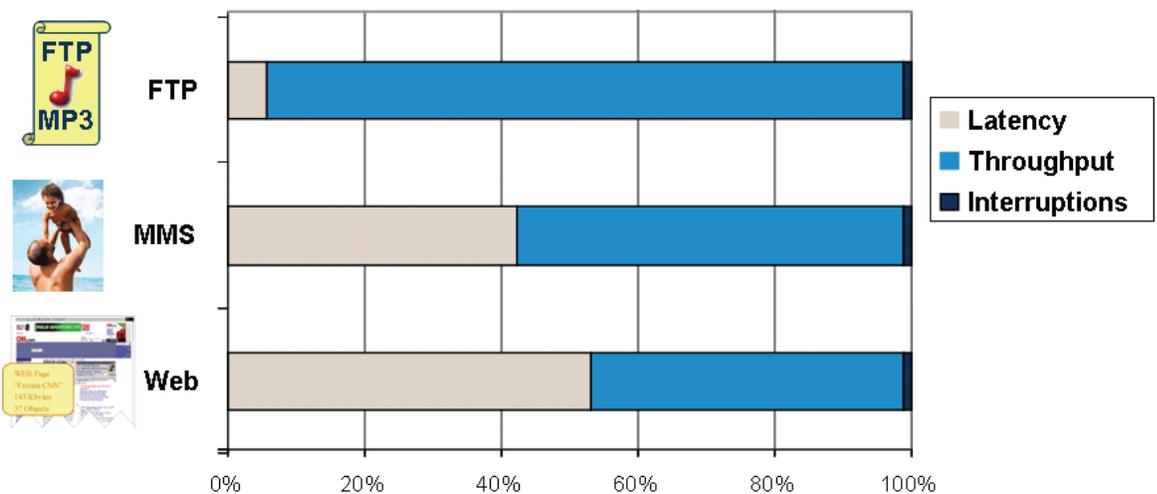


Figure 1) Contribution to user experience for different type of services for WCDMA Release 99

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 end-user performance is largely determined by the data rate of the radio link, as illustrated in Figure 1. A single user downloading a large file can occupy a significant amount of the total cell capacity. Consequently, system load has a substantial impact on the perceived performance when end-users download large files. Simulations show that in a moderately loaded system, HSPA can reduce the time it takes to download large files by a factor of 20 and to upload large files by a factor of 10.

End-to-end latency – which is the average time it takes for a small IP packet to travel from a UE (User Equipment) through the HSDPA system to an Internet server and back – is a critical component that affects end-user perception of TCP/IP-based applications. Latency has been measured in numerous commercial HSDPA networks. The measured average end-to-end latency in a commercial network with core and radio equipment from Ericsson was below 70 ms. With the full introduction of Enhanced Uplink in the network, Ericsson predicts that this latency will be reduced to below 50 ms.

3.2 Improved system capacity

A further benefit of HSPA is greater system capacity. For the operator, this means reduced production cost per bit. HSPA increases capacity in several ways:

- Shared-channel transmission, which results in efficient use of available code and power resources in WCDMA
- A shorter TTI, which reduces round-trip time and improves the tracking of fast channel variations
- Link adaptation, which maximizes channel usage and enables the base station to operate close to maximum cell power
- Fast scheduling, which prioritizes users with the most favorable channel conditions
- Fast retransmission and soft-combining, which further increase capacity
- 16QAM (Quadrature Amplitude Modulation), which yields higher bit-rates

Depending on the deployment scenario, the combined capacity gain over WCDMA 3GPP Release 99 is up to five-fold in the downlink and up to two-fold in the uplink.

3.3 Integral part of WCDMA

Another benefit of HSPA is that it is an integral part of WCDMA. Wide-area mobile coverage can be provided with HSPA: it does not need any additional spectrum or carriers. Currently, WCDMA can provide simultaneous voice and data services (multi-services) to users on the same carrier. This also applies to HSPA, which means that spectrum can be used efficiently.

4 High Speed Downlink Packet Access

In WCDMA 3GPP Release 5, HSDPA adds a new transport channel to WCDMA– the High Speed Downlink Shared Channel (HS-DSCH) – which provides enhanced support for high-performance packet data applications in the downlink.

HSDPA transmission facilitates several new features, and to support them with minimal impact on the existing radio interface protocol architecture, a new MAC sub-layer, MAC-hs, has been introduced. MAC-hs enables a functional split to be retained between layers and nodes from WCDMA 3GPP Releases 99 and 4.

Minimizing architectural changes enables a smooth upgrade to HSDPA, and ensures HSDPA operation in environments where not all cells have HSDPA functionality. In WCDMA, both voice and data services can run simultaneously on the same frequency carrier. Services that run on HSDPA can also use the same frequency carrier.

HSDPA is based on ‘fat-pipe’, shared-channel transmission. Its key features are:

- Shared channel and multi-code transmission
- Higher-order modulation
- Short Transmission Time Interval (TTI)
- Fast link adaptation
- Fast scheduling
- Fast hybrid Automatic Repeat reQuest (ARQ)

The general principles behind these features are described below.

4.1 The concept of HSDPA

Shared channel and multi-code transmission

HSDPA is based on shared channel transmission, which means that some channel codes and the transmission power in a cell are seen as a common resource that is dynamically shared between users in the time and code domains.

Shared channel transmission results in more efficient use of available codes and power resources in WCDMA compared with the use of a dedicated channel (WCDMA 3GPP Release 99).

The shared code resource on to which the HS-DSCH is mapped consists of up to 15 codes. The actual number employed depends on the number of codes supported by the terminal or system, operator settings and system capacity. A fixed value can be set or algorithms for dynamic behavior can be introduced to maximize the code utilization on a shared Release 99/HSDPA carrier.

Figure 2 shows an example of how codes are dynamically allocated per TTI to one or more users.

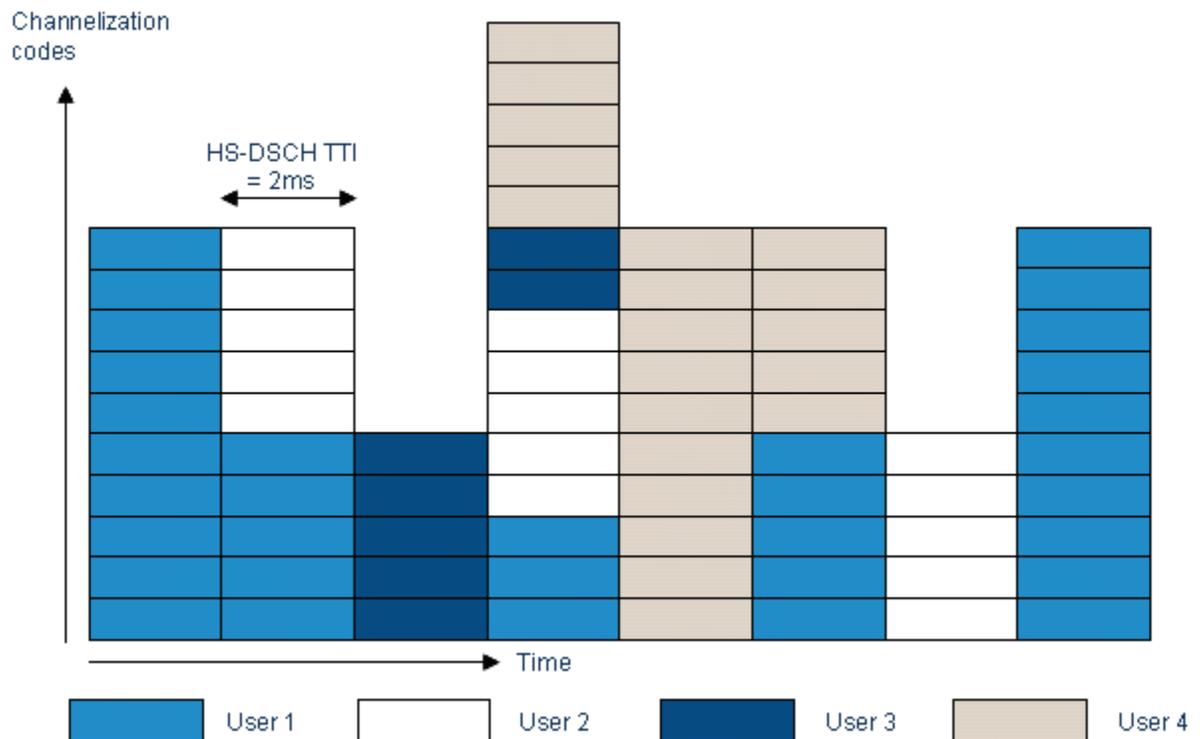


Figure 2) HS-DSCH code and time structures.

Higher-order modulation

WCDMA 3GPP Release 99 uses Quadrature Phase Shift Keying (QPSK) modulation for downlink transmission. Besides QPSK, HSDPA can also use 16 Quadrature Amplitude Modulation (16QAM) to provide higher data rates. Because 16QAM has twice the peak rate capability of QPSK, it makes more efficient use of bandwidth than QPSK. However, it also requires better radio channel conditions than QPSK. QPSK uses two bits per symbol and 16QAM uses four bits per symbol, as illustrated in Figure 3.

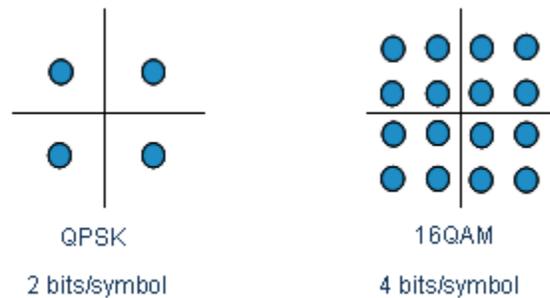


Figure 3) Modulation schemes used with HSDPA.

Short Transmission Time Interval

WCDMA 3GPP Release 99 uses a TTI of 10 ms, 20 ms or 40 ms in the downlink. With HSDPA, the TTI is reduced to 2 ms in the downlink. Channel codes from the shared code resource are dynamically allocated every 2 ms, or 500 times per second. A short TTI reduces round-trip time and improves the tracking of channel variations – a feature that is exploited by link adaptation and channel-dependent scheduling. Although time is the primary way of sharing the ‘fat-pipe’ resource among users, it is also possible to share resources in the code domain by using different subsets of the total HS-DSCH channel code set, as illustrated in Figure 2.

Fast link adaptation

The radio channel conditions experienced by different downlink communication links vary significantly, both in time and between different positions in the cell. Each terminal that uses high-speed services transmits regular channel quality reports to the base station. Fast link adaptation adjusts the transmission parameters instantaneously to the radio conditions reported back by the terminal and, when channel conditions permit, enables the use of high-order modulation.

WCDMA uses power control to compensate for differences and variations in the instantaneous radio channel conditions of the downlink. In principle, power control gives communication links with bad channel conditions a proportionally larger part of the total available cell power. This ensures similar service quality to all communication links, despite differences in radio channel conditions. A disadvantage with power control is that available output power is not always fully used. Some power needs to be reserved to be available for ongoing connections that might need more power in case radio conditions might deteriorate. The surplus of output power cannot be used to increase the system throughput. Therefore, in terms of overall system throughput, power control is not the most efficient means of allocating available resources.

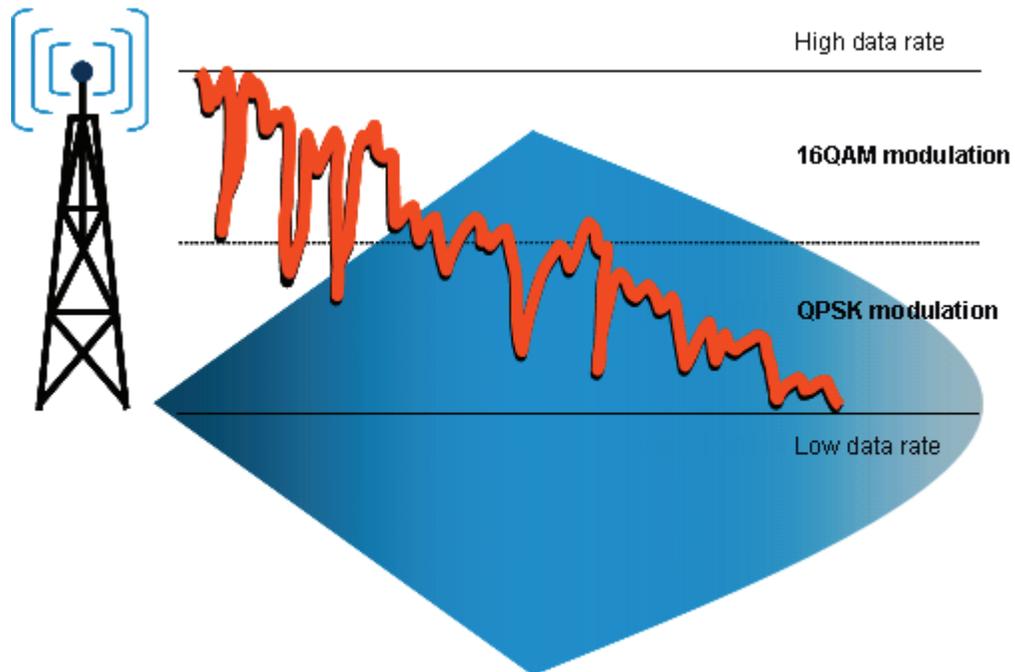


Figure 4) Data rate is adjusted based on instantaneous radio conditions.

Instead of using power control to compensate for rapidly varying radio conditions in the downlink, HSDPA relies on bit-rate adjustment. That is, while keeping transmission power constant, it adjusts the data rate. Commonly known as rate adaptation or link adaptation, this method is more efficient than power control for services that tolerate short-term variations in the data rate. What is more, to further increase peak data rates, HSDPA can use spectral-efficient 16QAM modulation when channel conditions permit, as illustrated in Figure 4.

Fast scheduling

The fast scheduling feature determines the user equipment (UE) the shared channel transmission should be directed to at any given moment. The objective is to transmit to users with favorable radio conditions, as shown in Figure 5.

The scheduler estimates the instantaneous radio conditions of the downlink channel to the terminal. Each terminal that uses high-speed services transmits regular channel quality reports to the base station, and the scheduler determines overall HSDPA performance. For each TTI, the scheduler decides which users the HS-DSCH should be transmitted to, and in close co-operation with the link adaptation mechanism, determines the modulation and number of codes to be used. This yields the actual transmission bit-rate. Instead of sequentially allocating radio resources among users (round-robin scheduling), capacity can be increased significantly using channel-dependent scheduling. The aim of channel-dependent scheduling is to transmit to users with favorable instantaneous channel conditions, which provides a gain known as multi-user diversity.

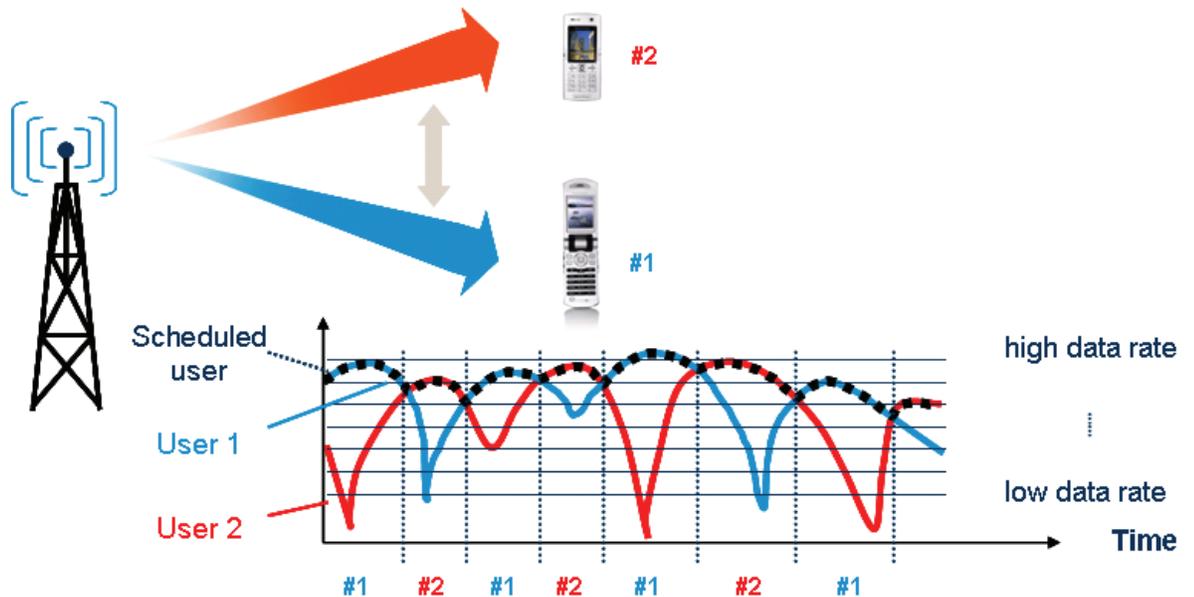


Figure 5) Schedule users with favorable radio conditions.

Another type of channel-dependent scheduling is where users with good radio conditions get all the radio resources assigned to them and users with bad radio conditions get almost no radio resources assigned to them. Although this maximizes system throughput, it could be desirable to add some fairness to this scheme. A proportional fair scheduler better exploits the channel conditions and ensures that all users receive a fair share of the system throughput.

As cell load increases, the number of users queued for scheduling increases. Therefore, the probability of scheduling users with good channel quality also increases. This typically results in a high carrier-to-interference ratio for the scheduled user. Traffic priorities can also be taken into account. For example, streaming services can be prioritized ahead of background users.

A practical scheduling strategy usually exploits short-term variations while maintaining some degree of long-term fairness between users. The differences between various scheduling strategies are most obvious when system load is heavy.

The dedicated uplink and downlink channels of Release 99 use soft handover, while HS-DSCH does not. Implementing soft handover (which by definition implies multiple base stations) for the high-speed channels is not feasible, since fast channel-dependent scheduling is handled by a single base station.

Fast hybrid Automatic Repeat reQuest

The UE can rapidly request the retransmission of missing data and combine information from the original transmission with that of the later transmission, before attempting to decode the message. This approach, called soft-combining, improves performance and provides robustness. A negative acknowledge (NACK) reply is sent when data is missing at the receiving end. An acknowledge (ACK) reply is sent when received data is correct. Previously, retransmissions were only handled by the Radio Node Controller (RNC), but with the introduction of HSDPA a part of this functionality has been moved to the base station. This means that functionality resides closer to the air interface and latency is reduced.

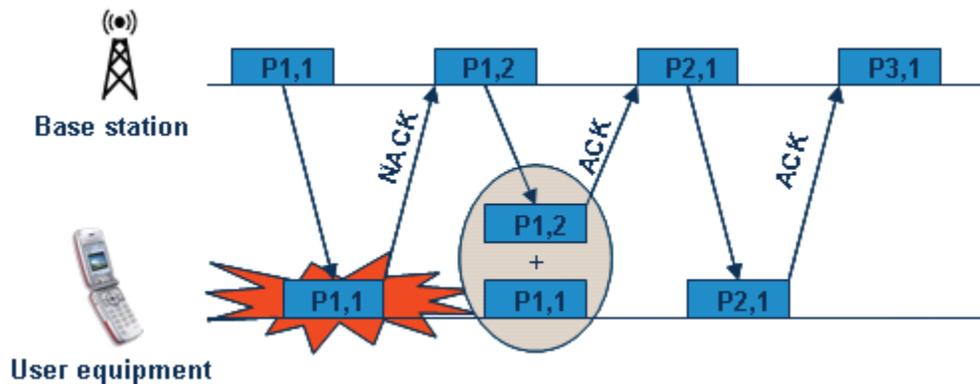


Figure 6) The UE rapidly request the retransmission of missing data.

4.2 HSDPA terminal categories

HSDPA requires new UEs. An HSDPA-enabled UE must contain the processing power to handle fast hybrid ARQ, multi-code processing, etc. Twelve different terminal categories have been defined to accommodate low- and high-end implementations, as shown in Table 1.

Differentiators between terminal categories include, for instance, the support of modulation scheme QPSK and/or 16QAM. Categories 6 and 12 support 3.6 Mbit/s and 1.8 Mbit/s respectively, with five HS-DSCH codes. Another differentiator is the number of codes supported by the UE. For instance a UE that supports ten codes can achieve up to 7.2 Mbit/s where a 15-code UE supports speeds of up to 14 Mbit/s.

The initial HSDPA devices were based on Category 12 and support a maximum bit-rate on Layer 1 of 1.8 Mbit/s. Already, Category 6 data cards and handheld devices are being introduced, which increase the speed to 3.6 Mbit/s. Category 8 devices, introduced in the first quarter of 2007, offer peak data rates of 7.2 Mbit/s.

| UE Category | Maximum number of HS-DSCH codes | Layer 1 peak rate (Mbps) | Minimum inter TTI interval | QPSK/ 16QAM |
|-------------|---------------------------------|--------------------------|----------------------------|-------------|
| Category 1 | 5 | 1.2 | 3 | Both |
| Category 2 | 5 | 1.2 | 3 | Both |
| Category 3 | 5 | 1.8 | 2 | Both |
| Category 4 | 5 | 1.8 | 2 | Both |
| Category 5 | 5 | 3.6 | 1 | Both |
| Category 6 | 5 | 3.6 | 1 | Both |
| Category 7 | 10 | 7.2 | 1 | Both |
| Category 8 | 10 | 7.2 | 1 | Both |
| Category 9 | 15 | 10.2 | 1 | Both |
| Category 10 | 15 | 14.4 | 1 | Both |
| Category 11 | 5 | 0.9 | 2 | QPSK |
| Category 12 | 5 | 1.8 | 1 | QPSK |

Table 1) HSDPA terminal categories

5 Enhanced Uplink

Introduced in WCDMA 3GPP Release 6, Enhanced Uplink adds a new transport channel to WCDMA called Enhanced Dedicated Channel (E-DCH). Enhanced Uplink improves uplink performance with reduced latency, increased data rates and increased capacity, making it a natural complement to HSDPA (introduced in Release 5) for high-performance packet data applications.

Enhanced Uplink transmission provides several new features. As with HSDPA, introducing these new features has minimal impact on the existing radio interface protocol architecture. New MAC entities are also introduced alongside the existing ones in the UE, base station and the RNC.

High uplink bit-rates are desirable from both system and end-user perspectives. It is also very important that a relatively high data rate is likely to be supported wherever a user is located – that is, coverage of a given data rate should be as high as possible. As with HSDPA, Enhanced Uplink can use the same frequency carrier as Release 99.

In order to meet these targets, Enhanced Uplink supports several new features:

- Multi code transmission
- Short Transmission Time Interval
- Fast hybrid Automatic Repeat reQuest
- Fast scheduling

While similar techniques have been applied for HSDPA, there are some fundamental differences between the uplink and the downlink. The shared resource in the uplink is the interference (total received power) at the base station, which depends on the decentralized power resource in each UE. In the downlink, the shared resource consists of transmission power and channelization codes, and is centralized to the base station. This difference has implications for scheduler design.

5.1 The concept of Enhanced Uplink

Multi code transmission

In contrast to HSDPA, the new uplink channel that is introduced for Enhanced Uplink is not shared between users, but is dedicated to a single user. Up to four codes can be used to increase the uplink data rate, as illustrated in Table 2.

Short Transmission Time Interval

WCDMA 3GPP Release 99 uses a TTI of 10 ms, 20 ms or 40 ms in the uplink. Enhanced Uplink operates with a TTI of 2 ms or 10 ms in the uplink. A short TTI enables significant reduction in overall latency and provides the means for the other features to adapt rapidly.

Fast hybrid Automatic Repeat reQuest

The fast hybrid ARQ protocol used is similar to the one used for HSDPA. The base station can rapidly request retransmission of erroneously received data, which provides better robustness and lower retransmission latencies.

Soft(er) handover is possible with Enhanced Uplink. For a soft(er) handover, all involved base stations and sectors attempt to decode the data. If an ACK is received from at least one of them, the UE considers the data to be successfully received.

Fast hybrid ARQ with soft combining can be exploited not only to provide robustness against unpredictable interference, but also to improve link efficiency.

Fast scheduling

In the uplink, the common resource shared among the terminals is the amount of tolerable interference; that is, the total received power at the base station. The amount of common uplink resources a terminal is using depends on the data rate used. Generally, the higher the data rate, the larger the required transmission power and the higher the resource consumption.

Fast scheduling enables rapid resource reallocation between UEs, exploiting the 'burstiness' in packet data transmissions. It also enables the system to admit a larger number of high-data rate users and rapidly adapts to interference variations – leading to an increase both in capacity and the likelihood that a user will experience high data rates.

The scheduling algorithm is not standardized and different scheduling strategies can be implemented. This flexibility is useful, as different environments and traffic types can have different requirements on the scheduling strategy.

A UE can, for instance, be scheduled from just one base station or from several base stations at the same time. In the latter case, soft handover must be supported for Enhanced Uplink. The UE is not only informed about the interference level in the own cell, but also about interference levels in the neighboring cells. The output power of the UE can be reduced if the interference level is too high in neighboring cells. Soft handover support in the uplink also provides a macro diversity gain of 1.5 dB.

5.2 Enhanced Uplink terminal categories

Enhanced Uplink will require new UEs, which must have the processing power to handle the new functionality described above. Six different terminal categories have been defined to accommodate low- and high-end implementations, as shown in Table 2.

| UE Category | Codes x spreading | TTI 10 or 2 ms | Layer 1 peak rate 10 ms TTI | Layer 1 peak rate 2 ms TTI |
|-------------|----------------------|----------------|-----------------------------|----------------------------|
| Category 1 | 1 x SF4 | 10 ms | 0.73 Mbps | - |
| Category 2 | 2 x SF4 | Both | 1.46 Mbps | 1.46 Mbps |
| Category 3 | 2 x SF4 | 10 ms | 1.46 Mbps | - |
| Category 4 | 2 x SF2 | Both | 2.0 Mbps | 2.92 Mbps |
| Category 5 | 2 x SF2 | 10 ms | 2.0 Mbps | - |
| Category 6 | 2 x SF2 + 2 x SF4 | Both | 2.0 Mbps | 5.76 Mbps |

Table 2) Enhanced Uplink terminal categories.

Differentiators between terminal categories include the TTI time supported. Some categories support TTI of only 10 ms, while others support both 2 ms and 10 ms. Another differentiator is the number of codes used and their spreading factor.

The initial Enhanced Uplink devices are based on Category 3 and support a maximum bit-rate on Layer 1 of 1.4 Mbit/s. The first commercial devices are expected in the first half of 2007.

6 High Speed Packet Access evolution

HSPA is evolving further over time. Different enhancements are being introduced in different 3GPP releases.

With HSPA evolved, higher-order modulation can be supported in both the uplink (16QAM) and downlink (64QAM). 16QAM modulation enables peak data rates of up to 12 Mbit/s in the uplink, while 64QAM modulation enables peak data rates of up to 21 Mbit/s in the downlink.

In addition, 2x2 MIMO (Multiple Input Multiple Output) is supported in the downlink with HSPA evolved. This uses two antennas to effectively double the peak rate on the downlink; that is, enabling a peak data rate of 28 Mbit/s. When 2x2 MIMO is combined with 64QAM, a peak data rate of up to 42 Mbit/s is enabled in the downlink. Latency will also be further reduced with HSPA evolved.

7 Conclusion

WCDMA is evolving, and the first step is to improve the downlink using HSDPA. This greatly improves the end-user experience by increasing bit-rates to as much as 14 Mbit/s in the downlink, reducing latency and increasing system capacity up to five-fold. Further improvements are made with the introduction of Enhanced Uplink. This increases the bit-rate in the uplink to as much as 5.8 Mbit/s, reduces latency further and increases system capacity two-fold.

Currently, WCDMA can provide voice and data services on the same carrier simultaneously. No new spectrum or carriers are needed to roll out HSPA in the network.

With the advantages of HSPA, WCDMA will further enable operators to provide end-users with more advanced mobile/wireless broadband applications, with wide-area coverage and mobility.

8 Glossary

| | |
|----------------|--|
| 16QAM | 16 Quadrature Amplitude Modulation |
| 3GPP | Third Generation Partnership Project |
| 64QAM | 64 Quadrature Amplitude Modulation |
| ACK | Acknowledge |
| ARQ | Automatic Repeat reQuest |
| E-DCH | Enhanced Dedicated Channel |
| HS-DSCH | High Speed Downlink Shared Channel |
| HSDPA | High Speed Downlink Packet Access |
| HSPA | High Speed Packet Access |
| HSUPA | High Speed Uplink Packet Access |
| MAC | Medium Access Control |
| MIMO | Multiple Input Multiple Output |
| NACK | Negative Acknowledge |
| QPSK | Quadrature Phase Shift Keying |
| RNC | Radio Node Controller |
| TCP | Transmission Control Protocol |
| TTI | Transmission Time Interval |
| UE | User Equipment |
| WCDMA | Wideband Code Division Multiple Access |