HSDPA for Improved Downlink Data Transfer

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Executive Summary

Data services are expected to have significant growth over the next few years and will likely become the dominant source of 3G traffic and revenue. The current 3G operators in Japan and Korea are already experiencing great success with their data services. For example, DoCoMo's WCDMA-FOMA service is already generating more than 20 percent of the total revenue with 4+ millions subscribers (through May 2004) despite a modest start in 2001. SKT (South Korean Telecom) has reported that 34 percent of its ARPU was related to data usage for Q3-03 particularly after the deployment of 1xEV-DO.

In order to meet the increasing demand for high data-rate multimedia services, the 3rd Generation Partnership Project (3GPP) has released* a new high-speed data transfer feature named High-Speed Downlink Packet Access (HSDPA).

HSDPA provides impressive enhancements over WCDMA R'99 for the downlink. It offers peak data rates of up to 10 Mbps, resulting in a better end-user experience for downlink data applications, with shorter connection and response times. More importantly, HSDPA offers three- to five-fold sector throughput increase, which translates into significantly more data users on a single frequency (or carrier). The substantial increase in data rate and throughput is achieved by implementing a fast and complex channel control mechanism based upon short physical layer frames, Adaptive Modulation and Coding (AMC), fast Hybrid-ARQ and fast scheduling.

HSDPA higher throughputs and peak data rates will help stimulate and drive consumption of data-intensive applications that cannot be supported by R'99. In fact, HSDPA allows a more efficient implementation of interactive and background Quality of Service (QoS) classes, as standardized by 3GPP. HSDPA high data rates improve the use of streaming applications, while lower roundtrip delays will benefit Web browsing applications. Another important benefit of HSDPA is its backwards compatibility with R'99. This makes its deployment very smooth and gradual on an as needed basis.

The deployment of HSDPA is very cost effective since the incremental cost is mainly due to Node Bs (or BTS) and RNC (Radio Network Controller) software/hardware upgrades. In fact, in a capacity-limited environment (high subscriber density and/or data-traffic volume per subscriber), the network cost to deliver a megabyte of data traffic is about three cents for a typical dense urban environment, as opposed to seven cents for R'99 assuming an incremental cost of 20 percent.

The ability to offer higher peak rates for an increasingly performance-demanding end-user at a substantially lower cost will create a significant competitive advantage for HSDPA operators. Supporting rich multimedia applications and content and more compelling devices at lower user costs will enable early adopters to differentiate themselves with advanced services, resulting in higher traffic per user and increased subscriber growth, data market share and profitability.

* Release 5

1.0 HSDPA Concept and Key Features

R'99 already includes three different channels for downlink packet data transmission: Dedicated Channel (DCH), Downlink-Shared Channel (DSCH) and Forward Access Channel (FACH). The FACH is a common channel offering low latency. However, it is not efficient since it does not support fast closed loop power control. It is therefore limited to carrying only small amounts of data traffic. The DCH is the primary data channel and can be used for any traffic class. In the downlink, the DCH is allocated a certain orthogonal variable spreading factor (OVSF: 4-512) according to the connection peak data rate[7], while the block error rate (BLER) is controlled by inner and outer loop power control. The DCH code and power allocation are therefore inefficient for bursty and low duty cycle data applications since channel re-allocation can be very slow (in the range of 500 ms)[5]. The DSCH provides the possibility to time-multiplex different users, improving the channel re-allocation time[5].

The HSDPA concept can be seen as an extension of the DSCH with the introduction of new features such as Adaptive Modulation and Coding (AMC), short frames, multi-code operation, fast L1 Hybrid-ARQ (HARQ) and Node B scheduling. In fact, these features replace the two basic WCDMA features, namely Variable Spreading Factor (VSF) and fast power control[5]. This section explains HSDPA key features.

1.1 HSDPA New Channel Structure

A new transport channel named High-Speed Downlink Shared Channel (HS-DSCH) has been introduced as the primary radio bearer. Similar to the DSCH, the HS-DSCH resources can be shared between all users in a particular sector. The primary channel multiplexing occurs in the time domain, where each Transmission Time Interval (TTI) consists of three slots (or 2 ms.) The TTI is also referred to as a "sub frame." The TTI has been significantly reduced from the 10, 20, 40 or 80 ms TTI sizes supported in R'99 in order to better achieve short round trip delay between the UE (User Equipment) and the Node B, and improve the link adaptation rate and efficiency of the AMC (cf. section 1.2).

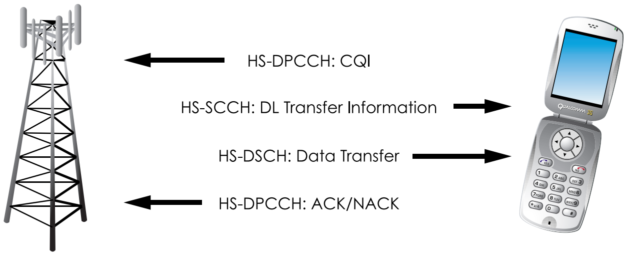
Within each 2 ms TTI, a constant Spreading Factor (SF) of 16 is used for code multiplexing, with a maximum of 15 parallel codes allocated to the HS-DSCH. These codes may all be assigned to one user during the TTI, or may be split across several users. The number of parallel codes allocated to each user depends on cell loading, QoS requirements and the UE code capabilities (five, 10 or 15 codes).

In order to support the HS-DSCH operation, two control channels have been added: the High-Speed Shared Control Channel (HS-SCCH) and the High-Speed Dedicated Physical Control Channel (HS-DPCCH).

The HS-SCCH is a fixed rate (60 kbps, SF=128) channel used for carrying downlink signaling between the Node B and the UE before the beginning of each scheduled TTI. This includes the UE identity (via a UE-specific CRC), HARQ-related information and the parameters of the HS-DSCH transport format selected by the link-adaptation mechanism. Multiple HS-SCCHs can be configured in each sector to support parallel HS-DSCH transmissions. A UE can be allocated a set of up to four HS-SCCHs, which it needs to monitor continuously. In any given TTI, a maximum of one of these HS-SCCHs may be addressed to a particular UE. When a UE detects a message addressed to it on a specific HS-SCCH, it may restrict its monitoring of HS-SCCHs to only that HS-SCCH in the next TTI[3], therefore reducing the complexity of the UE.

The HS-DPCCH (SF=256) carries ACK/NACK signaling indicating whether the corresponding downlink transmission was successfully decoded, as well as a Channel Quality Indicator (CQI) to be used for the purpose of link adaptation. The CQI is based on the Common Pilot Channel (CPICH) and is used to estimate the transport block size, modulation type and number of channelization codes that can be supported at a given reliability level in case of a downlink transmission. The feedback cycle of the CQI can be set as a network parameter in predefined steps of 2 ms. When longer feedback cycles are used, the PDCH power-control commands can be used to update the channel quality estimate.

Figure 1-1: HSDPA channel operation



1.2 Adaptive Modulation and Coding

Adaptive Modulation and Coding (AMC) is a fundamental feature of HSDPA. It consists of continuously optimizing the code rate, the modulation scheme, the number of codes employed and the transmit power per code based on the channel quality reported (CQI feedback) by the UE.

The HS-DSCH encoding scheme is based on the R'99 rate (1/3 Turbo encoder) but adds rate matching with puncturing and repetition to improve the granularity of the effective code rate (1/4 to 3/4). In order to achieve very high data rates, HSDPA adds a higher order modulation (16QAM) to the existing QPSK modulation used for R'99 channels. Different combinations of modulation and the channel coding-rate (based on the Transport Format and resource combinations or TFRC) can be used to provide different peak data rates (e.g. 119 kbps/code with QPSK and 1/4 code rate, 712 kbps/code with 16QAM and 3/4 code rate). Essentially, when targeting a given level of reliability, users experiencing more favorable channel conditions (e.g. closer to the Node B) will be allocated higher data rates. The HSDPA-capable UE can support the use of five, 10 and 15 multi-codes. A single user can receive up to 15 multi-codes resulting in a potential peak data rate of 10.8 Mbps*. However, the maximum specified peak data rate with HSDPA is 14.4 Mbps (or 960 kbps/code) when 16QAM modulation is used with no coding (effective code rate of one) and 15 multi-codes. Achieving this rate in a real system remains very unlikely as it would require an unloaded system serving a single user extremely close to the Node B. Figure 1-2 shows the mapping of the data rate at the physical layer and the channel quality (E_C/N_t or C/I) as a result of AMC.

Another benefit of AMC is better utilization of the Node B power. If no power constraints are specified, the leftover power from the dedicated channels (R'99) can be allocated to HS-DSCH resulting in near-maximum power utilization.

1.3 Hybrid-ARQ with Soft Combining

The retransmission mechanism selected for HSDPA is Hybrid Automatic Repeat Request (HARQ) with Stop and Wait protocol (SAW). HARQ allows the UE to rapidly request retransmission of erroneous transport blocks until they are successfully received. HARQ functionality is implemented at the MAC-hs (Media Access Control high speed**) layer, which is terminated

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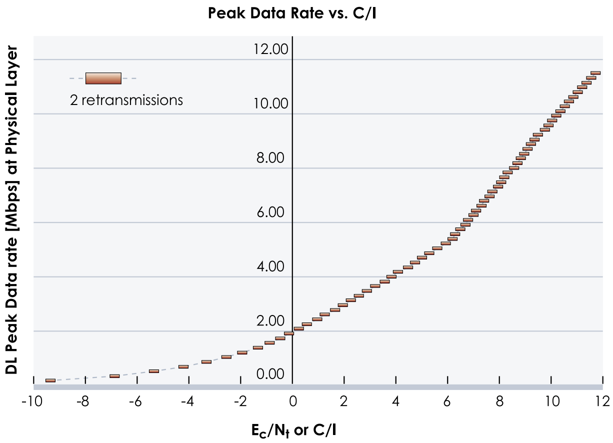
* Assuming an inter-TTI=1
** New MAC sub-layer for HSDPA

Figure 1-2: Peak data rate vs. C/I as a result of AMC. The graph corresponds to a 10 km/h multi-path channel model, 80 percent of Node B power allocated to HSDPA and two retransmissions per packet (Source: QUALCOMM)



at the Node B, as opposed to the RLC (Radio Link Control), which is terminated at the S-RNC (Serving-RNC). Therefore the retransmission delay of HSDPA is much lower than for R'99. In normal circumstances, a NACK may require less than 10 ms at the MAC layer, while it can take up to 100 ms at the RLC layer when I_{ub} signaling is involved[9]. This significantly reduces the delay jittering for TCP/IP and delay sensitive applications.

In order to better use the waiting time between acknowledgments, multiple processes can run for the same UE using separate TTIs. This is referred to as N-channel SAW (N=up to six for Advanced Node B implementation). While one channel is awaiting an acknowledgment, the remaining N-1 channels continue to transmit.

With HARQ, the UE does not discard the energy from failed transmissions; the UE stores and later combines it with the retransmission(s) to increase the probability of successful decoding. This is a form of soft combining. HSDPA supports both Chase Combining (CC) and Incremental Redundancy (IR). CC is the basic combining scheme. It consists of the Node B simply retransmitting the exact same set of coded symbols of the original packet. With IR, different redundancy information can be sent during re-transmissions, thus incrementally increasing the coding gain. This can result in fewer retransmissions than for CC and is particularly useful when the initial transmission uses high coding rates (e.g. 3/4)[5]. However, it results in higher memory requirements for the UE.

1.4 Fast Scheduling

The scheduler is a key element of HSDPA that determines the overall behavior of the system and, to a certain extent, its performance.
For each TTI, it determines which terminal (or terminals) the HS-DSCH should be transmitted to and, in conjunction with the AMC, at which data rate. One important change from R'99 channels is that the scheduler is located at the Node B as opposed to the RNC. In conjunction with the short TTI (2 ms) and the CQI feedback, this enables the scheduler to quickly track the UE channel condition and adapt the data rate allocation accordingly. Several algorithms can be used for the scheduler. Some of them are presented below: Round Robin (RR), Maximum Carrier to Interference (C/I) and Proportional Fair (PF).

RR schedules users according to a first-in first-out approach. It provides a high degree of fairness between the users, but at the expense of the overall system throughput (and therefore spectral efficiency), since some users can be served even when they are experiencing destructive fading (weak signal).

The maximum C/I scheme schedules users with the highest C/I during the current TTI. This naturally leads to the highest system throughput since the served users are the ones with the best channel. However, this scheme makes no effort to maintain any kind of fairness among users. In fact, users at the cell edge will be largely penalized by experiencing excessive service delays and significant outage. The PF scheme offers a good trade-off between RR and maximum C/I. The PF schedules users according to the ratio between their instantaneous achievable data rate and their average served data rate. This results in all users having equal probability of being served even though they may experience very different average channel quality. This scheme provides a good balance between the system throughput and fairness.

It is important to mention that the implementation of QoS (i.e. different subscription classes) creates new constraints on the scheduler. Other parameters such as user priority level may override the above scheduling algorithms. The fairness between the users will then be dominated by the QoS requirements.

1.5 Mobility

Unlike R'99, HSDPA does not use soft handover. Instead, a hard handover algorithm has been proposed to switch between Node Bs because it was simple to support. The UE continuously monitors all the Node Bs in its active set and reports to UTRAN when a change in the best cell occurs. The UTRAN would then re-configure the serving HS-DSCH cell using either synchronous (provides shortest service interruption) or asynchronous (provides shortest handover time) re-configurations.

Both inter-Node B and intra-Node B handovers are supported. However, in the case of inter-Node B handover, the MAC-hs buffer would be flushed and the lost data would need to be re-transmitted at the RLC level.

1.6 UE Capabilities

Twelve new categories have been specified by Release 5 for HSDPA UEs (see Table 1-1) according to the following parameters:

- Maximum number of HS-DSCH multi-codes that the UE can simultaneously receive (five, 10 or 15).

- Minimum inter-TTI time, which defines the minimum time between the beginning of two consecutive transmissions to this UE. If the inter-TTI time is one, this means that the UE can receive HS-DSCH packets during consecutive TTIs, i.e. every 2 ms. If the inter-TTI time is two, the scheduler would need to skip one TTI between consecutive transmissions to this UE.

- Maximum number of HS-DSCH transport block bits received within an HS-DSCH TTI. The combination of this parameter and the inter-TTI interval determines the UE peak data rate. For example, the transport block size and the inter-TTI interval for category 11 are 3650 bits and 2 (or 4) ms. This leads to a data rate of 0.9 Mbps.

- The maximum number of soft channel bits over all the HARQ processes. This can impact the UE receiver performance particularly in poor quality locations where the number of retransmissions can be high. 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 channels.

- Supported modulations (QPSK only or both QPSK and 16QAM).

These 12 categories provide a much more coherent set of capabilities as compared to R'99 which gives UE manufacturers freedom to use completely atypical combinations.

Table 1-1: HSDPA UE categories[4]

Category	Codes	Inter-TT1	TB Size	Total # of Soft Bits	Modulation	Data Rate
1	5	3	7300	19200	QPSK/16QAM	1.2 Mbps
2	5	3	7300	28800	QPSK/16QAM	1.2 Mbps
3	5	2	7300	28800	QPSK/16QAM	1.8 Mbps
4	5	2	7300	38400	QPSK/16QAM	1.8 Mbps
5	5	1	7300	57600	QPSK/16QAM	3.6 Mbps
6	5	1	7300	67200	QPSK/16QAM	3.6 Mbps
7	10	1	14600	115200	QPSK/16QAM	7.2 Mbps
8	10	1	14600	134400	QPSK/16QAM	7.2 Mbps
9	15	1	20432	172800	QPSK/16QAM	10.2 Mbps
10	15	1	28776	172800	QPSK/16QAM	14.4 Mbps
11	5	2	3650	14400	QPSK only	0.9 Mbps
12	5	1	3650		QPSK only	1.8 Mbps

2.0 System and End-User Application Performance

2.1 HSDPA Link Budget and Peak Data Rates

Since HSDPA is expected to be overlaid on a WCDMA (R'99) network, the principle of HSDPA link budget is to estimate the maximum data rate achievable in the downlink at the cell edge, assuming that the coverage is uplink limited. An example of WCDMA link budget is shown in Table 2-1. The path loss was calculated for four different morphologies (dense urban, urban, sub-urban and rural) considering 65 percent loading, 90 percent cell edge reliability and 64 kbps Packet Switch Radio Access Bearer (RAB). The resulting cell edge HSDPA data rates are shown in Table 2-2. The HSDPA peak data rate calculation is based upon the main following parameters:

- Path loss as calculated by the WCDMA link budget
- Percentage of Node B's power allocated to HSDPA data users: In this example 80 percent of the power was allocated to HSDPA and the remaining 20 percent for overhead channels. The 80 percent power allocation has been used in previous simulations presented in 3GPP, even though it would be optimistic for initial HSDPA deployments. All 15 codes were assumed to be available for HSDPA.
- Scheduler margin: For HSDPA, the combination of AMC and HARQ allows selecting different operating points based on the initial transmission power. It is therefore possible to adopt either a more conservative strategy using more power, but resulting in fewer retransmissions, or a more aggressive strategy using less power, but resulting in more retransmissions.
- Orthogonality factor: This allows accounting for non-orthogonal interference received by the serving cell because of multi-path.

Table 2-1: WCDMA link budget (Uplink) assuming an UL data rate of 64 kbps with 90 percent cell edge reliability

	Dense Urban	**Urban**	**Suburban**	**Rural**
Network Design Parameters				
Channel Model	TU3 & TU30	TU3 & TU30	TU3 & TU30	RA 3 & RA 120
Service	PS 64	PS 64	PS 64	PS 64
Data Rate	64 kbps	64 kbps	64 kbps	64 kbps
FER	10%	10%	10%	10%
Eb/No	4.3 dB	4.3 dB	4.3 dB	4.6 dB
Ec/Nt	-13.5 dB	-13.5 dB	-13.5 dB	-13.2 dB
UL Loading	65%	65%	65%	65%
Cell Edge Reliability	90%	90%	90%	90%
Area Reliability	96%	96%	97%	97%
Log-Normale Fading Std	12 dB	10 dB	8 dB	6 dB
Log-Normale Fading Margin	15.4 dB	12.8 dB	10.3 dB	7.7 dB
In-Building Penetration	18 dB	15 dB	12 dB	10 dB
Body Loss	1 dB	1 dB	1 dB	1 dB
Soft Handover Gain @ 50% Correlation	3.0 dB	3.0 dB	3.0 dB	3.0 dB
Node B Parameters				
Node B Antenna Gain	18.0 dBi	18.0 dBi	18.0 dBi	18.0 dBi
Node B Cable Losses	3.0 dB	3.0 dB	3.0 dB	3.0 dB
Node B Noise Figure	4.0 dB	4.0 dB	4.0 dB	4.0 dB
Thermal Noise Floor	-173.8 dBm/Hz	-173.8 dBm/Hz	-173.8 dBm/Hz	-173.8 dBm/Hz
Rise Over Thermal at Node B	4.6 dB	4.6 dB	4.6 dB	4.6 dB
Interference Noise Power	-99.4 dBm	-99.4 dBm	-99.4 dBm	-99.4 dBm
Rx Sensitivity	-112.9 dBm	-112.9 dBm	-112.9 dBm	-112.6 dBm
UE Parameters				
UE Tx Power (mW)	126.0 mW	126.0 mW	126.0 mW	126.0 mW
UE Tx Power (dBm)	21.0 dBm	21.0 dBm	21.0 dBm	21.0 dBm
UE Antenna Gain	0.0 dB	0.0 dB	0.0 dB	0.0 dB
UE Tx EIRP	21.0 dBm	21.0 dBm	21.0 dBm	21.0 dBm
Max Path Loss	**117.5 dB**	**123.1 dB**	**128.6 dB**	**132.9 dB**
Cell Radius (Slope Model)	**0.500 km**	**0.825 km**	**2.037 km**	**6.281 km**

Table 2-2: Example of HSDPA link budget

	Dense Urban	**Urban**	**Suburban**	**Rural**
UL WCDMA Network Design				
Channel Model	TU3 & TU30	TU3 & TU30	TU3 & TU30	RA 3 & RA 120
Service	PS 64	PS 64	PS 64	PS 64
Data Rate	64 kbps	64 kbps	64 kbps	64 kbps
Path Loss	117.5 dB	123.1 dB	128.6 dB	132.9 dB
HSDPA Related Parameters				
Overhead Channels (C-PICH, P-CCPCH, S-C)	20%	20%	20%	20%
%Power Allocated to HSDPA	80%	80%	80%	80%
Scheduling Margin	-2.2 dB	-2.2 dB	-2.2 dB	-2.2 dB
Interference Factor LOC/LOR @ Cell Edge	1 dB	1 dB	1 dB	1 dB
HS-SCCH Ec/Nt	-19.4 dB	-19.4 dB	-19.4 dB	-19.4 dB
HS-SCCH Margin	5.0 dB	5.0 dB	5.0 dB	5.0 dB
Orthogonality Factor	50.00%	50.00%	50.00%	90.00%
Scheduling Gain	0.0 dB	0.0 dB	0.0 dB	0.0 dB
Average SPER	60%	60%	60%	60%
BTS Parameters				
Node B Antenna Gain	18.0 dBi	18.0 dBi	18.0 dBi	18.0 dBi
BTS Cable Losses	3.0 dB	3.0 dB	3.0 dB	3.0 dB
Body Loss	1 dB	1 dB	1 dB	1 dB
BTS Tx Power (W)	20.0 W	20.0 W	20.0 W	20.0 W
BTS Tx Power (dBm)	43.0 dBm	43.0 dBm	43.0 dBm	43.0 dBm
UE Parameters				
UE Noise Figure	8.0 dB	8.0 dB	8.0 dB	8.0 dB
UE Antenna Gain	0.0 dB	0.0 dB	0.0 dB	0.0 dB
Thermal Noise Floor	-173.8 dBm/Hz	-173.8 dBm/Hz	-173.8 dBm/Hz	-173.8 dBm/Hz
Total Traffic Ec/LOR	-1.0 dB	-1.0 dB	-1.0 dB	-1.0 dB
Control Channel Ec/LOR	-12.0 dB	-11.9 dB	-11.9 dB	-12.8 dB
Available Ec/LOR	-1.3 dB	-1.3 dB	-1.3 dB	-1.3 dB
Max. Ec/Nt	-3.8 dB	-3.8 dB	-3.9dB	-2.9 dB
Max PHY Data-Rate	**2080 kbps**	**2080 kbps**	**1920 kbps**	**2400 kbps**
Max MAC Data-Rate	**832 kbps**	**832 kbps**	**768 kbps**	**960 kbps**

The link budget estimates the user's channel quality (i.e. E_c/N_t) that is then mapped to the maximum achievable physical layer (PHY) data rate (adjusted for RLC overhead). The MAC level data rate accounts for HARQ retransmissions.

Table 2-2 indicates that for 80 percent power allocation to HSDPA and two retransmissions per transport block (typical value), the possible peak data rate at the cell edge for a single user can reach 2 Mbps at the physical layer and 800 kbps at the MAC layer. This represents an impressive improvement over what R'99 can offer at the cell edge. In an actual loaded system, HSDPA user data rates can be at least three times higher than what one can get with the currently deployed WCDMA networks. It is important to note, however, that the peak data rate calculation does not reflect any time-multiplexing, scheduling strategy or UE code capabilities. It simply estimates the maximum data rate that a user can get if all the Node B resources (power and codes) are available.

As mentioned before, the obtained data rates strongly depend on the percentage of power allocated to HSDPA users and E_b/N_0. Since HSDPA and R'99 channels may operate on the same frequency (at least in early deployment phases), the power sharing becomes an important issue for WCDMA (UMTS) operators. A good trade-off between voice capacity, data sector throughput and offered data rates must be found. Figure 2-1 illustrates the impact of HSDPA power allocation on the achievable data rates at the cell edge. It is clear that the highest data rates will be obtained when HSDPA is deployed on a separate frequency. Additional simulations have also shown that the average user throughput across the sector decreases linearly with the percentage of Node B power allocated to HSDPA.

2.2 HSDPA Sector Throughput

The HSDPA sector throughput depends on many parameters, such as Node B system loading, Node B scheduler algorithm, UE capabilities, traffic usage, percentage of power allocated to HSDPA, radio environment (i.e. channel model) and the network layout. Several simulations have been performed by QUALCOMM to estimate the HSDPA sector throughput and its sensitivity to some of the above parameters. It was found that for a typical outdoor urban environment (assuming 75 percent of the users are static or pedestrian and 25 percent are vehicular at 30 km/h), the average sector throughput is 1.8 to 2.2 Mbps for the basic configuration (five codes UE capability, QPSK only and no receive diversity). This result is based on a Proportional Fair scheduler, a full-buffer traffic model and a dedicated HSDPA frequency with 80 percent power for HSDPA users (i.e. 20 percent overhead channels). This corresponds to an almost 200 percent improvement over WCDMA R'99 (700-800 kbps) and 350 percent over EGPRS*.

As shown in Figure 2-2, the sector throughput increases with the UE capabilities. In fact, 15-code capability can improve the sector throughput by an average of 10 percent, while 16QAM modulation can add another six percent to eight percent. Receive diversity, if used, can bring 40 to 55 percent improvement resulting in a sector throughput of 3.2 to 3.6 Mbps. Note that the receive diversity gains derive from internal simulations assuming equal antenna gains and no envelope correlation between the two antennas. In reality, the expected gains might be lower depending on the antenna gain difference (between the primary and the secondary antenna) and the envelope correlation coefficient.

The use of equalization is also expected to further improve the sector throughput by an additional 15 to 25 percent.

* 480 kbps assuming all coding schemes (MCS1-9) and up to four time slots

It is important to note that these simulation results are obtained assuming a proportional fair scheduler that is well known in the industry. However, the scheduler remains proprietary to each infrastructure vendor and it is possible that the initial implementation will be based on a "less polished" type of algorithm. In this case, the sector throughput will be lower.

2.3 Applications and End-User Experience

HSDPA considerably improves the 3G end-user data experience by enhancing downlink performance. As shown in Figure 2-3, HSDPA significantly reduces the time it takes a mobile user to retrieve broadband content from the network. A reduced delay is important for many applications such as interactive games. In general, HSDPA allows a more efficient implementation of "interactive" and "background" Quality of Service (QoS) classes as standardized by 3GPP. HSDPA high data rates also improve the use of streaming applications, while lower roundtrip delays will benefit Web browsing applications. In addition, HSDPA's improved capacity opens the door for new and data-intensive applications that cannot be fully supported with R'99 because of bandwidth limitations (Figure 2-4).

Figure 2-1: HSDPA peak user data rates vs. percentage of Node B power

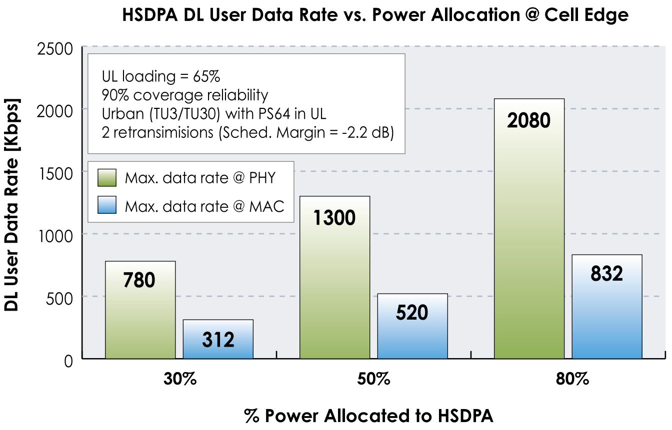


Figure 2-2: HSDPA sector throughput

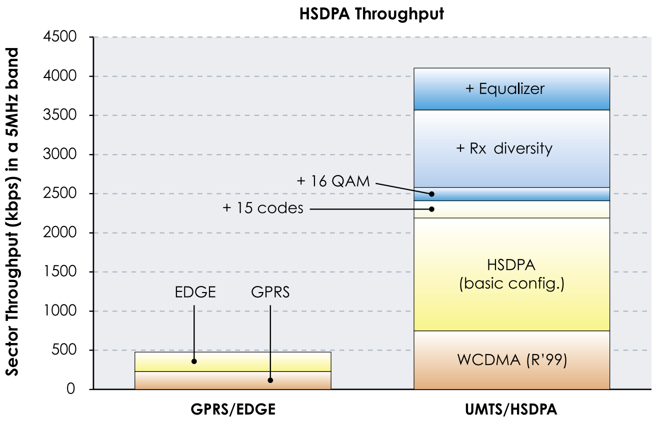
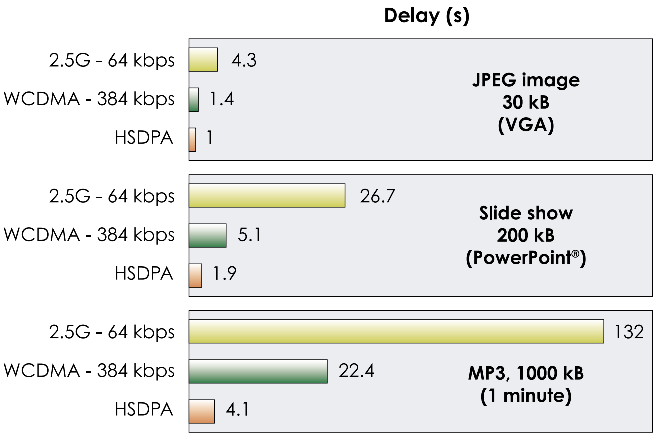
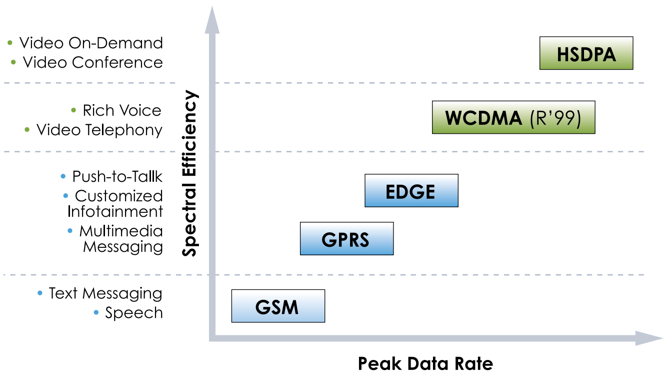


Figure 2-3: Example of user delay experience



Source: Ericsson

Figure 2-4: HSDPA enables new and more efficient applications



Source: UMTS Forum (for service evolution)

3.0 HSDPA Evolution

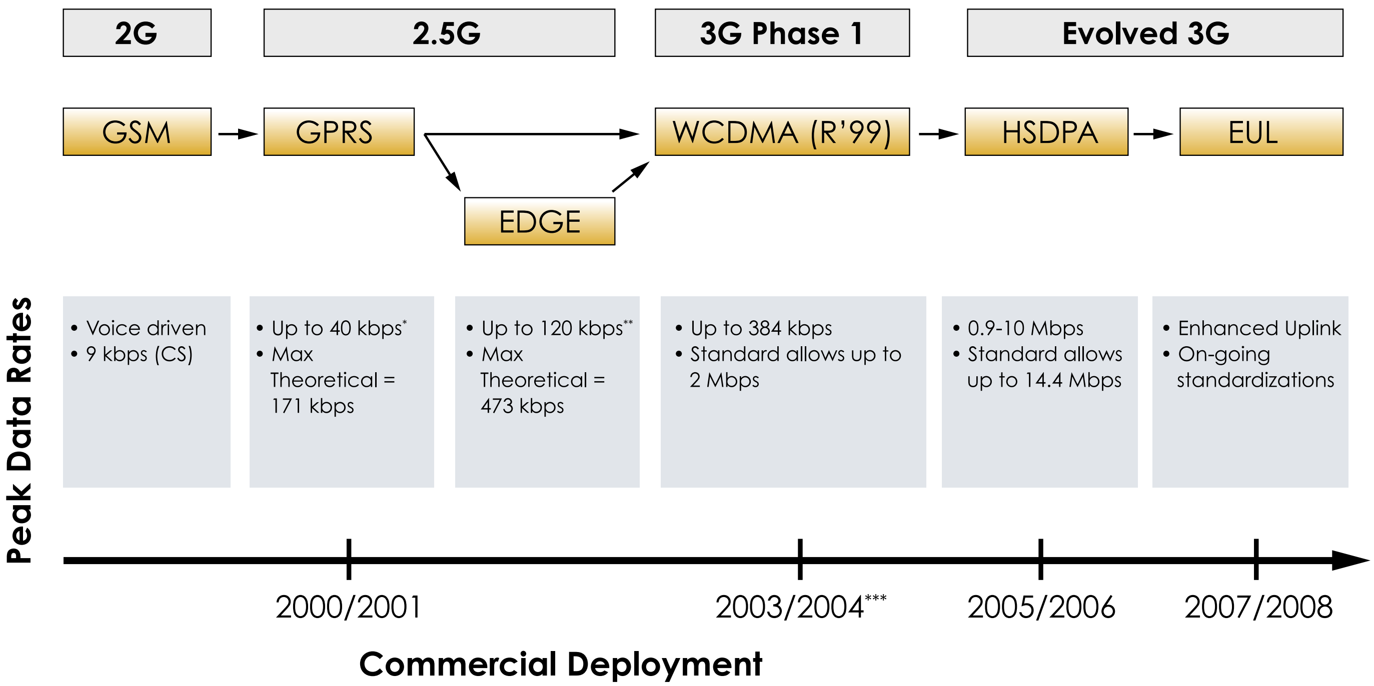
Additional performance improvements are foreseen for HSDPA with the introduction of additional features such as equalization and advanced Multiple-Input Multiple-Output (MIMO) techniques.

The benefits of HSDPA as explained in the previous sections apply to the downlink since most of the expected 3G data traffic will be initially downlink driven. Release 6 will include a major feature to improve the uplink as well. This feature is called Enhanced Uplink (EUL). EUL standardization is still ongoing, with a possible completion date of December 2004. EUL uses similar key features as HSDPA such as HARQ, short TTI and Node B scheduling. Initial simulations performed by QUALCOMM showed:

- 50 to 70 percent improvement of uplink sector throughput
- 20 to 55 percent reduction in user packet delay
- 50 percent increase in user packet call throughput

EUL is a natural evolution step. It will complement HSDPA by improving uplink data transfer. The first commercial deployments of EUL are expected in 2007 (cf. Figure 3-1).

Figure 3-1: 2G to 3G evolution



* Assume CS2, 4 TS and 10 kbps/TS @ C/I=15 dB

** Assume MCS6, 4 TS and 30 kbps/TS @ 15 dB

*** WCDMA has been commercially available in Japan since 2001

4.0 Networks Economics

In the previous sections, it has been shown that adding HSDPA into an operator's wireless network provides for the delivery of higher sector and user throughputs along with lower user latencies. These improvements in the delivery of data will enable operators to provide a host of new compelling and content rich services and applications. In this section, the cost of delivering data will be examined and it will be shown how the introduction of HSDPA can help operators to significantly reduce the cost of providing data services. By delivering low cost, content rich applications, operators will be able to differentiate their services, create brand loyalty and grow their data revenue and margins per subscriber.

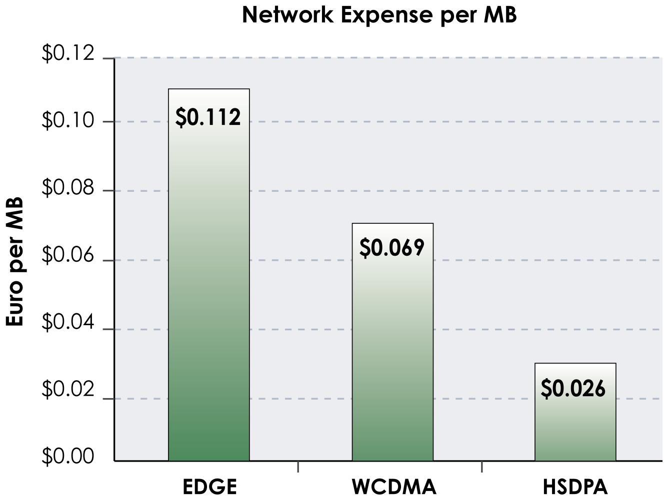
The cost of delivering data (the network expense) is defined as the sum of the network operating expense and capital depreciation. The network expense is driven largely by the aggregate sector throughput of a base station. Assuming constant per site costs, the more megabytes that can be driven through a site (from higher sector throughputs) the lower the cost of delivering each megabyte. Thus the HSDPA improvements in spectral efficiency result in lower per Megabyte (MB) delivery costs compared to EDGE and R'99. Figure 4-1 illustrates the per-MB-network expense for HSDPA vs. R'99 and EDGE with the following assumptions:

- Green field deployment (1000 km^2 coverage)
- 80 percent Network Utilization Factor*
- 15 percent Busy Hour, 25 Active Days Per Month
- Network Expense = Operating Expense + Capital Depreciation
- Aggregate data traffic density > 7,600 kbps/sq km

For the purposes of this analysis the cost of an HSDPA carrier is assumed to be 20 percent more than an R'99 carrier. There are a few ways that an operator can introduce HSDPA into their network starting from an R'99 base. Operators can either upgrade existing R'99 channel cards to HSDPA (many vendors support a software upgrade from R'99 to HSDPA) or deploy a new HSDPA carrier (adding RF and HSDPA channel cards). Other changes at the Node B would likely include adding more backhaul to support the enhanced capacity of the Node B. The RNC should need nothing more than a software upgrade and the SGSN and GGSN should remain unaltered.

As the costs fall from roughly eleven cents/MB with EDGE to under three cents/MB with HSDPA, operators can begin to offer greater volumes of content to a wider audience of consumers

Figure 4-1: Network expense per MB: Costs include network operating expense and depreciation. Assumes 15 percent of traffic demand occurs at the busy hour. Assumes aggregate data traffic density > 7,600 kbps/sq km.



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* Network Utilization Factor: To account for the non-uniform distribution of traffic in the network

at lower prices. A comparison can be made to the migration of wireless voice service from analog to digital. With analog service the cost to provide a minute of voice service was relatively high; this high cost limited the penetration of the wireless market and the number of minutes per month subscribers could afford to talk. With the introduction of digital wireless voice services the cost of providing a minute of talk time came down dramatically. The lower cost structure brought reduced pricing plans, making the service affordable to a wider audience and enabling wireless penetration and usage to climb.

As mentioned previously, with the introduction of HSDPA operators will be able to provide a wide range of compelling applications and services. In particular, there is a growing demand for content rich media services such as video on demand, audio on demand, picture/video messaging and location-based services. The spectral efficiency advantages of HSDPA will enable operators to deliver these services at lower costs and with a better user experience than legacy technologies. The introduction of HSDPA can also open up other business segments to the operator. Services the operator may wish to consider include high-speed laptop access for the enterprise and consumer segments, and the introduction of fixed wireless broadband access in regions where cable and DSL offerings may not be able to reach.

5.0 Conclusion

HSDPA provides impressive enhancements over WCDMA R'99 for the downlink. It offers peak data rates of up to 10 Mbps, resulting in a better end-user experience for downlink data applications (shorter connection and response times). More importantly, HSDPA offers three- to five-fold sector throughput increase, which results in significantly more data users on a single frequency. HSDPA higher throughputs and peak data rates will help stimulate and drive up consumption of data intensive applications that cannot be supported by R'99. In fact, HSDPA allows a more efficient implementation of interactive and background Quality of Service (QoS) classes as standardized by 3GPP. HSDPA high data rates improve the use of streaming applications, while lower roundtrip delays will benefit Web browsing applications. Another important benefit of HSDPA is its backwards compatibility with R'99. This makes its deployment very smooth and gradual on an "as needed" basis.

The deployment of HSDPA is very cost effective since the incremental cost is mainly due to Node Bs and RNC upgrades. In a capacity-limited environment, the network cost to deliver a megabyte of data traffic is three cents for a typical dense urban environment, as opposed to seven cents for R'99 (assuming an incremental cost of 20 percent).

The ability to offer higher peak rates for an increasingly performance demanding end-user at a substantially lower cost will create a significant competitive advantage for HSDPA operators. Supporting rich multimedia applications and content and more compelling devices at lower user cost will drive higher traffic per user and will enable early movers to differentiate themselves with advanced services — increasing their subscriber growth, data market share and profitability.

6.0 References

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