HSDPA Mobile Broadband Data

A Smarter Approach to UMTS Downlink Data

UMTS mobile wireless systems have enjoyed widespread uptake of high-quality circuit-switched applications like voice and video telephony. However, they have yet to deliver to the vision of ubiquitous mobile data — primarily due to the absence of an efficient high-speedpacket-switched data transmission platform. Data services like mobile internet access require asymmetric packet switched networks to best utilise the available spectrum in a multiuser environment. High-speed downlink packet access (HSDPA) in release 5 of the UMTS standard provides high-speed downlink data channels that can be shared efficiently between multiple users. It offers increased data rates (up to 14 Mbits/s), as well as improved error control handling and other techniques that increase the overall performance of the network. In this paper, we describe the characteristics of HSDPA systems and explain how they will enable the widespread deployment of cost-effective mobile broadband data services.

Voice and video telephony have symmetric bandwidth needs with strict latency and quality of service (QoS) requirements. These are met in today's release 99 UMTS networks using dedicated circuit-switched data channels (DCH) that provide up to 384 Kbits/s in both uplink and downlink transmissions. However, these channels are not readily shared between users. The next release of the UMTS standard (known as release 4) provides a downlink shared channel (DSCH) which is a radio link that can be assigned to a different user every 10 ms. Although DSCH was defined in release 99, support of the feature was not mandatory and it has yet to be deployed in a UMTS network. HSDPA offers high-speed downlink shared channels (HS-DSCH) that can switch between users every 2 ms. Using these channels, HSDPA systems can offer excellent packet-switched data services to several users simultaneously and efficiently.

HSDPA Physical Channels

Three new physical channels are introduced with HSDPA to enable HS-DSCH transmission. Two are used for control, and a third carries high speed downlink user data as shown in Figure 1. The high-speed shared control channel (HS-SCCH) is a downlink control channel that informs mobile devices when HSDPA data is scheduled for them, and how they can receive and decode it. The high-speed dedicated physical control channel (HS-DPCCH) is an uplink control channel used by the mobile to report the downlink channel quality and request retransmissions.

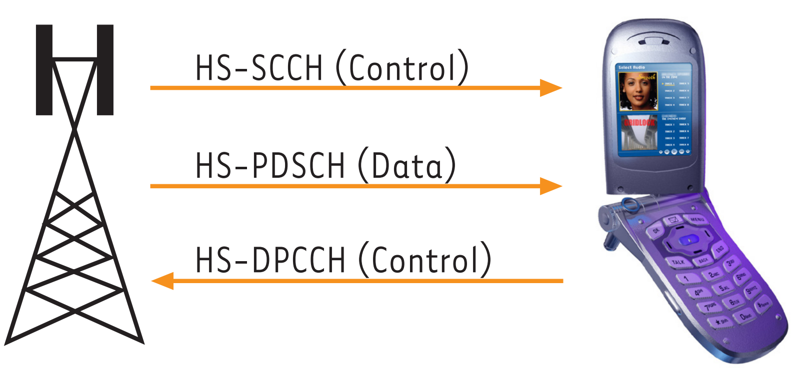

Figure 1. The three new physical channels used by HSDPA.

The high-speed physical downlink shared channel (HS-PDSCH) is a downlink physical channel that carries the HS-DSCH user data. Several HS-PDSCHs are assigned to a mobile for each transmission. The maximum number of HS-PDSCHs that can be allocated ranges from 5 to 15 depending on the category of the mobile device. A list of mobile categories and their characteristics is shown in Table 1 (page 7).

In HSDPA, each HS-PDSCH has a different OVSF channelization code. In UMTS, allocations of spectrum are assigned with a 5 MHz bandwidth. Channels are created within this spectrum using code division multiple access (CDMA). Each channel has a different orthogonal variable spreading factor (OVSF) channelization code. The number of codes available and the amount of data each can carry depends upon the spreading factor (SF) of the channel.

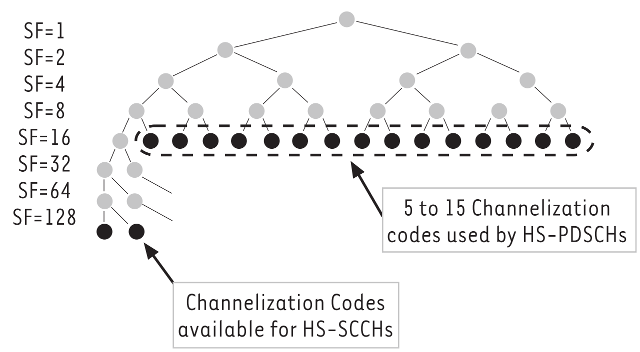

Figure 2. The HSDPA OVSF code tree.

The HSDPA standards specify the use of spreading factor 16 (SF16) channels for the HS-PDSCH and spreading factor 128 (SF128) channels for the HS-SCCH. As illustrated in Figure 2, up to 15 channels with SF16 are allocated for HS-PDSCHs.

Increased Data Rates using 16-QAM

HSDPA allows the use of 16-QAM modulation on HS-PDSCH channels to double the data rate of transmissions in favourable channel conditions. Release 99 and release 4 UMTS physical channels use the quadrature phase shift keying (QPSK) modulation to transmit two data bits per symbol. For HS-PDSCHs in release 5, 16-ary quadrature amplitude modulation (16QAM) can also be used to transmit 4 data bits per symbol as shown in the constellation diagrams in Figure 3.

Figure 3. Constellation diagrams for QPSK and 16QAM.

Although 16QAM doubles the potential data rate over the air interface relative to QPSK modulation, 16QAM signals are more susceptible to channel impairments and so the full gains can only be realized in high channel quality conditions. Also 16QAM signals require the use of a higher-performance receiver than QPSK signals. The decision to transmit QPSK or 16QAM is made in the network using channel quality information provided by the mobile terminal via the uplink control channel.

Dynamic Control of HS-DSCH Transmission Parameters

HSDPA handsets take measurements of the downlink physical channel quality, and transmit the channel quality indicator (CQI) in the uplink control channel to the WCDMA basestation (called Node B in UMTS). To make best use of the channel in varying conditions, an HSDPA system dynamically varies the number of physical channels, the modulation scheme and the code rate. The Node B calculates these parameters based on the CQI values it receives from the mobile device. When channel conditions deteriorate, the modulation scheme drops from 16QAM to QPSK, the number of physical channels used can be decreased and the effective code rate can be reduced through lower puncturing rates. By varying the CQI values, the mobile device aims to keep the transport block error rate at 0.1. The resulting data rate to the mobile device varies with the channel quality. The ability to vary the data rate sent to the mobile device in response to changes in the channel quality removes the need for the HS-PDSCHs channels to be power controlled. However, in situations where the channel is very good, the Node B decreases the power with which the HS-PDSCHs are transmitted.

The CQIs also enable the Node B to optimize the transmission to every user. An opportunistic scheduling algorithm can use the CQIs to transmit at the highest data rate to the users with the best channel quality. This concept is illustrated in Figure 4. The Node B basestation will transmit to user 2 first because the CQI of user 2 indicates the selection of a higher data rate. The scheduling algorithm then selects user 1 as its CQI increases. Naturally, a scheduler must ensure that all users receive satisfactory performance. This feature increases the effective channel utilization.

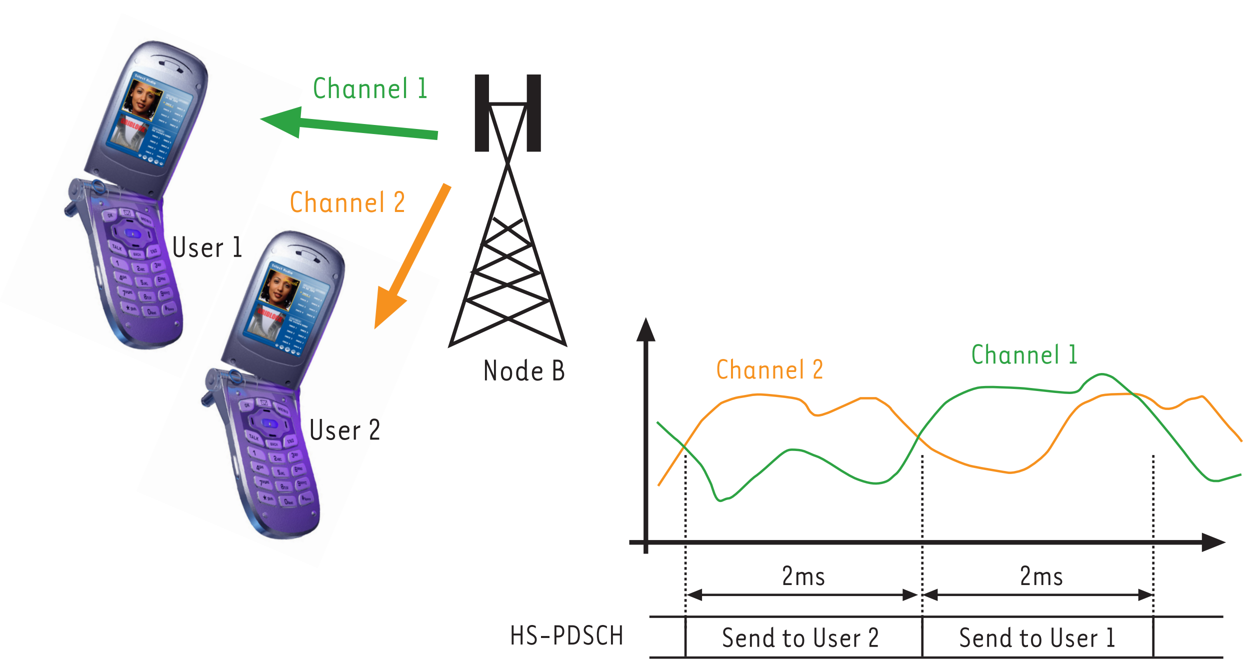

Figure 4. Opportunistic scheduling of HS-DSCH transmissions.

Advanced Layer-1 Error Control

Hybrid automatic repeat request (HARQ) functionality is an important feature of HSDPA channels. Data blocks that are not correctly received by the mobile device are requested to be transmitted again. The likelihood of successfully decoding the transport block is increased by combining the resulting retransmission with the original transmission in the mobile device. In HSDPA, HARQ is implemented at the physical layer and therefore multiple retransmissions can be requested without the intervention of higher layers. This results in reduced data latency and increased channel utilization, both of which are important in packet data transmission systems.

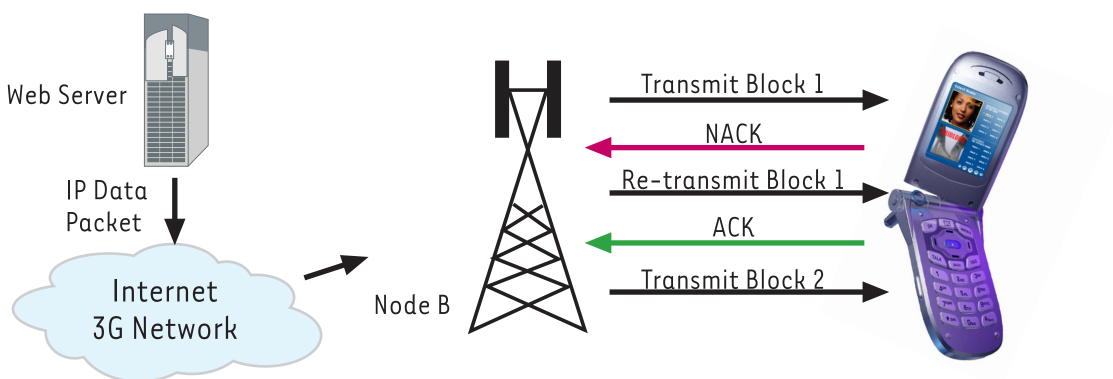

Figure 5. HARQ operation. A "NACK" indication from the mobile device results in the retransmission of the previous coded transport block.

The principal operation of HARQ retransmissions is illustrated in Figure 5. A transport block is transmitted to the mobile device where it is decoded and a CRC over the data is checked. If the CRC passes, the mobile device sends an acknowledgement (ACK) to the Node B in the HS-DPCCH, otherwise, it sends a negative ACK (NACK).

In the example shown in Figure 5, the first transmission was not correctly decoded so the mobile device transmitted a NACK to the Node B. The Node B responds by retransmitting the same transport block a second time. This second transmission is combined in the mobile device with the first transmission, and a decode is attempted. If the decode fails, the mobile device will transmit a NACK again and the transport block will be retransmitted a third time. When the decode is successful and the CRC passes, the mobile device transmits an ACK to the Node B. On receiving the ACK, the Node B transmits the next transport block to the mobile device and the whole process repeats for the new transport block.

HSDPA supports a retransmission and combining technique called incremental redundancy (IR). Every time a block needs to be retransmitted, a different puncturing pattern is used so that a different subset of bits is received every time. These can be combined in the receiver to improve the channel decoding performance. It is possible for the first transmission to be successfully decoded even when bits have been punctured because the turbo coding employed in HSDPA can compensate for the lost information. The principle of data puncturing and combining for IR is illustrated in Figure 6. If the same puncturing pattern is used in retransmissions, the IR technique reverts to chase combining. The UMTS standard [1] defines how many received samples a mobile device must store for use with IR (see Table 1, page 7).

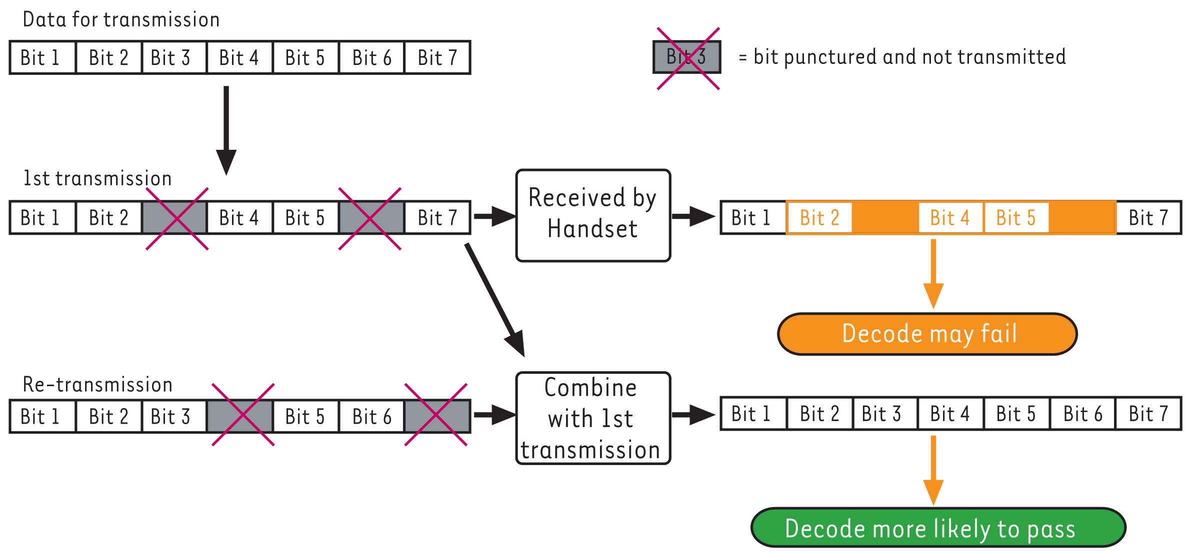

Figure 6. Incremental Redundancy in an HSDPA Mobile Terminal.

Not All HSDPA Terminals Are the Same

The 3GPP standards that define HSDPA operation ensure that terminals with higher-performance receivers will receive higher data rates on average than lower-performing terminals. This is a fundamental change from the operation of the release 99 channels, which are power controlled to achieve a constant data rate. The HSDPA capable Node B varies the data rate sent to a terminal to achieve a constant block error rate (BLER) of 10%. Thus, a higher-performance terminal will command a higher data rate than a lower-performance terminal operating in the same conditions. HSDPA applications require high data rates and as a result benefit especially from these data rate increases.

The relationship between terminal performance and user data throughput allows terminal manufacturers and chip set vendors to differentiate their products. Higher-performance terminals will deliver higher average data rates on any given HSDPA network and are therefore more desirable to both network operators and users. The receiver architecture chosen can have a significant effect on the performance of a chip set and terminal, as illustrated in the BER and throughput curves shown in Figure 7. At high signal to noise ratio the advanced receiver achieves almost twice the throughput in a pedestrian-B channel. These simulation results show the BER output of the receiver, as well as the throughput computed from the BLER on the output of the bit rate processing. The simulations use a fixed QPSK modulation with a variable block size and do not include HARQ, which will provide a similar performance benefit for both types of receivers. Under these assumptions, and using a typical distribution of SNR that could be observed within a macrocell environment, the average link throughput to a terminal with an advanced receiver would reach 500 Kbits/s, whereas a standard RAKE receiver would only achieve approximately 300 Kbits/s. This indicates a 65% increase in average datarate. The average SNR observed in microcell environments is usually greater than that in macrocells, accentuating the advantage of advanced receiver designs. For a typical microcell SNR distribution, the average link throughput with an advanced receiver could be expected to reach 1 Mbit/s compared to only 550 Kbits/s using a conventional RAKE receiver. This indicates an 80% increase in average data rate.

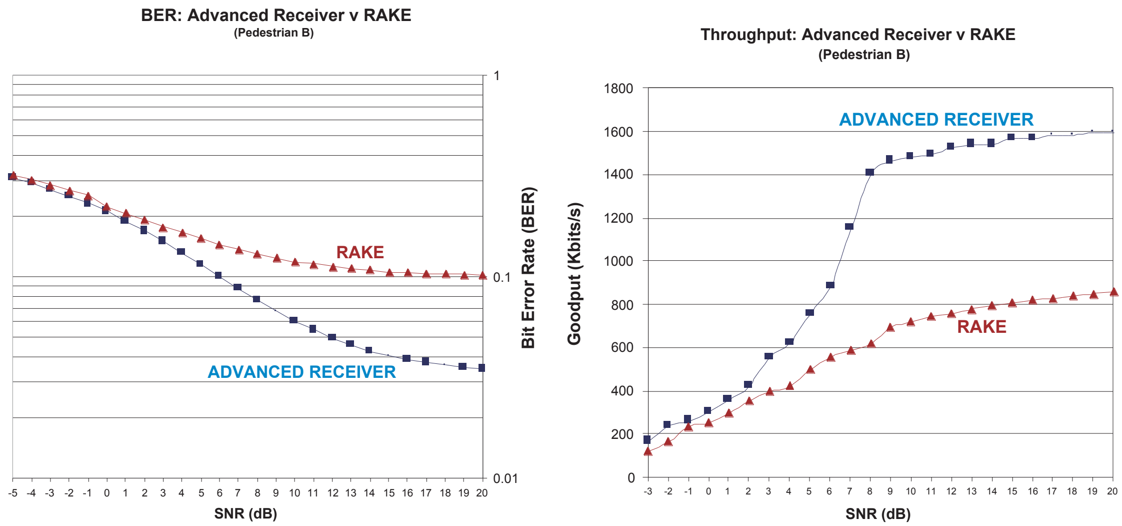

Figure 7. Plots showing performance gain and corresponding HSDPA throughput of an Advanced HSDPA Receiver over a release-99 RAKE receiver. These curves are for 1.8 Mbits/s QPSK HSDPA in a PED-B channel.

Architecture of an HSDPA-Enabled Smartphone

Typically, an HSDPA-enabled smartphone should be backward compatible with 2.5G and 3G systems so that it can be used on any GSM/UMTS network. It should also take advantage of the higher data rates available in UMTS cells that have HSDPA transmit capability. Figure 8 shows a high level functional block diagram of the digital communications engine of an HSDPA-enabled smartphone. The HSDPA baseband processor incorporates a separate receiver that operates on HS-DSCH and HS-SCCH channels. The HSDPA and rel-99 WCDMA receivers operate simultaneously as DCH channels are used during HSDPA transmissions. Data-only terminals could be designed that had no voice-capability. The architecture would not vary by much in such designs.

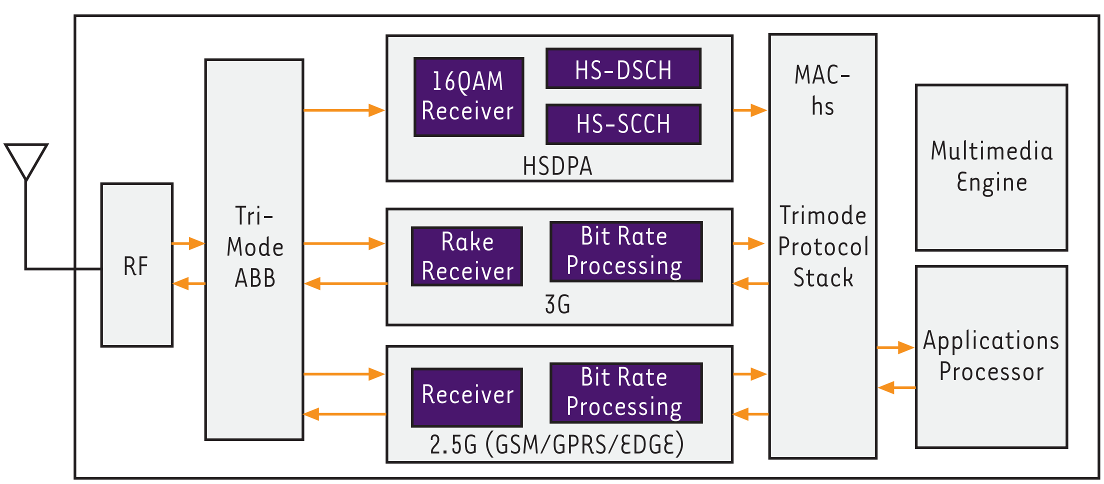

Figure 8. Smartphone block diagram.

12 different categories of HSDPA capable mobile device are defined in the release 5 UMTS standards. The categories support different peak data rates and provide for varying levels of implementation complexity as shown in Table 1.

Mobile Device Category	Peak Data Rate	HS-PDSCHs Received	Modulation Scheme	Total Number of Soft Channel Bits
11	0.9 Mbits/s	5	QPSK	14400
12	1.8 Mbits/s	5	QPSK	28800
1	1.2 Mbits/s	5	QPSK or 16QAM	19200
2	1.2 Mbits/s	5	QPSK or 16QAM	28800
3	1.8 Mbits/s	5	QPSK or 16QAM	28800
4	1.8 Mbits/s	5	QPSK or 16QAM	38400
5	3.6 Mbits/s	5	QPSK or 16QAM	57600
6	3.6 Mbits/s	5	QPSK or 16QAM	67200
7	7.2 Mbits/s	10	QPSK or 16QAM	115200
8	7.2 Mbits/s	10	QPSK or 16QAM	134400
9	10.1 Mbits/s	15	QPSK or 16QAM	172800
10	14.0 Mbits/s	15	QPSK or 16QAM	172800

Table 1. The 12 categories of mobile device defined for HSDPA.

[1] 3GPP TS25.306. V5.8.0 UE radio access capabilities

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