S-72.3260 Radio Resource Management Methods
High-Speed Downlink Packet Access (HSDPA)

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Outline

- HSDPA Concept
- HSDPA Physical Layer Structure
- HSDPA Terminal Capability and Achievable Data Rates
- HSDPA Performance
- Evolution Beyond Release 5

The lecture is based on Chapter 11 of H. Holma and A. Toskala (Eds.): *WCDMA for UMTS,* Third edition.

HSDPA Concept

- HSDPA is a new feature in “Release 5” of 3GPP.
- The key idea of the HSDPA concept is to increase the packet data throughput at the WCDMA downlink.
- With HSDPA, two of the most fundamental features of WCDMA, namely variable spreading factor (SF) and fast power control, are disabled and replaced by means of adaptive modulation and coding, extensive multicode operation, and a fast and spectrally efficient retransmission strategy.

The High-Speed Downlink Shared Channel (HS-DSCH)

- In the earlier WCDMA version (“Release ’99”), only the QPSK modulation scheme was used.
- In HSDPA, also the 16 QAM scheme is available. It doubles the peak data rate compared to QPSK, allowing up to 10 Mbps peak data rate with 15 codes of spreading factor 16.
- If QPSK is used, only a phase estimate is necessary for the demodulation process. In the 16 QAM case, amplitude estimation is required to separate the constellation points, and also the phase information needs to be more accurate compared to the QPSK case.

HS-DSCH Channel Coding

- Some simplifications when compared to Release '99: (i) Since there is now only one active transport channel, the blocks related to the channel multiplexing for the same users can be left out; (ii) the interleaving only spans over a single 2 ms period and there is no separate intra-frame or inter-frame interleaving; (iii) turbo coding is the only coding scheme used.
- By varying the transport block size, the modulation scheme and the number of multicodes, effective code rates within the range 0.15–0.98 can be achieved.
- The HSDPA capable Node B has the responsibility of selecting the transport format to be used along with the modulation and number of codes on the basis of the information at the Node B (Base Transceiver Station) scheduler.

The Hybrid ARQ (HARQ) Functionality

- A new feature in HSDPA. There are basically two different ways of operating HARQ in HSDPA. A key idea is that the packet combining operations are performed in the physical layer.
- *Chase combining* (or *soft combining*): all the transmission attempts of a packet are identical. If the retransmitted packet is again erroneous, then the previous and current packet are combined to recover from errors. The retransmissions continue until either the errors are resolved or the maximum number of retransmissions is reached. In the latter case, higher-layer protocols will deal with the errors.
- *Incremental redundancy (IR):* similar to Chase combining, except that instead of being identical to the first transmission attempt, the retransmission contains additional redundant bits, which are combined with the previous transmission to resolve the errors.
- Fixed 24-bit CRC (cyclic redundancy check) is used for error detection.

The High-Speed Shared Control Channel (HS-SCCH) (1)

- Carries the key information necessary for HS-DSCH demodulation.
- The number of HS-SCCHs allocated corresponds to the maximum number of users that will be code-multiplexed. Each terminal will only need to consider a maximum of four HS-SCCHs at a given time; the HS-SCCHs that are to be considered are signalled to the terminal by the network.
- Each HS-SCCH block has a three-slot duration that is divided into two functional parts. The HS-SCCH uses half-rate convolutional coding with the two parts of the block encoded separately. For protection, both HS-SCCH parts employ terminal-specific masking.

The High-Speed Shared Control Channel (HS-SCCH) (2)

- The first slot (first part) carries the time-critical information that is needed to start the demodulation process in due time. Part 1 parameters indicate: (i) the codes to despread; (ii) if QPSK or 16 QAM is used.
- The next two slots (second part) contain less time-critical parameters. CRC is included to check the validity of the HS-SCCH information and HARQ process information. Part 2 parameters indicate: (i) the redundancy version (soft combining or incremental redundancy); (ii) the ARQ process number to show which ARQ process the data belongs to; (iii) whether the current packet is the first transmission or a retransmission.

The Uplink High-Speed Dedicated Physical Control Channel (HS-DPCCH)

- Works in parallel with the existing uplink channel structure from Release '99.
- The HS-DPCCH is divided into two parts and carries the following information: (i) ACK/NACK transmission to show the results of the CRC check after the packet decoding and combining; (ii) Downlink Channel Quality Indicator (CQI) to indicate which estimated transport block size, modulation type and number of parallel codes could be received with reasonable block error rate in the downlink direction.

The HSDPA Physical Layer Operation Procedure (1)

- The scheduler in the Node B evaluates for the different users, what the channel conditions are, and what is the demand for service.
- Once a particular TTI (transmission time interval) of three slots (2 ms) has been assigned to a terminal, the Node B identifies the necessary HS-DSCH parameters. For instance, how many codes are available, can 16 QAM be used, and what are the terminal capability limitations. The terminal soft memory capability also determines which kind of HARQ can be used.
- The Node B starts to transmit the HS-SCCH two slots before the corresponding HS-DSCH TTI to inform the terminal of the necessary parameters.

The HSDPA Physical Layer Operation Procedure (2)

- The terminal monitors the HS-SCCHs given by the network, and once the terminal has decoded Part 1 from an HS-SCCH intended for that terminal, it will start to decode the rest of that HS-SCCH and will buffer the necessary codes from the HS-DSCH.
- Upon having the HS-SCCH parameters decoded from Part 2, the terminal can determine to which ARQ process the data belongs and whether it needs to be combined with data already in the soft buffer.
- After decoding the possibly combined data, the terminal sends in the uplink direction an ACK/NACK indicator depending on the outcome of the CRC check on the HS-DSCH data. The time interval from the end of the HS-DSCH TTI to the start of the ACK/NACK transmission in the uplink is specified to be 7.5 slots.
- If the network continues to transmit data for the same terminal in consecutive TTIs, the same HS-SCCH will be used.

HSDPA Terminal Capability and Achievable Data Rates (1)

- The 12 categories specified for the HSDPA terminals in Release 5 of 3GPP are shown in the table below. The maximum data rates range from 0.9 to 14.4 Mbps. The last two terminal categories support only QPSK modulation.

Category	Maximum number of parallel codes HS-DSCH	Minimum inter-TTI interval	Transport channel bits per TTI	ARQ type at maximum data rate	Achievable maximum data rate (Mbps)
1	5	3	7298	Soft	1.2
2	5	3	7298	IR	1.2
3	5	2	7298	Soft	1.8
4	5	2	7298	IR	1.8
5	5	1	7298	Soft	3.6
6	5	1	7298	IR	3.6
7	10	1	14411	Soft	7.2
8	10	1	14411	IR	7.2
9	15	1	20251	Soft	10.2
10	15	1	27952	IR	14.4
11	5	2	3630	Soft	0.9
12	5	1	3630	Soft	1.8

HSDPA Terminal Capability and Achievable Data Rates (2)

- Besides the UE (user equipment) capability, the terminal data rate can be largely varied by changing the coding rate as well. The table below shows the maximum data rates when the number of codes is constant (15), but the coding rate and the modulation scheme are varied.

Modulation	Effective code rate	Max. throughput (Mbps)
QPSK	1/4	1.8
QPSK	2/4	3.6
QPSK	3/4	5.3
16 QAM	2/4	7.2
16 QAM	3/4	10.7

Factors Governing HSDPA Performance

- *Channel conditions:* Time dispersion, cell environment, terminal velocity, experienced own cell interference to other cell interference ratio ($I_{\text{or}}/I_{\text{oc}}$).
- *Terminal performance:* Basic detector performance (e.g. sensitivity and interference suppression capability) and HSDPA capability level, including supported peak data rates and number of multicodes.
- *Nature and accuracy of radio resource management (RRM):* Power and code resources allocated to the HSDPA channel, and accuracy/philosophy of the Signal to Interference power ratio (SIR) estimation and the packet scheduling algorithms.

Spectral Efficiency and Code Efficiency

- Spectral efficiency is improved at lower SIR ranges (medium to long distance from Node B) by introducing more efficient coding and fast HARQ with redundancy combining (no transmissions are wasted). Further, extensive multicode operations offer high spectral efficiency, similar to variable SF but with higher resolution. At very good SIR conditions (vicinity of Node B), HSDPA offers higher peak data rates and thus better channel utilisation and spectral efficiency.
- Code efficiency is obtained by offering more user bits per symbol and thus more data per channelisation code. This is achieved through higher-order modulation and reduced coding. Further, the use of time multiplexing and shared channels generally leads to better code utilisation for bursty traffic.

Dynamic Range

- The principle of HSDPA is to adapt to the current channel conditions by selecting the most suitable modulation and coding scheme, leading to the highest throughput level.
- The key measure for describing the link performance is the narrowband *signal to interference and noise ratio (SINR)* as experienced by the UE detector.
- Measured in the SINR domain, the total link adaptation dynamic range of HSDPA is typically around 30–35 dB.

User Scheduling and Cell Throughput

- The HSDPA cell throughput depends significantly on the interference distribution across the cell, and the multicode and power resources allocated to HSDPA.
- The chosen packet scheduling method has a significant impact on the overall cell throughput. This is related to the gain by *multiuser diversity:* with fast scheduling and multiple users it is possible at any time to pick the "best" user in the cell.
- One of the often referred-to fast scheduling methods is the *proportional fair* algorithm, which offers a trade-off between user-fairness and cell capacity. To identify the best user for scheduling, a relative channel quality indicator is calculated for each user as the ratio:

$$\text{Scheduling metric} = \frac{\text{User's instantaneously supported data rate}}{\text{User's average served throughput}}.$$

Evolution Beyond Release 5

- Multiple Receiver and Transmit Antenna Techniques
- High Speed Uplink Packet Access (HSUPA)