High-Speed Downlink Packet Access (HSDPA)

- HSDPA Background & Basics
- Principles: Adaptive Modulation & Coding, HARQ
- Channels/ UTRAN Architecture
- Resource Management: Fast Scheduling, Mobility
- Performance Results
HSDPA Background

- **Initial goals**
  - Establish a more spectral efficient way of using DL resources providing data rates beyond 2 Mbps, (up to a maximum theoretical limit of 14.4 Mbps)
  - Optimize interactive & background packet data traffic, support streaming service
  - Design for low mobility environment, but not restricted
  - Techniques compatible with advanced multi-antenna and receivers

- **Standardization started in June 2000**
  - Broad forum of companies
  - Major feature of Release 5

- **Enhancements in Rel.7 → HSPA+**
  - Advanced transmission to increase data throughput
  - Signaling enhancements to save resources
HSDPA Basics

- Evolution from R.99/ Rel.4
  - 5 MHz BW
  - Same spreading by OVSF and scrambling codes
  - Turbo coding

- New concepts in Rel.5
  - Adaptive modulation (QPSK vs. 16QAM), coding and multicodes (fixed SF = 16)
  - Fast scheduling in NodeB (TTI = 2 msec)
  - Hybrid ARQ

- Enhancements in Rel.7 → HSPA+
  - Signaling enhancements
  - 64QAM
  - MIMO techniques, increase of the bandwidth
Higher Order Modulation

- Standard modulation scheme in UMTS R.99
  - QPSK: 2 bit per symbol
- With HSDPA the modulation can be switched between
  - QPSK: 2 bit per Symbol
  - 16QAM: 4 bit per Symbol

Low Bitrate $\rightarrow$ Robust

High Bitrate $\rightarrow$ Sensitive to disturbances
Adaptive Modulation and Coding

- For wireless data, link adaptation through **Rate Control** is more effective than Power Control.

- Users in favorable channel conditions are assigned higher code rates and higher order modulation (16QAM).
  - This means higher data rates = Reduced latency

- Users in worse condition will get lower code rate and lower modulation (QPSK).
  - More robust transmission with lower data rate

- Decision on modulation and coding is based on fast feedback from the UE about channel quality (CQI).
Hybrid ARQ

- H-ARQ automatically adapts to instantaneous channel conditions by:
  - Fast retransmissions at MAC-sublayer
  - Adding redundancy only when needed
- The retransmitted packets are combined with the original packet to improve decoding probability.
- Simple form of Hybrid ARQ shows significant gains over link adaptation alone.
- Different schemes can be used for retransmission of the original data packet:
  - Chase-Combining
  - Incremental Redundancy
Fast Scheduling

- **Principle of fast scheduling**
  - Assign the resources to the best user(s) in time to maximise throughput
  - Channels are uncorrelated $\rightarrow$ Multi-User Diversity Gain

- There exist various variants, which mainly differ in their consideration of channel quality and user throughput, e.g.
  - Round Robin
  - Max C/I
  - Proportional Fair

- With HSDPA the resource management is shifted to the NodeB
  - No Soft Handover
HS-DSCH Principle I

- Channelization codes at a fixed spreading factor of SF = 16
  - Up to 15 codes in parallel

- OVSF channelization code tree allocated by CRNC
  - HSDPA codes autonomously managed by NodeB MAC-hs scheduler
  - Example: 12 consecutive codes reserved for HS-DSCH, starting at $C_{16,4}$
    - Additionally, HS-SCCH codes with SF = 128 (number equal to simult. UE)
Resource sharing in code as well as time domain:
- Multi-code transmission, UE is assigned to multiple codes in the same TTI
- Multiple UEs may be assigned channelization codes in the same TTI

Example: 5 codes are reserved for HSDPA, 1 or 2 UEs are active within one TTI
UMTS Channels with HSDPA

Rel.5 HS-DSCH
- DL PS service
- (Rel.6: DL DCCH)

R.99 DCH (in SHO)
- UL/DL signalling (DCCH)
- UL PS service
- UL/DL CS voice/ data

Cell 1
= Serving HS-DSCH cell

Cell 2

UE
HSDPA Channels

- **HS-PDSCH**
  - Carries the data traffic
  - Fixed SF = 16; up to 15 parallel channels
  - QPSK: 480 kbps/code, 16QAM: 960 kbps/code

- **HS-SCCH**
  - Signals the configuration to be used next: HS-PDSCH codes, modulation format, TB information
  - Fixed SF = 128
  - Sent two slots (~1.3 msec) in advance of HS-PDSCH

- **HS-DPCCH**
  - Feedbacks ACK/NACK and channel quality indicator (CQI)
  - Fixed SF = 256, code multiplexed to UL DPCCH
  - Feedback sent ~5 msec after received data
Timing Relations (DL)

- **NodeB Tx view**
- Fixed time offset between the HS-SCCH information and the start of the corresponding HS-DSCH TTI: $\tau_{\text{HS-DSCH-control}} = 2 \times T_{\text{slot}} = 1.33$ msec
- HS-DSCH and associated DL DPCH not time-aligned
Timing Relations (UL)

- UE Rx view
- Alignment to $m \times 256$ to preserve orthogonality to UL DPCCH
- HS-PDSCH and associated UL DPCH not time-aligned (but “quasi synch”)

Diagram:
- Uplink DPCCH
- HS-PDSCH
- HS-DPCCH
- T_{\text{slot}} (0.67 ms)
- $3 \times T_{\text{slot}}$ (2 ms)
- $\tau_{\text{UEP}} = 7.5 \times T_{\text{slot}}$ (5 ms)
- $m \times 256$ chips

Legend:
- DATA
- CQI
- A/N
HSDPA Architecture

Evolution from R.99/Rel.4
- HSDPA functionality is intended for transport of dedicated logical channels
- Takes into account the impact on R.99 networks

HSDPA in Rel.5
- Additions in RRC to handle HSDPA
- RLC nearly unchanged (UM & AM)
- Modified MAC-d with link to MAC-hs entity
- New MAC-hs entity located in the NodeB
MAC-hs in NodeB

MAC-hs Functions
- Priority handling
- Flow Control
  - To RNC
  - To UE
- Scheduling
  - Select which user/queue to transmit
  - Assign TFRC & Tx power
  - HARQ handling
- Service measurements
  - e.g. HSDPA provided bitrate

MAC-hs - Control

Scheduling

Priority Queue distribution

UE #1

Priority Queue

Priority Queue

Priority Queue

UE #2

UE #N

MAC-d flows

HS-DSCH

Cf. 25.321

TFRC: Transport Format and Resource Combination

Cf. 25.321
MAC-hs in UE

MAC-hs Functions

- HARQ handling
  - ACK/ NACK generation
- Reordering buffer handling
  - Associated to priority queues
  - Flow control per reordering buffer
  - Memory can be shared with AM RLC
- Disassembly unit

Cf. 25.321
Data Flow through Layer 2

Segmentation & Concatenation

Reassembly

Higher Layer PDU

RLC SDU

MAC-d SDU

MAC-d PDU

MAC-hs SDU

Transport Block (MAC-hs PDU)

CRC

L1

L2 RLC (non-transparent)

L2 MAC-d (non-transparent)

L2 MAC-hs (non-transparent)
Hybrid Automatic Repeat Request

- HARQ is a *stop-and-wait ARQ*
  - Up to 8 HARQ processes per UE
- Retransmissions are done at *MAC-hs layer*, i.e. in the Node B
  - Triggered by NACKs sent on the HS-DPCCH
- The mother code is a R = 1/3 Turbo code
- *Code rate adaptation* done via rate matching, i.e. by puncturing and repeating bits of the encoded data
- Two types of retransmission
  - **Incremental Redundancy**
    - Additional parity bits are sent when decoding errors occurred
    - Gain due to reducing the code rate
  - **Chase Combining**
    - The same bits are retransmitted when decoding errors occurred
    - Gain due to maximum ratio combining
- HSDPA uses a mixture of both types
HARQ Processes

- HARQ is a simple stop-and-wait ARQ
- Example
  - $\text{RTT}_{\text{min}} = 5 \text{ TTI}$
  - Synchronous retransmissions (MAC-hs decides on transmission)
- UE support up to 8 HARQ processes (configured by NodeB)
  - Min. number: to support continuous reception
  - Max. number: limit of HARQ soft buffer
  - Number of HARQ processes configured specifically for each UE category
HSDPA UE Categories

- The specification allows some freedom to the UE vendors

- 12 different UE categories for HSDPA with different capabilities (Rel.5)

- The UE capabilities differ in
  - Max. transport block size (data rate)
  - Max. number of codes per HS-DSCH
  - Modulation alphabet (QPSK only)
  - Inter TTI distance (no decoding of HS-DSCH in each TTI)
  - Soft buffer size

- The MAC-hs scheduler needs to take these restrictions into account
## HSDPA – UE Physical Layer Capabilities

<table>
<thead>
<tr>
<th>HS-DSCH Category</th>
<th>Maximum number of HS-DSCH multi-codes</th>
<th>Minimum inter-TTI interval</th>
<th>Maximum MAC-hs TB size</th>
<th>Total number of soft channel bits</th>
<th>Theoretical maximum data rate (Mbit/s)</th>
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Note: UEs of Categories 11 and 12 support QPSK only

cf. TS 25.306
Channel Quality Indicator (CQI)

- Signaled to the Node B in UL each 2 msec on HS-DPCCH

- Integer number from 0 to 30 corresponds to a Transport Format Resource Combination (TFRC) given by
  - Modulation
  - Number of channelization codes
  - Transport block size

- For the given conditions the BLER for this TFRC shall not exceed 10%

- Mapping defined in TS 25.214 for each UE category
# CQI – Mapping Table

<table>
<thead>
<tr>
<th>CQI value</th>
<th>Transport Block Size</th>
<th>Number of HS-PDSCH</th>
<th>Modulation</th>
<th>Reference power adjustment $\Delta$</th>
<th>$N_{IR}$</th>
<th>$X_{RV}$</th>
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</table>

- Tables specified in TS 25.214
  - For each UE category
  - Condition: $\text{BLER} \leq 10\%$
- Example is for UE category 10
HSDPA Fast Scheduling

3G (R.99) with dedicated channels

3G with high speed feedback/scheduling on shared channels

Note: No fast channel quality feedback
HSDPA Resource Allocation

- **QoS & Subscriber Profile**
  - QoS: guar. bitrate, max. delay
  - GoS: gold/ silver/ bronze

- **Feedback from UL**
  - CQI, ACK/NACK

- **UE service metrics**
  - Throughput, Buffer Status

- **Radio resources**
  - Power, OVSF codes

- **UE capabilities**
  - max. TFRC

**Scheduler**

- **Scheduler Output**
  - Scheduled Users
  - TFRC: Mod., TB size, # codes, etc.
  - HS-PDSCH power

**Scheduling targets**
- Maximize network throughput
- Satisfy QoS/ GoS constraints
- Maintain fairness across UEs and traffic streams
Scheduling Disciplines

◆ Task
  ◆ Select UEs (and associated priority queues) to transmit within next TTI
  ◆ Usually this is done by means of ranking lists
◆ Depending on the ranking criterion it can be distinguished between three major categories
  ◆ Round Robin: allocate each user equal amount of time
  ◆ Proportional Fair: equalise the actual channel rate / throughput ratio
  ◆ Max C/I: prefer the users with good channel conditions
◆ To provide GoS/ QoS additional inputs are to be used
  ◆ Additional scheduling weights and rate constraints based on the requested GoS/ QoS
  ◆ This can be traded-off with channel conditions
  ◆ Special scheduling schemes are needed for providing delay critical services, e.g. VoIP
Comparison of Schedulers

- Simple Round Robin doesn’t care about actual channel rate
- Proportional Fair offers higher cell throughput
- QoS aware algorithm offers significantly higher user perceived throughput than PF with similar cell throughput
Mobility Procedures I

- HS-DSCH for a given UE belongs to only one of the radio links assigned to the UE (serving HS-DSCH cell)

- The UE uses soft handover for the uplink, the downlink DCCH and any simultaneous CS voice or data
  - Using existing triggers and procedures for the active set update (events 1A, 1B, 1C)

- Hard handover for the HS-DSCH, i.e. Change of Serving HS-DSCH Cell within active set
  - Using RRC procedures, which are triggered by event 1D
- Inter-NodeB serving HS-DSCH cell change
- Note: MAC-hs needs to be transferred to new NodeB!
**HS-DSCH Serving Cell Change**

- **Event 1D**: change of best cell within the active set
- **Hysteresis and time to trigger** to avoid ping-pong
  (HS-DSCH: 1..2 dB, 0.5 sec)
Example: HS-DSCH hard handover (synchronized serving cell change)
HSDPA – Managed Resources

a) OVSF Code Tree

- Codes reserved for HS-PDSCH/ HS-SCCH
- Codes available for DCH/ common channels

b) Transmit Power

- Tx power available for HS-PDSCH/ HS-SCCH
- Tx power available for DCH/ common channels

Note: CRNC assigns resources to Node B on a cell basis
Cell and User Throughput vs. Load

- 36 cells network
- UMTS composite channel model
- FTP traffic model (2 Mbyte download, 30 sec thinking time)

- The user throughput is decreased when increasing load due to the reduced service time
- The cell throughput increases with the load because overall more bytes are transferred in the same time
HSDPA Performance per Category

- 36 cells network
- UMTS composite channel model
- FTP traffic model (2 Mbyte download, 30 sec thinking time)

- Higher category offers higher max. throughput limit
  - Cat.6: 3.6 MBit/sec
  - Cat.8: 7.2 MBit/sec

- Max. user perceived performance increased at low loading
- Cell performance slightly better
Impact from Higher Layers

- Maximum MAC-hs throughput is determined by the MAC-d PDU size and the max. number of MAC-d PDUs, which fit into the max. MAC-hs PDU.

- Maximum RLC throughput is further limited by:
  - The RLC window size, which is limited to 2047 PDUs
  - Round-trip time RTT
Coverage Prediction with HSDPA

- Example Scenario
  - 15 users/cell
  - Pedestrian A channel model
  - Plot generated with field prediction tool

HSDPA Throughput depends on location
HSDPA References

- **Papers:**

- **Standards**
  - TS 25.xxx series: RAN Aspects
  - TR 25.858 “HSDPA PHY Aspects”
  - TR 25.308 “HSDPA: UTRAN Overall Description (Stage 2)”
  - TR 25.877 “Iub/Iur protocol aspects”
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ACK</td>
<td>(positive) Acknowledgement</td>
</tr>
<tr>
<td>ALCAP</td>
<td>Access Link Control Application Protocol</td>
</tr>
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<td>AM</td>
<td>Acknowledged (RLC) Mode</td>
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<td>AMC</td>
<td>Adaptive Modulation &amp; Coding</td>
</tr>
<tr>
<td>CAC</td>
<td>Call Admission Control</td>
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<td>CDMA</td>
<td>Code Division Multiple Access</td>
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<td>CQI</td>
<td>Channel Quality Indicator</td>
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<td>Dynamic Bearer Control</td>
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<td>Dedicated Physical Control Channel</td>
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<td>Grade of Service</td>
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<td>HARQ</td>
<td>Hybrid Automatic Repeat Request</td>
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<td>H-RNTI</td>
<td>HSDPA Radio Network Temporary Identifier</td>
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<td>High Speed Downlink Packet Access</td>
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<td>High Speed Dedicated Physical Control Channel</td>
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<td>High Speed Downlink Shared Channel</td>
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<td>HS-PDSCH</td>
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<td>HS-SCCH</td>
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