High-Speed Downlink Packet Access (HSDPA)

- HSDPA Background & Basics
- Principles: Adaptive Modulation, Coding, HARQ
- Channels/ UTRAN Architecture
- Principles: Fast scheduling, Mobility
- Performance Results
Motivation (as of 2000)

- As the UMTS networks are rolled out, the demand for high bandwidth services is expected to grow rapidly.
- By 2010, 66% of the revenues will come from data services \textit{(source: UMTS forum)}.
- Release 99/4 systems alone will not be capable to meet these demands. (Realistic outdoor data rates will be limited to 384kbps).
- A more spectral efficient way of using DL resources is required.
- Competition with CDMA 2000 1x EV-DO/DV
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 R7 → HSPA+**
  - Advanced transmission to increase data throughput
  - Signaling enhancements to save resources
HSDPA Basics

- Evolution from R99/ R4
  - 5MHz BW
  - Same spreading by OVSF and scrambling codes
  - Turbo coding

- New concepts in R5
  - Adaptive modulation (QPSK vs. 16QAM), coding and multicodes (fixed SF = 16)
  - Fast scheduling in NodeB (TTI = 2ms)
  - Hybrid ARQ

- Enhancements in R7 → HSPA+
  - Signaling enhancements
  - 64QAM
  - MIMO techniques, increase of the bandwidth
HSDPA Techniques

- Adaptive modulation and coding (AMC)
  - Modulation can be switched between QPSK and 16QAM
  - Adaptation of FEC coding rate
  - Fast feedback from UE about channel quality (CQI)
- Hybrid ARQ
  - Fast retransmission in MAC-layer (S&W protocol)
  - Retransmitted packets combined with original ones
  - Adaptive redundancy
- Fast scheduling
  - Allocate resources to users with good channel quality → Multi-user diversity gain
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)
HS-DSCH Principle II

- 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)

R99 DCH (in SHO)
- UL/DL signalling (DCCH)
- UL PS service
- UL/DL CS voice/data
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 (~1.3msec) 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 ~5msec 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**: $\tau_{HS-DSCH\text{-control}} = 2 \times T_{slot} = 1.33\text{msec}$
- **HS-DSCH and associated DL DPCH not time-aligned**

- **Downlink DPCH**
- **HS-SCCH**
  - ch. code & mod
  - TB size & HARQ Info

- **HS-PDSCH**
  - DATA

- $T_{slot}$ (2560 chips)
- $3 \times T_{slot}$ (2 msec)
- $2 \times T_{slot}$

$T_{slot}$ (2 msec)
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”)

- $T_{\text{slot}}$ (0.67 ms)
- $3 \times T_{\text{slot}}$ (2ms)
- $\tau_{\text{UEP}} = 7.5 \times T_{\text{slot}}$ (5ms)
- 0-255 chips

- Uplink DPCCH
- HS-PDSCH
- HS-DPCCH

- $m \times 256$ chips
HSDPA Architecture

Evolution from R99/R4
- HSDPA functionality is intended for transport of dedicated logical channels
- Takes into account the impact on R.99 networks

HSDPA in R5
- 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 Node B
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

**TFRC:** Transport Format and Resource Combination
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

MAC-hs
- Disassembly
- Reordering
- Re-ordering queue distribution
- HARQ

Associated Uplink Signalling
HS-DPCCH

Associated Downlink Signalling
HS-SCCH

To MAC-d

MAC – Control
Data Flow through Layer 2
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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<tr>
<td>Category 1</td>
<td>5</td>
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**Note:** UEs of Categories 11 and 12 support QPSK only

*cf. TS 25.306*
Channel Quality Indicator (CQI)

- Signalled to the Node B in UL each 2ms on HS-DPCCH
- Integer number from 0 to 30 corresponds to a Transport Format Resource Combination (TFRC) given by
  - Modulation
  - Number of channelisation 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 Δ</th>
<th>Nᵢₑ</th>
<th>Xᵣᵥ</th>
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<tr>
<td>0</td>
<td>N/A</td>
<td>Out of range</td>
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</table>

- **Tables specified in TS 25.214**
  - For each UE category
  - Condition: BLER ≤ 10%
- **Example for UE category 10**
HSDPA Fast Scheduling

3G (Rel.99) with dedicated channels

Note: No fast channel quality feedback

3G with high speed feedback/scheduling on shared channels

2 TTI @1.2M
2 TTI @76k
7 TTI @614k
1 TTI @1.2M
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 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 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
Mobility Procedures II

- Inter-Node B 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

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”
### Abbreviations

<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>
<tr>
<td>AM</td>
<td>Acknowledged (RLC) Mode</td>
</tr>
<tr>
<td>AMC</td>
<td>Adaptive Modulation &amp; Coding</td>
</tr>
<tr>
<td>CAC</td>
<td>Call Admission Control</td>
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<tr>
<td>CDMA</td>
<td>Code Division Multiple Access</td>
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<tr>
<td>CQI</td>
<td>Channel Quality Indicator</td>
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<tr>
<td>DBC</td>
<td>Dynamic Bearer Control</td>
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<tr>
<td>DCH</td>
<td>Dedicated Channel</td>
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<tr>
<td>DPCCH</td>
<td>Dedicated Physical Control Channel</td>
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<tr>
<td>FDD</td>
<td>Frequency Division Duplex</td>
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<td>FEC</td>
<td>Forward Error Correction</td>
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<td>First In First Out</td>
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<td>GoS</td>
<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>HSDPA</td>
<td>High Speed Downlink Packet Access</td>
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<td>HS-DPCCH</td>
<td>High Speed Dedicated Physical Control Channel</td>
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<td>HS-DSCH</td>
<td>High Speed Downlink Shared Channel</td>
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<td>HS-PDSCH</td>
<td>High Speed Physical Downlink Shared Channel</td>
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<td>HS-SCCH</td>
<td>High Speed Signaling Control Channel</td>
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<td>IE</td>
<td>Information Element</td>
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<td>MAC-d</td>
<td>dedicated Medium Access Control</td>
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<td>MAC-hs</td>
<td>high-speed Medium Access Control</td>
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<td>Mux</td>
<td>Multiplexing</td>
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<td>NACK</td>
<td>Negative Acknowledgement</td>
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<td>NBAP</td>
<td>NodeB Application Part</td>
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<td>OVSF</td>
<td>Orthogonal Variable SF (code)</td>
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<td>PDU</td>
<td>Protocol Data Unit</td>
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<td>PHY</td>
<td>Physical Layer</td>
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<td>Quality of Service</td>
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<td>Quadrature Phase Shift Keying</td>
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<td>Service Data Unit</td>
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<td>SF</td>
<td>Spreading Factor</td>
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<td>Transport Block</td>
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<td>TFRC</td>
<td>Transport Format &amp; Resource Combination</td>
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<td>TFRC Indicator</td>
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<td>Transmission Time Interval</td>
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<td>Unacknowledged (RLC) Mode</td>
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<td>16QAM</td>
<td>16 (state) Quadrature Amplitude Modulation</td>
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