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 (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 Mbit/s, (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<sub>16,4</sub>
    - 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

Cell 1

- Serving HS-DSCH cell

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

Cell 2

UL/DL DPCH

HS-DPCCH

HS-SCCH

HS-PDSCH

UE

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 information (CQI)
  - Fixed SF = 256, code multiplexed to UL DPCCH
  - Feedback sent ~5msec after received data
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 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
Data Flow through Layer 2

Reassembly
Segmentation & Concatenation

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)
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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<tbody>
<tr>
<td>Category 1</td>
<td>5</td>
<td>3</td>
<td>7298</td>
<td>19200</td>
<td>1.2</td>
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<td>Category 2</td>
<td>5</td>
<td>3</td>
<td>7298</td>
<td>28800</td>
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<td>28800</td>
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<td>Category 4</td>
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<td>2</td>
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<td>38400</td>
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<td>Category 5</td>
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<td>7298</td>
<td>57600</td>
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<td>Category 6</td>
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<td>7298</td>
<td>67200</td>
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<td>Category 7</td>
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<td>14411</td>
<td>115200</td>
<td>7.2</td>
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<td>Category 8</td>
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<td>14411</td>
<td>134400</td>
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<td>Category 9</td>
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<td>1</td>
<td>20251</td>
<td>172800</td>
<td>10.1</td>
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<td>Category 10</td>
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<td>27952</td>
<td>172800</td>
<td>14.0</td>
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<td>Category 11*</td>
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<td>2</td>
<td>3630</td>
<td>14400</td>
<td>0.9</td>
</tr>
<tr>
<td>Category 12*</td>
<td>5</td>
<td>1</td>
<td>3630</td>
<td>28800</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Note: UEs of Categories 11 and 12 support QPSK only

cf. TS 25.306
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

C/I
C/I
CQI
CQI
C/Q
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 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-Node B serving HS-DSCH cell change
- Note: MAC-hs needs to be transferred to new NodeB!
HSDPA – Managed Resources

a) OVSF Code Tree

SF=16

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

Higher Layer Impact

<table>
<thead>
<tr>
<th>Throughput [kbit/s]</th>
<th>Cat.6 - 336bit</th>
<th>Cat.8 - 336bit</th>
<th>Cat.8 - 656bit</th>
<th>Cat.10 - 336bit</th>
<th>Cat.10 - 656bit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. RLC Throughput, RTT = 120msec</td>
<td>4000</td>
<td>6000</td>
<td>8000</td>
<td>10000</td>
<td>12000</td>
</tr>
<tr>
<td>Max. RLC Throughput, RTT = 80msec</td>
<td>4000</td>
<td>6000</td>
<td>8000</td>
<td>10000</td>
<td>12000</td>
</tr>
<tr>
<td>Max. MAC-hs Throughput</td>
<td>14000</td>
<td>12000</td>
<td>10000</td>
<td>8000</td>
<td>6000</td>
</tr>
</tbody>
</table>
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>Full Form</th>
</tr>
</thead>
<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>
</tr>
<tr>
<td>CDMA</td>
<td>Code Division Multiple Access</td>
</tr>
<tr>
<td>CQI</td>
<td>Channel Quality Information</td>
</tr>
<tr>
<td>DBC</td>
<td>Dynamic Bearer Control</td>
</tr>
<tr>
<td>DCH</td>
<td>Dedicated Channel</td>
</tr>
<tr>
<td>DPCCH</td>
<td>Dedicated Physical Control Channel</td>
</tr>
<tr>
<td>FDD</td>
<td>Frequency Division Duplex</td>
</tr>
<tr>
<td>FEC</td>
<td>Forward Error Correction</td>
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<tr>
<td>FIFO</td>
<td>First In First Out</td>
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<tr>
<td>GoS</td>
<td>Grade of Service</td>
</tr>
<tr>
<td>HARQ</td>
<td>Hybrid Automatic Repeat Request</td>
</tr>
<tr>
<td>H-RNTI</td>
<td>HSDPA Radio Network Temporary Identifier</td>
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<tr>
<td>HSDPA</td>
<td>High Speed Downlink Packet Access</td>
</tr>
<tr>
<td>HS-DPCCH</td>
<td>High Speed Dedicated Physical Control Channel</td>
</tr>
<tr>
<td>HS-DSCH</td>
<td>High Speed Downlink Shared Channel</td>
</tr>
<tr>
<td>HS-PDSCH</td>
<td>High Speed Physical Downlink Shared Channel</td>
</tr>
<tr>
<td>HS-SCCH</td>
<td>High Speed Signaling Control Channel</td>
</tr>
<tr>
<td>IE</td>
<td>Information Element</td>
</tr>
<tr>
<td>MAC-d</td>
<td>dedicated Medium Access Control</td>
</tr>
<tr>
<td>MAC-hs</td>
<td>high-speed Medium Access Control</td>
</tr>
<tr>
<td>Mux</td>
<td>Multiplexing</td>
</tr>
<tr>
<td>NACK</td>
<td>Negative Acknowledgement</td>
</tr>
<tr>
<td>NBAP</td>
<td>NodeB Application Part</td>
</tr>
<tr>
<td>OVSF</td>
<td>Orthogonal Variable SF (code)</td>
</tr>
<tr>
<td>PDU</td>
<td>Protocol Data Unit</td>
</tr>
<tr>
<td>PHY</td>
<td>Physical Layer</td>
</tr>
<tr>
<td>QoS</td>
<td>Quality of Service</td>
</tr>
<tr>
<td>QPSK</td>
<td>Quadrature Phase Shift Keying</td>
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<tr>
<td>RB</td>
<td>Radio Bearer</td>
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<tr>
<td>RL</td>
<td>Radio Link</td>
</tr>
<tr>
<td>RLC</td>
<td>Radio Link Control</td>
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<td>RRC</td>
<td>Radio Resource Control</td>
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<td>RRM</td>
<td>Radio Resource Management</td>
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<tr>
<td>SDU</td>
<td>Service Data Unit</td>
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<tr>
<td>SF</td>
<td>Spreading Factor</td>
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<tr>
<td>TB</td>
<td>Transport Block</td>
</tr>
<tr>
<td>TFRC</td>
<td>Transport Format &amp; Resource Combination</td>
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<tr>
<td>TFRI</td>
<td>TFRC Indicator</td>
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<tr>
<td>TTI</td>
<td>Transmission Time Interval</td>
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<tr>
<td>UM</td>
<td>Unacknowledged (RLC) Mode</td>
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<tr>
<td>16QAM</td>
<td>16 (state) Quadrature Amplitude Modulation</td>
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