Enhanced Uplink Dedicated Channel (EDCH)
High Speed Uplink Packet Access (HSUPA)

- EDCH Background & Basics
- Channels/ UTRAN Architecture
- Principles: scheduling, handover
- Performance Results
Background

- E-DCH is a Rel-6 feature with following targets
  - Improve coverage and throughput, and reduce delay of the uplink dedicated transport channels
  - Priority given to services such as streaming, interactive and background services, conversational (e.g. VoIP) also to be considered
  - Full mobility support with optimizing for low/medium speed
  - Simple implementation
  - Special focus on co-working with HSDPA

- Standardization started in September 2002
  - Study item completed in February 2004
  - Stage II/III started in September/December 2004
  - Release 6 frozen in December 2005/March 2006
  - Various improvements have been introduced in Rel-7 & Rel-8
E-DCH Basics

E-DCH is a modification of DCH – *Not* a shared channel, such as HSDPA in the downlink!!

- PHY taken from R99
  - Turbo coding and BPSK modulation
  - Power Control
  - 10 msec/ 2 msec TTI
  - Spreading on separate OVSF code, i.e. code mux with existing PHY channels

- MAC similarities to HSDPA
  - Fast scheduling
  - Stop and Wait HARQ: but synchronous

- New principles
  - Intra Node B “softer” and Inter Node B “soft” HO should be supported for the E-DCH with HARQ
  - Scheduling distributed between UE and NodeB
E-DCH Scheduling

- UE sends scheduling information
  - MAC-e signaling
  - On E-DPCCH: “happy bit”
- NodeB allocates the resources
  - Absolute/relative scheduling grants
  - Algorithms left open from standards
- Depending on the received grants, UE decides on transmission
  - Maintains allocated resources by means of internal serving grants
  - Selects at each TTI amount of E-DCH data to transmit
  - Algorithms fully specified by UMTS standard
UMTS Channels with E-DCH

- **Cell 1**
  - E-DCH cell
  - UL/DL DPCH
  - R99 DCH (in SHO)
    - UL/DL signalling (DCCH)
    - UL/DL CS voice/data

- **Cell 2**
  - UL/LD DPCH

**Rel-6 E-DCH (in SHO)**
- UL PS service (DTCH)
- UL Signalling (DCCH)

- **Rel-5 HS-DSCH (not shown)**
  - DL PS service (DTCH)
  - DL signalling (Rel-6, DCCH)
E-DCH Channels

- **E-DPDCH**
  - Carries the data traffic
  - Variable SF = 256 ... 2
  - UE supports up to 4 E-DPDCH

- **E-DPCCH**
  - Contains the configuration as used on E-DPDCH
  - Fixed SF = 256

- **E-RGCH/ E-HICH**
  - E-HICH carries the HARQ acknowledgements
  - E-RGCH carries the relative scheduling grants
  - Fixed SF = 128
  - Up to 40 users multiplexed onto the same channel by using specific signatures

- **E-AGCH**
  - Carries the absolute scheduling grants
  - Fixed SF = 256
Timing Relation (UL)

Downlink DPCH

| CFN | CFN+1 |

Uplink DPCCH

0.4 × T_{slot} (1024 chips)
±148 chips

15 × T_{slot} (10 msec)

E-DPDCH/ E-DPCCH

10 msec TTI

2 msec TTI

Subframe #0 Subframe #1 Subframe #2 Subframe #3 Subframe #4

10 msec

E-DPDCH/ E-DPCCH time-aligned to UL DPCCH
## HSUPA UE Categories

<table>
<thead>
<tr>
<th>E-DCH Category</th>
<th>Max. num. Codes</th>
<th>Min SF</th>
<th>EDCH TTI</th>
<th>Maximum MAC-e TB size</th>
<th>Theoretical maximum PHY data rate (Mbit/s)</th>
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<tbody>
<tr>
<td>Category 1</td>
<td>1</td>
<td>SF4</td>
<td>10 msec</td>
<td>7110</td>
<td>0.71</td>
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<td>Category 2</td>
<td>2</td>
<td>SF4</td>
<td>10 msec/2 msec</td>
<td>14484/2798</td>
<td>1.45/1.4</td>
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<td>14484</td>
<td>1.45</td>
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<td>SF2</td>
<td>10 msec/2 msec</td>
<td>20000/5772</td>
<td>2.0/2.89</td>
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<td>SF2</td>
<td>10 msec/2 msec</td>
<td>20000/11484</td>
<td>2.0/5.74</td>
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</tbody>
</table>

Note: When 4 codes are transmitted, 2 codes are transmitted with SF2 and 2 with SF4

cf. TS 25.306
E-DCH UTRAN Architecture

Evolution from Rel-5
- E-DCH functionality is intended for transport of dedicated logical channels (DTCH/ DCCH)

E-DCH in Rel-6
- Additions in RRC to configure E-DCH
- RLC unchanged (UM & AM)
- New MAC-es entity with link to MAC-d
- New MAC-e entity located in the Node B
- MAC-e entities from multiple NodeB may serve one UE (soft HO)
MAC-e/es in UE

MAC-e/es Functions
- Priority handling
  - Per logical channel
- Multiplexing
  - MAC-d flow concept
  - Mux of data from multiple MAC-d flows into single MAC-e PDU
- Scheduling
  - Maintain scheduling grant
  - E-TFC selection
  - HARQ handling

Cf. 25.309
MAC-e in NodeB

MAC-e Functions
- Per user
  - HARQ handling: ACK/ NACK generation
  - De-multiplexing
  - E-DCH control: Rx/ Tx control signals
- E-DCH scheduling for all users
  - Assign resources (scheduling grants)
- Iub overload control

Cf. 25.309
MAC-es in SRNC

MAC-es Functions
- Queue distribution
- Reordering
  - Per logical channel
  - In-sequence delivery
  - Macro-diversity combining: frame selection
- Disassembly

Cf. 25.309
Data Flow through Layer 2

- **DDI**: Data Description Indicator (6bit)
  - MAC-d PDU size
  - Log. Channel ID
  - Mac-d flow ID
- **N**: Number of MAC-d PDUs (6bit)
- **TSN**: Transmission Sequence Number (6bit)
Hybrid ARQ Operation

- N-channel parallel HARQ with stop-and-wait protocol
  - Number of HARQ processes $N$ to allow uninterrupted E-DCH transmission
    - 10 msec TTI: 4
    - 2 msec TTI: 8
- Synchronous retransmissions
  - Retransmission of a MAC-e PDU follows its previous HARQ (re)transmission after $N$ TTI = 1 RTT
  - Incremental Redundancy via rate matching
- Max. # HARQ retransmissions specified in HARQ profile
E-DCH UE Scheduling

- UE maintains internal serving grant SG
- SG are quantized Maximum E-DPDCH/ DPCCH power ratio (TPR), which are defined by 3GPP
- Reception of absolute grant: SG = AG
  - No transmission: SG = “Zero_Grant”
- Reception of relative grants: increment/ decrement index of SG in the SG table
- AG and RG from serving RLS can be activated for specific HARQ processes for 2msec TTI
- UE selects E-TFC at each TTI
- Allocates the E-TFC according to the given restrictions
  - Serving grant SG
  - UE transmit power
- Provides priority between the different logical channels
### Scheduling Grant Table

<table>
<thead>
<tr>
<th>Index</th>
<th>Scheduled Grant</th>
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<td>37</td>
<td>(168/15)²*6</td>
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<td>36</td>
<td>(150/15)²*6</td>
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<td>35</td>
<td>(168/15)²*4</td>
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<tr>
<td>34</td>
<td>(150/15)²*4</td>
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<td>33</td>
<td>(134/15)²*4</td>
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<td>32</td>
<td>(119/15)²*4</td>
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<td>31</td>
<td>(150/15)²*2</td>
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<td>30</td>
<td>(95/15)²*4</td>
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<tr>
<td>29</td>
<td>(168/15)²</td>
</tr>
<tr>
<td>28</td>
<td>(95/15)²</td>
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<tr>
<td>27</td>
<td>(85/15)²</td>
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<tr>
<td>26</td>
<td>(75/15)²</td>
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<tr>
<td>25</td>
<td>(65/15)²</td>
</tr>
<tr>
<td>24</td>
<td>(55/15)²</td>
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<tr>
<td>23</td>
<td>(45/15)²</td>
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<tr>
<td>22</td>
<td>(35/15)²</td>
</tr>
<tr>
<td>21</td>
<td>(25/15)²</td>
</tr>
<tr>
<td>20</td>
<td>(15/15)²</td>
</tr>
</tbody>
</table>

- Scheduling grants are max. E-DPDCH/ DPCCH power ratio (TPR – traffic to pilot ratio)
  - Power Ratio is related to UE data rate

- Relative Grants
  - SG moves up/ down when RG = UP/ DOWN

- Absolute Grants
  - SG jumps to entry for AG
  - 2 reserved values for ZERO_GRANT/ INACTIVE
Timing Relation for Scheduling Grants

- AG and RG associated with specific uplink E-DCH TTI, i.e. specific HARQ process
  - Association based on the timing of the E-AGCH and E-RGCH. Timing is tight enough that this relationship is un-ambiguous.
  - Example: 10msec TTI
Scheduling Information

- Happy bit signaling
  - One bit status flag send on E-DPCCH at each TTI
- Criterion for happy bit
  - Set to “unhappy” if UE is able to send more data than given with existing serving grant
  - Otherwise set to “happy”
- Scheduling Information Reporting
  - Content of MAC-e report
    - Provides more detailed information (log. channel, buffer status, UE power headroom)
    - Will be sent less frequently (e.g. every 100 msec)
  - Parameters adjusted by RRC (e.g. reporting intervals, channels to report)
HSUPA Scheduling

EDCH NodeB Scheduler

- QoS Parameters
  - Throughput bounds
- Feedback from UE
  - Scheduling Information Reports
- Radio resources
  - UL Load (interference)
- Other constraints
  - NodeB decoding capabilities
  - Iub bandwidth limit
- UE capabilities

Allocate (absolute/relative) Scheduling Grants (max. allowed power offsets)

UE allocates transport formats according to the allocated grants
NodeB Load Scheduling Principle

E-DCH scheduler constraint
- Keep UL load within the limit

Scheduler controls:
- E-DCH load portion of non-serving users from other cells
- E-DCH resources of each serving user of own cell

Principles:
- Rate vs. time scheduling
- Dedicated control for serving users
- Common control for non-serving users

Note: Scheduler cannot exploit fast fading!
E-DCH Scheduling Options

Rate Scheduling

- UEs are continuously active
- Data rate is incremental increased/decreased by relative scheduling grants
- No sync between UEs required
- Load variations can be kept low
- For low to medium data rates

Time Scheduling

- UEs are switched on/off by absolute scheduling grants
- UEs should be in sync
- Load variations might be large
- For (very) high data rates
Non-scheduled Mode

- Configured by the SRNC
  - UE is allowed to send E-DCH data at any time
  - Signaling overhead and scheduling delay are minimized
  - Support of QoS traffic on E-DCH, e.g. VoIP & SRB

- Characteristics
  - Resource given by SRNC:
    - Non-scheduled Grant = max. # of bits that can be included in a MAC-e PDU
    - UTRAN can reserve HARQ processes for non-scheduled transmission
  - Non-scheduled transmissions defined per MAC-d flow
    - Multiple non-scheduled MAC-d flows may be configured in parallel
    - One specific non-scheduled MAC-d flow can only transmit up to the non-scheduled grant configured for that MAC-d flow
  - Scheduled grants will be considered on top of non-scheduled transmissions
    - Scheduled logical channels cannot use non-scheduled grant
    - Non-scheduled logical channels cannot transmit data using Scheduling Grant
E-DCH Power Control – Tx Power of E-DPCCH/ E-DPDCH

- E-DCH is power-controlled the same way as R99 DCH
  - E-DPCCH/ E-DPDCH power controlled with offsets relative to DPCCH
    - DPCCH still under closed inner/outer loop power control
    - E-DPCCH/ DPCCH offset signaled by RRC
  - E-DPDCH/ DPCCH offset adjusted according to selected E-TFC
    - Reference PO/ reference E-TFCI signaled by RRC
    - Calculated for other E-TFCI from reference PO (specified in standard)
    - Additional offset $\Delta$HARQ in HARQ profile for each MAC-d flow to satisfy different QoS requirements

- E-DCH quality control loop
  - Each MAC-es PDU received by the SRNC contains indication of how many retransmissions were required to decode it
    - Measure of the received E-DCH quality
  - SRNC may react as follows
    - Update SIR target setting for DPCCH via DCH FP signaling
    - Signal new power offset settings to UE/ NodeB via RRC signaling
E-DCH Operation in Soft Handover

- Macro-diversity operation on multiple NodeBs
  - Softer handover combining in the same NodeB
  - Soft handover combining in RNC (part of MAC-es)
- Independent MAC-e processing in both NodeBs
  - HARQ handling rule: if at least one NodeB tells ACK, then ACK
  - Scheduling rule: relative grants "DOWN" from any NodeB have precedence
Mobility Handling

- The UE uses soft handover for associated DCH as well as for E-DCH
  - Using existing triggers and procedures for the active set update (events 1A, 1B, 1C)
  - E-DCH active set is equal or smaller than DCH active set
    - New event 1J: non-active E-DCH link becomes better than active one

- The UE receives AG on E-AGCH from only one cell out of the E-DCH active set (serving E-DCH cell)
  - E-DCH and HSDPA serving cell must be the same
  - Hard Handover, i.e. change of serving E-DCH cell
  - Using RRC procedures, which maybe triggered by event 1D
    - Could be also combined with Active Set Update
Mobility Procedures

Inter-Node B serving E-DCH cell change within E-DCH active set
Note: MAC-e still established in both NodeBs!
Serving E-DCH Cell Change

- Handover of E-DCH scheduler control
  - No changes in UL transport bearer
  - No MAC-es RESET
- Handover of HS-DSCH serving cell
  - DL transport bearer setup
  - MAC-hs RESET

**Diagram Details:**
- **SRNC** = DRNC
- **SRNC**
- **Target serving E-DCH cell**
- **Source serving E-DCH cell**
- **UE**
- **Radio Bearer Reconfiguration**
- **RL Reconfiguration Prepare**
- **RL Reconfiguration Ready**
- **RL Reconfiguration Commit**
- **Radio Bearer Reconfiguration Complete**
- **UE receives now AG & dedicated RG from target cell**
- **Serving E-DCH cell change decision i.e. event 1D**
- **If new NodeB**
- **Synchronous Reconfiguration with \( T_{activation} \)**
E-DCH RRM Principle

E-DCH resources controlled by:
- UL load target
- E-DCH non-serving load portion

NodeB schedules E-DCH users according to RNC settings:
- Priority for non E-DCH traffic

RNC still controls non E-DCH load portion:
- By means of e.g. admission/congestion control
- Based on an estimate of non-E-DCH load
User Throughput vs. Aggregate Cell Throughput

- 36 cells network
- UMTS composite channel model
- FTP traffic model (2 Mbyte upload, 30 seconds thinking time)
- Maximum cell throughput reached for about 7...8 UEs per cell
  - Cell throughput drops if #UEs increases further since the associated signaling channel consume UL resources too
Single User Performance

- Average user throughput (RLC layer) for different channel profiles
  - 1 UE in the network
  - 1 target HARQ transmission
- For AWGN channel conditions:
  - 10ms TTI: up to 1.7 Mbps (near theoretical limit of 1.88 Mbps)
  - 2ms TTI: up to 3.6 Mbps (below theoretical limit of 5.44 Mbps)
  - E.g. due to restrictions from RLC layer (window size, PDU size)

![Graph showing average user throughput for different scenarios and TTI values.](image)
References

- Papers

- Standards
  - TS 25.xxx series: RAN Aspects
  - TR 25.896: “Feasibility Study for Enhanced Uplink for UTRA FDD”
  - TR 25.808: “FDD Enhanced Uplink; Physical Layer Aspects”
  - TR 25.309/ 25.319 (Rel.7 onwards): “Enhanced Uplink: Overall Description (Stage 2)”
### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACK</td>
<td>(positive) Acknowledgement</td>
</tr>
<tr>
<td>AG</td>
<td>Absolute Grant</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>BO</td>
<td>Buffer Occupancy</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>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>DDI</td>
<td>Data Description Indicator</td>
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<tr>
<td>DPCCH</td>
<td>Dedicated Physical Control Channel</td>
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<tr>
<td>E-AGCH</td>
<td>E-DCH Absolute Grant Channel</td>
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<td>E-DCH</td>
<td>Enhanced (uplink) Dedicated Channel</td>
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<td>E-HICH</td>
<td>E-DCH HARQ Acknowledgement Indicator Channel</td>
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<td>E-RGCH</td>
<td>E-DCH Relative Grant Channel</td>
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<td>E-TFC</td>
<td>E-DCH Transport Format Combination</td>
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<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>FIFO</td>
<td>First In First Out</td>
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<td>FP</td>
<td>Framing Protocol</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>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-e/es</td>
<td>E-DCH Medium Access Control</td>
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<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>Protocol Data Unit</td>
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<td>Physical Layer</td>
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<td>Power Offset</td>
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<td>Traffic to Pilot Ratio</td>
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<td>Transmission Time Interval</td>
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