Enhanced High-Speed Packet Access
HSPA+

- Background: HSPA Evolution
- Higher data rates
- Signaling Improvements
- Architecture Evolution/ Home NodeB
HSPA+ (HSPA Evolution) Background

- For operators deploying High Speed Packet Access (HSPA*) now, there is the need to continue enhancing the HSPA technology
  - 3GPP Long Term Evolution (LTE) being standardized now, but not backwards compatible with HSPA
  - 223 HSDPA operators in service in 93 countries (Oct. 08)**
  - Investment protection needed for current HSPA deployments

- HSPA+ effort introduced in 3GPP in March 2006
  - Initiated by 3G Americas & the GSMA
  - HSPA+ defines a broad framework and set of requirements for the evolution of HSPA
    - Rel.-7: improvements mainly in downlink
    - Rel.-8: further uplink enhancements

*HSPA is the combination of HSDPA and HSUPA
**http://www.3gamericas.org/pdfs/Global_3G_Status_Update.pdf
**HSPA+ Goals**

Based on the importance of the HSPA-based radio network, 3GPP agreed that HSPA+ should:

- Provide **spectrum efficiency, peak data rates & latency** comparable to LTE in 5 MHz
  - Exploit full potential of the CDMA air interface before moving to OFDM
- Allow operation in an **optimized packet-only** mode for voice and data
  - Utilization of shared channels only
- Be **backward compatible** with Release 99 through Release 6
- Offer a **smooth migration path to LTE/SAE** through commonality, and facilitate joint technology operation
- Ideally, only need a simple infrastructure upgrade from HSPA to HSPA+
- HSPA evolution is two-fold
  - Improvement of the radio
  - Architecture evolution

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**Aggressive HSPA+ goals for enhancing HSPA**
Higher Order Modulations (HOMs)

- **Uplink**
  - BPSK: 2 bits/symbol
- **Downlink**
  - 16QAM: 4 bits/symbol
  - 64QAM: 6 bits/symbol

- Increases the peak data rate in a high SNR environment
- Very effective for micro cell and indoor deployments

**HOMs increase the number of bits/symbols transmitted, thereby increasing the peak rate**
The use of Higher Order Modulations significantly increases the theoretical peak rates of HSPA.

Provides data rate benefits for users in very good channel conditions (e.g. quasi-static or fixed users close to the cell center, lightly loaded conditions).

* Part of 3GPP Rel-8

**Using 2 resource blocks for PUCCH and max prime factor restriction = 5
HSDPA 64-QAM – Micro Cell / Hotspot Deployment

~30% throughput increase for top 10% users

Key assumptions: 500m inter-site distance and 6dB attenuation from non-serving cells (models site-to-site isolation)

Results from 3GPP R1-063415

2 Rx Antenna, Equalizer

HOMs provide significant improvements for “hot spot” deployments
Multiple Antenna Techniques

- **Spatial Division Multiple Access (SDMA) or Beamforming**
  - Different data streams sent to different users using the same codes
  - Improves throughput even in low SINR conditions (cell-edge)
  - Already supported in Release 5/6, works with single antenna UEs

- **Spatial Multiplexing (SM) → SU-MIMO**
  - Multiple data streams sent to the same user
  - Significant throughput gains for UEs in high SINR conditions
  - *Double Transmit Adaptive Array (D-TxAA) was adopted for Rel-7 FDD and is based on dual codeword SU-MIMO*

- **Closed Loop Transmit Diversity (CLTD)**
  - Improves reliability on a single data stream
  - Fall back scheme if channel conditions do not allow SM
Fixed Beam Switching (FBS)

- Spatial partitioning of the sector area by help of a fixed number of beams
- S-CPICH (per beam) is introduced for improving UE channel estimation
- Beam specific secondary scrambling codes can be applied → code limitation preventable

From UL

Selection

Fixed spatial filters, e.g. Butler-Matrix or baseband implementation
Adaptive Beamforming/ Beam Pointing (BP)

- User specific antenna patterns are formed depending on a pre-defined optimisation criteria, e.g.
  - $MaxSINR$
  - $MaxSNR$

- $maxSNR$ significantly outperforms $maxSIR$

- For a low angular spread BP is nearly equivalent to $maxSNR$
The MIMO channel consists of $M$ Tx and $N$ Rx antennas. Each Tx antenna transmits a different signal. The signal from Tx antenna $j$ is received at all Rx antennas $i$. Channel capacity can increase linearly.

$$C_{\text{MIMO}} \leq \min\{M,N\} \cdot C_{\text{SISO}}$$
MIMO in HSPA+

Release 7 MIMO for HSDPA
- 2x2
- D-TxAA, Mode 1
- HS-DPCCH-only feedback (CQI and PCI reported on HS-DPCCH)
- PARC Algorithm with support for dual stream and single stream (different from Tx diversity i.e.; change per subframe and no antenna verification)
MIMO Performance Benefits

- 2x2 D-TxAA MIMO scheme doubles peak rate from 14.4 Mbps to 28.8 Mbps
- 2x2 D-TxAA MIMO provides significant experienced peak, mean & cell edge user data rate benefits for isolated cells or noise/coverage limited cells
- 2x2 D-TxAA MIMO provides 20%-60% larger spectral efficiency than 1x2

**Note:** All gains normalized to Near Cell Center SISO Data Rate

MIMO provides significant data rate and spectral efficiency benefits for isolated, noise limited cells
### HSDPA – UE Physical Layer Capabilities

<table>
<thead>
<tr>
<th>HS-DSCH Category</th>
<th>Maximum number of HS-DSCH multi-codes</th>
<th>Supported Modulation Formats</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>
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Note: UEs of Categories 15 – 20 support MIMO

cf. TS 25.306
### E-DCH – UE Physical Layer Capabilities

<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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<td>14484/ 2798</td>
<td>1.45/ 1.4</td>
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<tr>
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<td>Category 4</td>
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<td>20000/ 5772</td>
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<td>2.0</td>
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<td>10 msec/ 2 msec</td>
<td>20000/ 11484</td>
<td>2.0/ 5.74</td>
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<td>Category 7 (Rel.7)</td>
<td>4</td>
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<td>10 msec/ 2 msec</td>
<td>20000/ 22996</td>
<td>2.0/ 11.5</td>
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</table>

**NOTE 1:** When 4 codes are transmitted in parallel, two codes shall be transmitted with SF2 and two codes with SF4

**NOTE 2:** UE Category 7 supports 16QAM

*cf. 25.306*
Continuous Packet Connectivity (CPC)

- Uplink DPCCH gating during inactivity → significant reduction in UL interference
- F-DPCH gating during inactivity
- New uplink DPCCH slot format optimized for transmission
  DPCCH only

- HS-SCCH-less transmission introduced to reduce signaling bottleneck for real-time-services on HSDPA

CPC significantly reduces control channel overhead for low bit rate real-time services (e.g. VoIP)
CPC Performance Benefits

- CPC provides up to a factor of two VoIP on HSPA capacity benefit compared to Rel-99 AMR12.2 circuit voice and 35-40% benefit compared to Rel-6 VoIP on HSPA

![Graph showing VoIP capacity gains for AMR12.2, AMR7.95, and AMR5.9]

Note: All capacity gains normalized to AMR12.2 Circuit Voice Capacity

*CPC provides significant VoIP on HSPA capacity benefits*

*All VoIP on HSPA capacities assume two receive antennas in the terminal*
“Always On” Enhancement of CPC

- CPC allows UEs in CELL_DCH to “sleep” during periods of inactivity
  - Reduces signaling load and battery consumption (in combination with DRX)
- Allows users to be kept in CELL_DCH with HSPA bearers configured
- Need to page and re-establish bearers leads to call set up delay

Without CPC, users typically kept in URA_PCH or CELL_PCH state to save radio resources and battery

- CPC avoids re-establishment delays → improves “always on” experience
Enhanced CELL_FACH & Enhanced Paging Procedure

- UEs are not always kept in CELL_DCH state, eventually fall back to CELL_PCH/URA_PCH
- HSPA+ introduces enhancements to reduce the delay in signaling the transition to CELL_DCH → use of HSDPA in CELL_FACH and URA/CELL_PCH states instead of S-CCPCH
  - Enhanced CELL_FACH
  - Enhanced Paging procedure
- In Rel.-8 work item opened to improve RACH procedure
  - Direct use of HSUPA in CELL_FACH

Enhanced CELL_FACH/Paging/RACH reduces setup delay → improves PoC
E-RACH – High level description

- RACH preamble ramping as in R’99 with AICH/E-AICH acknowledgement
- Transition to E-DCH transmission in CELL_FACH
  - Possibility to seamlessly transfer to Cell_DCH
- NodeB can control common E-DCH resource in CELL_FACH
  - Resource assignment indicated from NodeB to UE
UTRAN Architecture

TCP RTT: 
~300ms

Multiple ARQ loops at different levels
RLC Throughput Limit vs. RLC Window Size

Theoretical limit: PHY >> RLC

Options to increase data rate:
- Increase PDU size/
  RLC window
- Reduce RTT

HSDPA increases peak data rate significantly, while it does not reduce RLC RTT equivalently!
Enhanced Layer-2 Support for High Data Rates

- Release 6 RLC layer cannot support new peak rates offered by HSPA+ features such as MIMO & 64-QAM
  - RLC-AM peak rate limited to ~13 Mbps, even with aggressive settings for the RLC PDU size and RLC-AM window size
- Release 7 introduces new Layer-2 features to improve HSDPA
  - Flexible RLC PDU size
  - MAC-ehs layer segmentation/reassembly (based on radio conditions)
  - MAC-ehs layer flow multiplexing
- Release 8 improves E-DCH
  - MAC-i/ MAC-is

Layer-2 enhancements to support higher rates of HSPA+
MAC-ehs in NodeB

MAC-ehs Functions (TS 25.321)
- Flow Control
- Scheduling/ Priority handling
- HARQ handling
- TFRC Selection
- Priority Queue Mux
- Segmentation
Evolved HSPA Architecture (1) – Objectives

- Further improve latency and bit rate with limited and controlled hardware and software impacts
- Take advantage of these improvements as soon as today
  - E.g. independently of the availability of the SAE Core
- Operate as a packet-only network based on shared channels only
- Backwards compatible with legacy terminals
- Simple upgrade of existing infrastructure (for both hardware, software)
2 deployment scenarios: standalone UTRAN or carrier sharing with "legacy" UTRAN
Evolved HSPA Architecture (3): Key features

- Optimal efficiency with all radio functions grouped together (Radio bearer control, RRC, handover control, RLC/MAC)

- Optimisation of resources
  - Central management of common channels

- Synergy with LTE
  - RLC, RRC already in the nodeB+
  - Ciphering and compression already in NodeB+ (with decision of PDCP in LTE eNodeB)
Home NodeB – Background

- Home NodeB (aka Femtocell) located at the customers premise
  - Connected via customers fixed line (e.g. DSL)
  - Small power (~100mW) to only provide coverage inside/ close to the building

- Advantages
  - Improved coverage esp. indoor
  - Single device for home/ on the move
  - Special billing plans (e.g. home zone)

- Challenges
  - Interference
  - Security
  - Costs
Home NodeB architecture principles based on extending Iu interface down to HNB (new Iuh interface)

RAN Gateway Approach with new “Iuh” Interface

- **Approach**
  - Leverage Standard CN Interfaces (Iu-CS/PS)
  - Minimise functionality within Gateway
  - Move RNC Radio Control Functions to Home NodeB and extend Iu NAS & RAN control layers over IP network

- **Features**
  - Security architecture
  - Plug-and-Play approach
  - Femto local control protocol
  - CS User Plane protocol
  - PS User Plane protocol
  - FMS interface
Summary

- Enhancements for HSDPA & E-DCH suggested for UMTS Rel.-7 & 8
  - Investment protection for HSPA operators
  - Fill the gap before deployment of LTE
  - Provide alternative to LTE in some selected scenarios

- Improvements on capacity and performance
  - Higher peak data rates
  - Signaling improvements
  - Architecture evolution

- HSPA+ features were designed to provide a smooth evolution from Rel-99 or Rel-5/Rel-6 HSPA by enabling:
  - Backwards compatibility
    - Legacy Rel-99/Rel-5/Rel-6 terminals can be supported on an HSPA+ carrier simultaneously with HSPA+ traffic
    - New HSPA+ terminals likely with support Rel-99 and/or Rel-5/Rel-6 HSPA
  - Simple upgrade of existing infrastructure (for both HW & SW)
A Smooth Evolution to HSPA+

HSPA+ IMPLEMENTATION
- 64-QAM DL/16-QAM UL, MIMO, L2 enh., CPC
- Enhanced CELL_FACH/ RACH/ Paging, Architecture Enhancements

HSPA+ Key Takeaways
- Higher Bit Rates & Increased Capacity
- Reduced Delay
- Smooth Evolution to HSPA+
- More than 2x HSPA peak rates, 35-40% improvement in VoIP capacity
- Saves 100s of ms of setup delay
- Coexistence with Rel99/HSDPA/HSUPA, SW upgrade to support HSPA+, availability expected 2008-2009

Enhanced performance on W-CDMA/HSPA through radio improvements and architecture evolution; smooth migration to LTE
HSDPA References

- **Papers:**

- **Standards**
  - TS 25.xxx series: RAN Aspects
  - TR 25.308 “HSDPA: UTRAN Overall Description (Stage 2)”
  - TR 25.319 “Enhanced Uplink: Overall Description (Stage 2)”
  - TR 25.903 “Continuous Connectivity for Packet Data Users”
  - TR 25.876 “Multiple-Input Multiple Output Antenna Processing for HSDPA”
  - TR 25.999 “HSPA Evolution beyond Release 7 (FDD)”
### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AICH</td>
<td>Acquisition Indicator Channel</td>
</tr>
<tr>
<td>AMR</td>
<td>Adaptive Multi-Rate</td>
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<tr>
<td>BPSK</td>
<td>Binary Phase Shift Keying</td>
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<td>CLTD</td>
<td>Closed Loop Transmit Diversity</td>
</tr>
<tr>
<td>CPC</td>
<td>Continuous Packet Connectivity</td>
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<td>CQI</td>
<td>Channel Quality Information</td>
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<td>DSL</td>
<td>Digital Subscriber Line</td>
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<td>E-RACH</td>
<td>Enhanced Random Access Channel</td>
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<td>F-DPCH</td>
<td>Fractional Dedicated Physical Control Channel</td>
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<td>GW</td>
<td>Gateway</td>
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<td>Home NodeB</td>
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<td>HOM</td>
<td>Higher Order Modulation</td>
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<td>HSPA</td>
<td>High-Speed Packet-Access</td>
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<td>IA</td>
<td>Intelligent Antenna</td>
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<td>LTE</td>
<td>Long Term Evolution</td>
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<td>enhanced high-speed Medium Access Control</td>
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<td>SDMA</td>
<td>Spatial-Division Multiple-Access</td>
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<td>SINR</td>
<td>Signal-to-Interference plus Noise Ratio</td>
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<td>Voice over Internet Protocol</td>
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<td>64QAM</td>
<td>64 (state) Quadrature Amplitude Modulation</td>
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