TECHNOLOGY WHITE PAPER

3G Evolution Towards High Speed Downlink Packet Access

This article describes the evolution of 3G with HSDPA. First market and technical motivations are explained. Then the different introduction phases of HDSPA to the market are handled, improving the data throughput and the spectral efficiency in a step by step approach. Further subjects are an overview of the basic features for HSDPA phase 1, a system overview and the impact of introducing this functionality into the RNC and Node B. In a next chapter the basics of HSDPA phase 2 are explained with some remarks to Node B V2 HW impacts. The article ends with a summary and a conclusion.

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3G EVOLUTION TOWARDS HIGH SPEED DOWNLINK PACKET ACCESS

The introduction of HSDPA will enhance 3G mobile systems by offering higher data rates in the downlink direction. The Evolium multi-standard base station architecture is ready for this evolution.

Introduction

Market motivation

High Speed Downlink Packet Access (HSDPA) supports the introduction of high bitrate data services and will increase network capacity, while minimizing operators' investment. It provides a smooth evolutionary path for Universal Mobile Telecommunications System (UMTS) networks to higher data rates and higher capacities, in the same way as Enhanced Data rates for GSM Evolution (EDGE) does in the Global System for Mobile communication (GSM) world. The introduction of shared channels for different users will guarantee that channel resources are used efficiently in the packet domain, and will be less expensive for users than dedicated channels.

A cost-effective system solution is essential to ensure that high bitrate data services can be offered by the operators at a price users will be willing to pay. With this in mind, it is important to reuse existing Alcatel platforms, such as Node Bs, Radio Network Controllers (RNC) and Operations and Maintenance Centers – Radio (OMCR), wherever possible, perhaps migrating to HSDPA via remote software reconfiguration.

Alcatel believes that operators can only offer low cost services to users if their systems offer low prices per Mbit/s.

Technical motivation

HSDPA aims to provide a spectrally efficient means to support services, such as Internet access and file download, that require high data rate packet transport on the downlink. It is well adapted to the urban environment and to indoor deployment.

HSDPA was introduced in the Third Generation Partnership Project (3GPP) release 5 standards. Assuming comparable cell sizes, it is anticipated that by using multi-code transmission it will be possible to achieve peak data rates of about 10 Mbit/s (the maximum theoretical rate is 14.4 Mbit/s). This will result in a six- to seven-fold throughput increase during an average downlink packet session compared with the Downlink Shared CHannel (DSCH) standards of 3GPP release 99.

3GPP standards beyond release 5 will aim to achieve further throughput increases, say peak data rates in the range 20 to 30 Mbit/s, by using Multiple Input Multiple Output (MIMO) or other antenna array techniques, and possibly asymmetric allocation of frequency spectrum in multi-carrier cells (e.g. a further 100% downlink packet session throughput increase by allocating an additional 5 MHz unpaired band).

HSDPA is based on the following key concepts:

- Adaptive modulation and coding schemes: Quadrature Phase Shift Keying (QPSK) and 16QAM (Quadrature Amplitude Modulation).
- Hybrid Automatic Repeat reQuest (HARQ) retransmission protocol.
- Fast packet scheduling controlled by the Medium Access Control – high speed (MAC-hs) protocol in Node B.

On the air interface, time is allocated to the User Equipment (UE) on a subframe basis. Modulation, code rate, power and other transmission parameters, such as the puncturing pattern, can be changed with every subframe.

Dedicated CHannels (DCH) were designed for circuit-switched services requiring a conversational Quality of Service (QoS): constant bitrate and stringent real-time requirements. Shared channels have been introduced to fit with packet services that are downlink oriented and of a bursty nature, and that are less sensitive to delay than circuit-switched services. They are suitable for streaming, interactive and background traffic classes.

HSDPA is based on a High Speed Downlink Shared CHannel (HS-DSCH), which is capable of supporting high data rates; it allows time and code multiplexing among different users. Consequently, it is well matched to the bursty nature of packet-based traffic in a multi-user environment.

Downlink dedicated channels and downlink shared channels can share the same frequency spectrum by using code multiplexing.

HSDPA evolution phases

3GPP release 3 identifies several phases of HSDPA evolution. The third phase is not yet certain, and is still being studied within 3GPP.

Phase 1: Basic HSDPA

The first phase, specified in 3GPP release 5, will see the introduction of several new basic functions with the objective of achieving a peak data rate of 10.8 Mbit/s:

- High speed downlink shared channel supported by control channels (see below).
- Adaptive modulation (QPSK and 16QAM) and rate matching.
- Shared medium access control (MAC-hs) in Node B.

Phase 2: HSDPA enhancements

The second phase, specified in 3GPP release 6, will introduce antenna array processing technologies to enhance the peak data rate to around 30 Mbit/s:

- Smart antenna using beamforming techniques for mobiles with one antenna.
- MIMO technologies for mobiles with from two to four antennas.

Phase 3: New air interface

Finally, phase 3 will see the introduction of a new air interface to HSPDA to increase the average bitrate:

- Orthogonal Frequency Division Multiplexing (OFDM) physical layer in combination with higher modulation schemes and array processing.
- MAC-hs/OFDM with fast scheduling to optimize performance by selecting dedicated sets of subcarriers for each mobile according to the quality of the air interface.
- Multi-standard MAC (Mx-MAC) as a control entity to realize fast switching between Orthogonal Frequency Division Multiple Access (OFDMA) and Code Division Multiple Access (CDMA) channels.

Only the first two phases are considered here.

Basic Principles of HSDPA Phase 1

Additional functions

In phase 1, the main changes compared with release 99 are that HSPDA:

- Shares the paired frequency bands with release 99 channels using code multiplexing.
- Uses three novel physical channels:
  - High Speed Physical Downlink Shared CHannel (HS-PDSCH): Carries actual packet data; Spreading Factor (SF) = 16, QPSK/16QAM, power controlled by Node B, up to 15 HS-PDSCHs per cell, aggregate data rates of up to 14.4 Mbit/s per cell (15 HS-PDSCHs, 16QAM, code rate 1).
  - High Speed Shared Control CHannel (HS-SCCH): Downlink channel which carries signaling information (channel code set, modulation scheme, transport block size, HARQ process number, redundancy and constellation version parameters, new data flag and UE identity), SF=128, QPSK, power controlled by Node B, up to 32 HS-SCCHs per cell, up to four HS-SCCHs per user equipment.
  - High Speed Dedicated Physical Control CHannel (HS-DPCCH): Uplink channel carrying signaling information (ACK/NACK and Channel Quality Indicator, CQI), SF=256, QPSK, terminated in Node B. HS-PDSCH, HS-SCCH and HS-DPCCH use a Transmission Time Interval (TTI) of 2 ms. This interval is also called a 'subframe'.
- HS-PDSCH uses adaptive modulation (QPSK/16QAM) and coding (Turbo coding). The turbo encoder has fixed code rate 1/3. Variable effective code rates are achieved by rate matching (puncturing or repetition). Link adaptation is implemented by Node B, which adapts the transmission format of HS-DSCH data packets according to the instantaneous quality of the propagation channel as reported by the user equipment by means of a CQI.
- MAC-hs is a novel MAC entity for controlling HS-DSCH (i.e. the transport channel comprising the HS-PDSCH). Located in Node B, its tasks include:
  - Flow control to Iub.
  - Buffering of packet data (MAC-d protocol data units) in priority queues.
  - Packet scheduling and priority handling, where scheduling is done in the time and code domain: Time Division Multiplex / Code Division Multiplex (TDM/CDM).
  - Fast packet scheduling mechanism, located in Node B, manages the HS-DSCH resources. With the aid of CQI reports from the user equipment, it

decides which user equipment should be scheduled within a particular 2 ms interval (TTI). It also selects the modulation and coding scheme, and the transmit power for the HS-DSCH data packets. A knowledge of the instantaneous quality of the propagation channels makes it possible to take advantage of multi-user diversity by avoiding the scheduling of data packets during destructive channel fades.
- HARQ termination and handling: Physical layer HARQ using incremental redundancy or chase combining is used for packet retransmissions.[1] As the HARQ protocol is terminated in Node B, there are no retransmissions via Iub. HARQ is an enhanced form of the ARQ retransmission protocol; erroneously received HS-DSCH data packets are stored in the user equipment and 'soft combined' with retransmissions of these data packets. It offers better error rate performance than conventional ARQ. When a data packet is retransmitted, the transmit format, modulation scheme and transmit power may be different from the original transmission.
- Transport Format Code (TFRC) selection, including power control and link adaptation.

• 3GPP does not restrict the number of user equipments accessing HSDPA. However, practical limits are set by the number of physical uplink channels and/or MAC-hs queues that can be processed by Node B.
• No macro-diversity transmission (Soft HandOver; SHO) is used with HS-PDSCH and HS-SCCH.
• A user equipment accessing HSDPA always has an associated DCH connection, possibly using macro-diversity transmission.
• Maximum transmit power for HS-PDSCHs and HS-SCCHs per cell can be set by the RNC via the control plane. Alternatively, all the available transmit power per cell not being used for release 99 non-HSDPA channels can be used for HS-PDSCHs and HS-SCCHs.

[1] In the case of chase combining, exactly the same information content is resent to the mobile, whereas in the case of incremental redundancy the content of the retransmitted packet is modified. In both cases, the mobile needs internal memory to store the original data packet which is combined with the retransmitted packet.

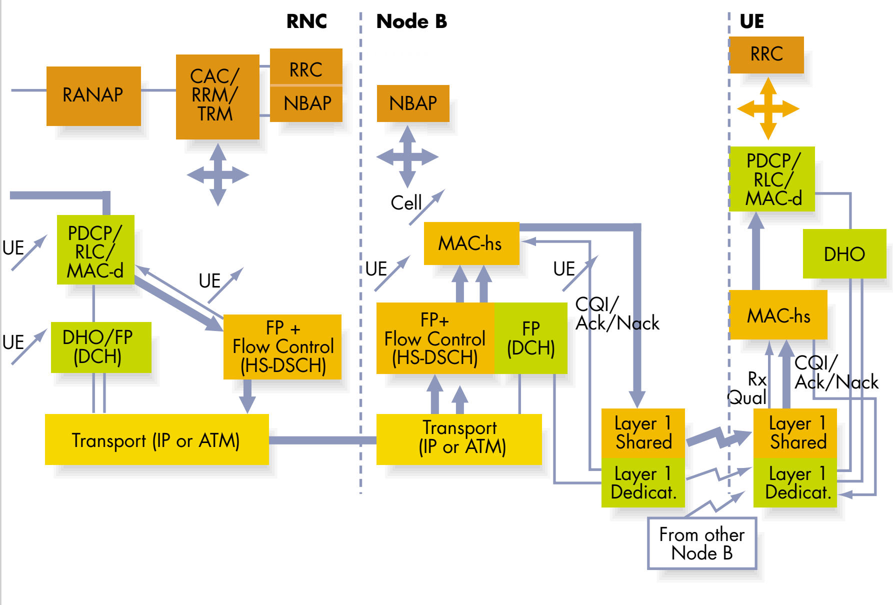
• When using 16QAM modulation, the Node B transmitter linearity requirements in terms of Error Vector Magnitude (EVM) are tighter than for release 99.
• ACK/NACK detection on HS-DPCCH has to satisfy certain radio performance requirements (yet to be specified by 3GPP).
• New RNC functions for HSDPA are:
  - Extension of Call Admission Control (CAC) and Radio Resource Management (RRM) algorithms to share physical resources in a cell between dedicated channels and HSDPA shared channels.
  - Slave function for data flow control; master function within Node B.
  - Higher data throughput for radio processing part of the user plane.

RAN environment for HSDPA

Figure 1 shows the functional entities, protocol entities and all the relevant interfaces required to realize HSDPA in the Radio Access Network (RAN).

The control plane protocol and functional entities are shown in the red blocks. The request to set up a channel with certain QoS parameters arrives at the RNC via the RANAP protocol; in cooperation with RRM and Transmission Resource Management (TRM), the CAC decides if this service is to be handled via a

Fig. 1 Node B transmit part of Alcatel's 4Tx open loop – closed loop diversity scheme



ATM: Asynchronous Transfer Mode **RANAP:** Radio Access Network Application Part dedicated or a shared channel. The decision is signaled to Node B via the Node B Application Part (NBAP) and to the user equipment via the Radio Resource Control (RRC).

The user plane data blocks arrive at the RNC from the core network using the Packet Data Compression Protocol (PDCP), which provides Internet Protocol (IP) header compression, and Radio Link Control (RLC), where a buffer is implemented for the non-transparent mode. In the MAC-d layer, channel type switching is performed using either dedicated or shared channel processing, depending on the decision of the CAC.

In the dedicated path case, the segmented data blocks are transferred to the Diversity HandOver (DHO) function and the Frame Protocol (FP) for the DCH. They terminate in Node B via the FP and are passed to layer 1 of the air interface. The user equipment receives the signal via layer 1 from different Node Bs (in the soft handover case), combines the signal using the DHO function and feeds it to MAC-d/RLC and PDCP.

In the shared path case, the segmented data blocks for each user are transferred to the FP for HS-DSCH. For each user, Node B receives an FP block for HS-DSCH. This is controlled by the flow control process; Node B, as the master, responds to capacity requests from the flow control part of the RNC by either allocating capacity or rejecting the request, depending on the available bandwidth and buffer status. Data stored in priority buffers is then scheduled by the MAC-hs process and forwarded to layer 1. MAC-hs takes the following parameters into account when making its scheduling decision: QoS parameters, CQI feedback from the user equipment indicating the quality of the air-interface, ACK/NACK of previously sent data blocks, priority buffer filling information, user priority as defined by the operator according to its billing model, and some fairness strategies to ensure that users with poor CQI are also served from time to time.

Combined with the CQI process is an adaptive radio link technique that matches the transmit power, modulation and rate matching schemes to the air-interface quality. The data blocks are received by various user equipments with the aid of HS-SCCH signaling, indicating which data block is for which user equipment. Information blocks are terminated by the MAC-hs and forwarded to the MAC-/RLC/PDCP. All user data is then forwarded to the higher layer and to the application. The user equipment determines the received channel quality in the layer 1 common part and forwards this information to MAC-hs. The received channel quality measurement is translated into a CQI value. The MAC-hs forwards the CQI together with the ACK/NACK information for the previous block to the dedicated layer 1 function for transmission on the uplink to Node B. The Node B extracts this information in the dedicated layer 1 part and transfers it to the MAC-hs for further scheduling.

Impact of HSDPA on the RNC (Phase 1)

The implementation of HSDPA will have a major impact on the RNC.

Extension of radio resource management

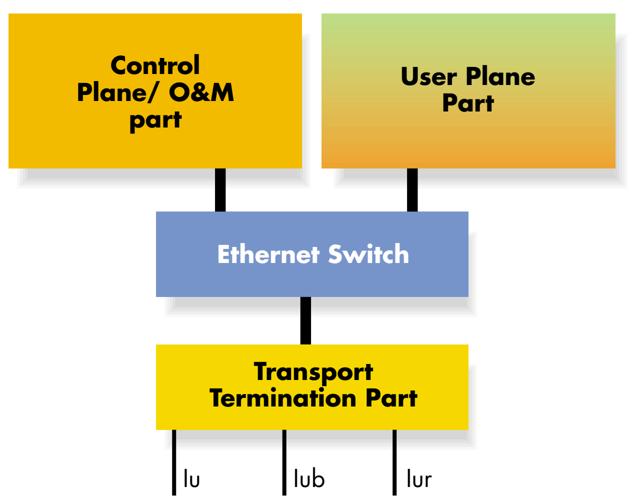
RRM is extended to the shared operation of dedicated and shared channels in a cell. A simple algorithm can be used for best effort services in HSDPA: always use the capacity that remains unused by the DCH channels in a cell. However, streaming services require a more intelligent algorithm with a dynamic behavior (breathing) when sharing dedicated and HSDPA channels.

In addition, the control plane protocols (RRC and NBAP) need to be extended to comply with the 3GPP definition.

The user plane protocols (PDCP/RLC/MAC-d) have to be designed to meet the bandwidth needs for a user allocated to an HSDPA channel. In addition, a new version of the frame protocol has to be designed, together with a suitable flow control mechanism. All these user plane protocols together with the functions of the dedicated channels (DHO and FP) have to be implemented on a single processing board to ensure fast and efficient switching from HS-DSCH to DCH channels, and vice versa.

Figure 2 shows the basic RNC hardware architecture.

Fig. 2 **RNC hardware architecture**



O&M: Operations and Maintenance

Impact of HSDPA on Node B

Architecture of HSDPA-ready Node B

Alcatel's current Node B (Evolium V2) can readily be upgraded to an HSDPA capable base station. The introduction of multi-sector MAC-hs features and the provision of downlink bitrates of up to 35 Mbit/s per Node B can be achieved without modifying the hardware. A further increase in the bitrate to 65 Mbit/s is possible, but requires hardware modifications to the Station Unit Module Unit (SUMU) in charge of Iub interfacing with the RNC.

The following approach was chosen for adapting to the HSDPA task without any hardware modifications:

- HSDPA and DCH channels are processed on different baseband processing boards (BB) in the Node B cluster.
- Up to six BB boards can be assigned to the HSDPA task; dedicated software is downloaded to these boards.
- HSDPA BB can provide HSDPA service simultaneously in up to six cells at an aggregate bitrate of 10.8 Mbit/s per board. HSDPA users in the same cell are processed by the same HSDPA BB board.
- A cluster of ten Digital Signal Processors (DSP) and various Field Programmable Gate Arrays (FPGA) on the HSDPA BB perform the downlink processing. They provide sufficient computational power and storage for the HSDPA task.

The impact of HSDPA on Node B V2/R2 can be summarized as follows:

- NBAP: Must support new or modified NBAP procedures. NBAP-d is terminated by the Master Processing Unit (MPU) of the BB board processing the associated DCH; the HSDPA BB boards do not receive NBAP messages. Control messages therefore have to be transferred from a DCH BB board to the associated HSDPA BB board. Software modifications to the MPU are required for both the DCH BB board and HSDPA BB board.
- HSDPA BB board: Software modifications are required to almost all the functional entities of the HSDPA BB board, the main functions of which are:
  - Symbol level processing and chip level processing for HS-PDSCHs and HS-SCCHs.
  - Path profiling, channel estimation and detection of uplink DPCCHs and HS-DPCCHs.
  - Implementation of MAC-hs, that is, termination of the frame protocol, flow control towards Iub, data buffering, scheduling, HARQ termination and handling, and Transport Format Identifier (TFRI) selection, including link adaptation and power control.
- Transmitter Equipment UMTS (TEU): 16QAM requires improved linearity of the power amplifier chain in terms of EVM compared with release 99. New software will implement more sophisticated clipping and predistortion algorithms.
- Node B interfaces: No change is needed to the user plane interfacing for aggregate downlink data rates of up to 35 Mbit/s. Modification of the internal data distribution to the HSDPA boards is only required when aggregate downlink data rates of up to 65 Mbit/s are required.
- Operations and Maintenance: Software mechanisms are needed for downloading different software to the DCH BB and HSDPA BB boards.

MAC-hs processing

HSDPA MAC-hs processing is implemented on the HSDPA BB boards, where it requires new DSP software. Up to six separate MAC-hs entities are supported by an HSDPA BB board, one MAC-hs entity to be used per cell. Each HSDPA BB board is equipped with 512 priority queues, supporting 64 user equipments with up to eight priority classes per user. Up to 32 HS-SCCHs can be provided per cell. The processing resources and priority queues available on the HSDPA BB board are shared by up to six MAC-hs entities, which must therefore be coordinated.

Basic Principles of HSDPA Phase 2

Multiple antenna transmission

UMTS Terrestrial Radio Access Frequency Division Duplex (UTRA/FDD) aims to support a variety of multiple antenna transmission techniques in order to enhance the coverage, system throughput and spectral efficiency of HSDPA. Some of these techniques are already part of 3GPP release 5, while others are being studied for possible inclusion in release 6 and beyond. *Table* 1 summarizes these techniques.

Tab. 1 Multiple antenna transmission techniques for HSDPA

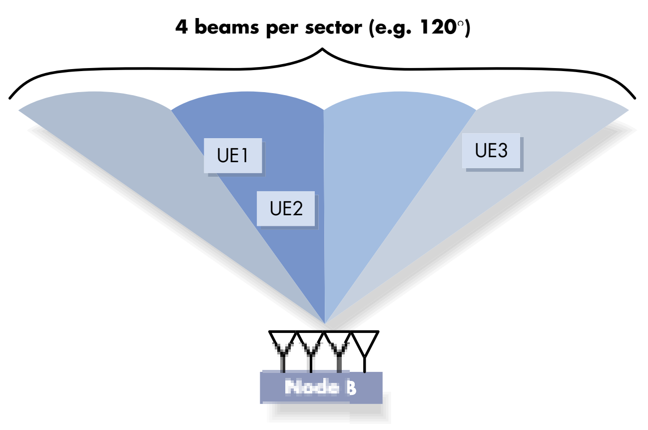
3GPP Release	Release 5	Release 6
Supported/planned techniques	2Tx diversity Beamforming	>2Tx diversity MIMO

A major aim of using multiple antenna transmission in macro-cellular environments is to increase the coverage radius at medium and higher data rates, say 384 kbit/s and above. In a typical deployment, two to four transmit (Tx) antennas are used per sector. Here we briefly highlight the multiple antenna transmission techniques envisaged for HSDPA.

Beamforming

A gain in the link budget can be achieved by focusing the transmit power in the user's direction; a 3dB gain is realized by doubling the number of transmit antennas. Antenna arrays with half a wavelength spacing between the elements are often used for beamforming. UTRA/FDD distinguishes between user-specific beamforming and beamforming with a grid of fixed beams. In the latter case, a dedicated scrambling code can be assigned to each beam, making a channelization code tree available in every beam. The increased code space can be exploited by assigning a packet scheduler per beam. Alternatively, a single scrambling code can be used per cell.

Fig. 3 Example beamforming scenario with SDMA; UE1 and UE3 are scheduled to receive a packet simultaneously, possibly using the same channelization codes, whereas UE1 and UE2 are not



Space Division Multiple Access (SDMA) can be used to increase the downlink cell throughput by scheduling data packets simultaneously to users served by different beams. This limits mutual interference between these users, making it possible to reuse the same channelization code resources. SDMA implementation requires extensions to the MAC-hs packet scheduler to enable the spatial separation of users and possibly code reuse. *Figure 3* shows a possible transmission scenario using SDMA. Alcatel's beamforming proposal is designed to facilitate the application of a grid of fixed beams by introducing a fast beam selection mechanism.

Transmit diversity

Spatial diversity gain is achievable by transmitting identical information via channels with uncorrelated fading. This is achieved by separating the transmit antennas either in position (e.g. by 10 to 20 wavelengths) or in polarization orientation. 3GPP release 5 defines two 2Tx diversity schemes (i.e. using two antennas) for HS-DSCH transmission: open loop Space Time Transmit Diversity (STTD) and closed loop Mode 1. Transmit diversity schemes with more than two antennas are envisaged in future 3GPP releases. Alcatel's 4Tx open loop – closed loop diversity proposal is designed for use with subarray antenna configurations. It achieves a spatial diversity gain by using 2Tx STTD between the subarrays, and an additional beamforming gain by applying 2Tx closed loop Mode 1 within each subarray. The Node B transmit part of the 4Tx open loop – closed loop diversity scheme is depicted in *Figure 4*.

Multiple Input Multiple Output (MIMO)

MIMO systems use multiple antennas at both the transmit and receive sides. They commonly apply spatial multiplexing; the data stream to be transmitted is split into, for example, two streams, each with half the data rate of the original stream, and these streams are transmitted via different antennas using the same channelization codes. Uncorrelated propagation channels, multiple receive (Rx) antennas and receiver structures using interference cancellation are typically required to detect the spatially multiplexed data streams. Spatial multiplexing has the potential to increase peak data rates by increasing the number of transmit antennas. As a first approximation, the increase is linear, for example, peak data rates of up to about 20 Mbit/s are expected for HSDPA using a 2Tx/2Rx MIMO scheme (16QAM, 15 codes, 30 streams, code rate 3/4). To use MIMO with HSDPA, the fast link adaptation mechanism must be modified for use with multiple data streams, for example, by transmitting a single transport block per TTI via multiple streams, or by transmitting a single transport block per TTI per stream. The application of MIMO transmission with HSDPA is illustrated in *Figure 5* for the case in which a single transport block is transmitted per TTI.

A new BB hardware version is needed to implement the above functions. In addition, the

SUMU to BB interface must be extended in terms of bandwidth. All other entities in the Node B can be reused.

Conclusion

HSDPA is an evolution of UMTS-FDD that offers the higher data rates that are needed to realize multimedia services for cellular mobile communication systems. A very efficient technology is the introduction of a downlink shared channel which achieves a statistical multiplexing gain. This is valid for background and best-effort services with an activity factor <<1.

Fig. 4 Node B transmit part of Alcatel's 4Tx open loop – closed loop diversity scheme

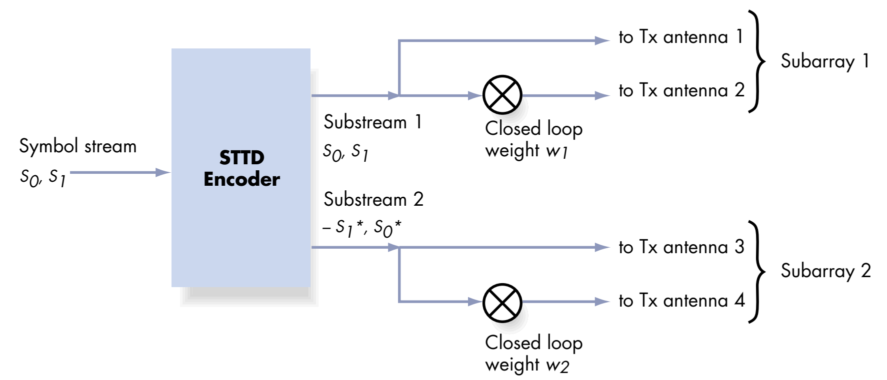
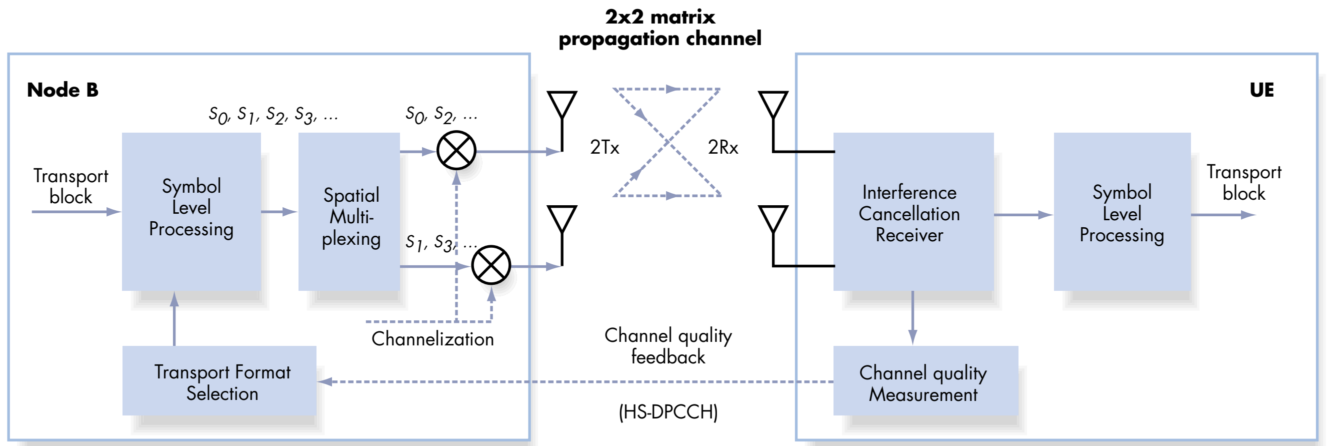


Fig. 5 Example of MIMO transmission scheme for HSDPA.



Two factors are of prime importance for the successful introduction of multimedia services:

- Improvement in spectral efficiency in bits/second/Hz.
- Low cost per Mbit/s.

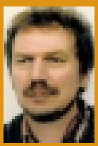
Both are required in order to offer attractive prices to users, so they will be encouraged to subscribe to such services.

Improvements in spectral efficiency will be realized step by step:

- *HSDPA Phase 1:* Dynamic radio link adaptation with variable rate matching (code puncturing) and variable modulation (QPSK/16QAM), HARQ and fast packet scheduling: peak rate 10.8 Mbit/s.
- *HSDPA Phase 2:* Introduction of antenna array processing: peak rate up to 30 Mbit/s.
- *HSDPA Phase 3:* Introduction of OFDM air-interface with selected subcarrier transmission per user equipment and 64 QAM: peak rate up to 50 Mbit/s.

The second factor will depend on the supplier's ability to develop cost-efficient RAN solutions.

Alcatel offers a solution for introducing HSDPA phase 1, which doesn't require any hardware modifications to Node B. HSDPA can be introduced by remote software downloading. Only minor hardware modifications are required in the RNC. The Alcatel/Evolium multi-standard base station architecture supports the introduction of HSDPA.



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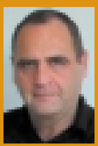

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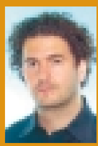

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Abbreviations

ARQ Automatic Repeat Request
BB Base Band processing module
BBI Base Band to Base Band Interface
CAC Call Admission Control
CDMA Code Division Multiple Access
CN Core Network
CQI Channel Quality Indicator
DCH Dedicated Channel (transport channel)
DDD Data Despreader Decoder
DHO Diversity Handover
DSCH DL Shared Channel (transport channel)
EDGE Enhanced Data Rates for GSM Evolution
EVM Error Vector Magnitude
FP Frame Protocol
H-ARQ Hybrid ARQ
HSDPA High Speed Downlink Packet Access
HS-DPCCH High Speed Dedicated Physical Control Channel
HS-DSCH High Speed Downlink Shared Channel
HS-PDSCH High Speed Physical Downlink Shared Channel
HS-SCCH High Speed Shared Control Channel
Iub RNC to Node B Interface
MAC Medium Access Control
MAC-d MAC Dedicated
MAC-HS Medium Access Control High Speed
MAC-HS/OFDM Medium Access Control High Speed for OFDM
MIMO Multiple In Multiple Out
MxMAC Multistandard MAC
NBAP Node B Application Part
NBAP-d NBAP Dedicated
Node B UMTS BTS
OFDM Orthogonal Frequency Division Multiplex
OL-CL Open Loop Closed Loop
O&M Operation and Maintenance
OMC-R Operation and Maintenance Center – Radio
PDCP IP Header Compression
QoS Quality of Service
RAN Radio Access Network
RANAP RAN Application Part
RLC Radio Link Control
RNC Radio Network Controller
RRC Radio Resource Control
RRM Radio Resource Management
SBI SUMU Baseband Interface
SDMA Space Division Multiple Access
SF Spreading Factor
SHO Soft Handover
STTD Space Time Transmit Diversity
SUMU Station Unit Module UMTS
SW Software
TEU Transmitter Equipment UMTS
TFRC Transport Format Code
TFRI Transport Format Identifier
TRM Transmission Resource Management
TSN Transport Sequence Number
TTI Transmission Time Interval
UE User Equipment
UL Uplink (UE to Node B direction)
UMTS Universal Mobile Telecommunication System
UTRA/FDD UMTS Terrestrial Radio Access Frequency Duplex Division

ARCHITECTS OF AN INTERNET WORLD

ALCATEL