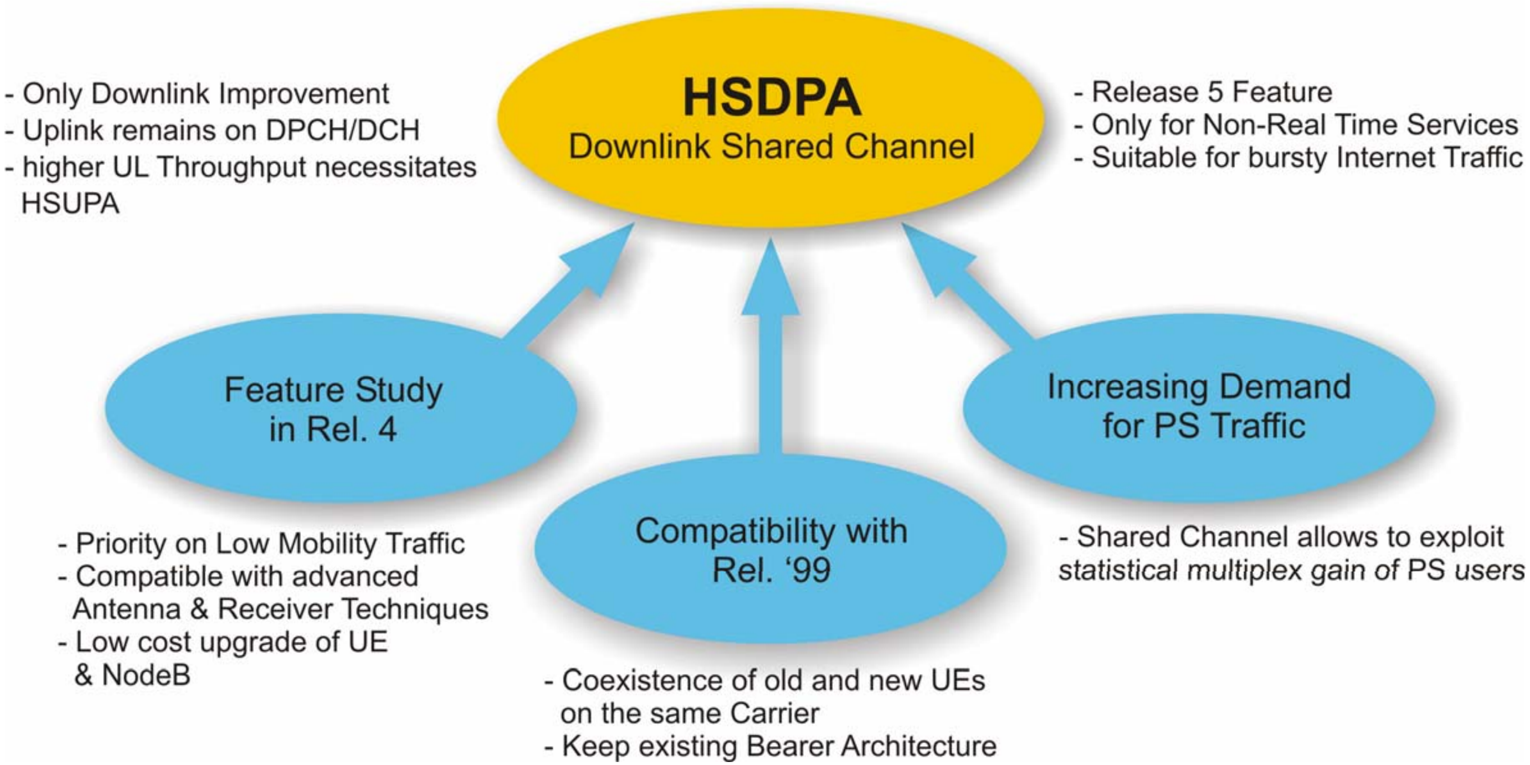
HSDPA (High Speed Downlink Packet Access) for WCDMA



HSDPA (High Speed Downlink Packet Access) for WCDMA

HSDPA considers the trend that the volume of IP-based traffic has already exceeded that for circuit-switched traffic in most fixed networks. The same change can be anticipated in mobile networks because new IP-based mobile services become available and are used by increasing number of people in their daily communication. Current estimates show that in advanced mobile communication markets, packet-switched traffic will overtake circuit-switched traffic in the near future. Delivery of digital content over mobile networks will generate additional traffic and revenue.

Feature Study

The HSDPA feature in 3GPP Release 5 is the result of a study carried out in the Release 4 time frame. This study considered a number of techniques in order to provide instantaneous high speed data in the downlink.
Some of the considerations and goals taken into account in the evaluation of the different techniques were:

- ⇒ To focus on the streaming, interactive and background services: services which require a constant and/high throughput or low error rate.
- ⇒ To prioritize urban environments and then indoor deployments (but not limited to these environments and supporting full mobility).
- ⇒ To enable compatibility with advanced antenna and receiver techniques: transmit and receive diversity methods are used and might be enhanced
- ⇒ To take into account mobile's processing time and memory requirements: ⇔ UE's limitations are taken into account by the network
- ⇒ To minimize changes on existing techniques and architectures: modest changes to NodeB hardware and UTRAN software

Compatibility with Release '99

HSDPA is designed to co-exist on the same carrier as the current Release '99 WCDMA services, enabling a smooth and cost-efficient introduction of HSDPA into existing WCDMA networks.

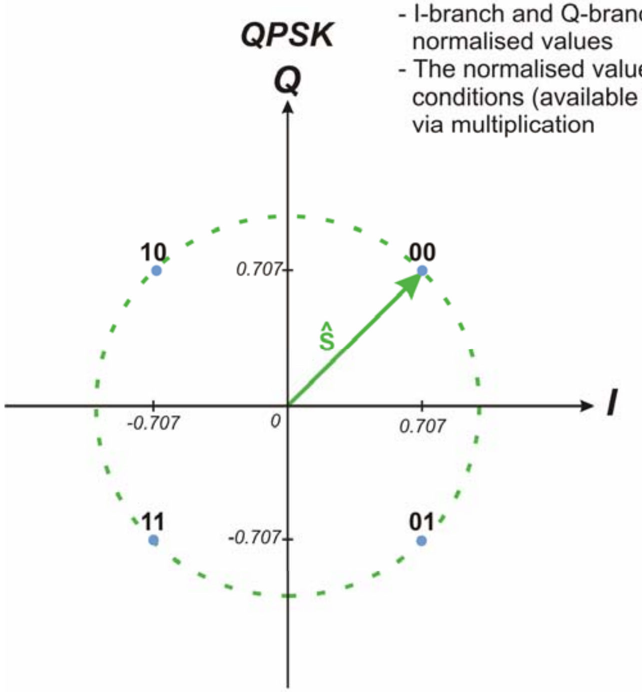
Demand for Packet Switched Traffic

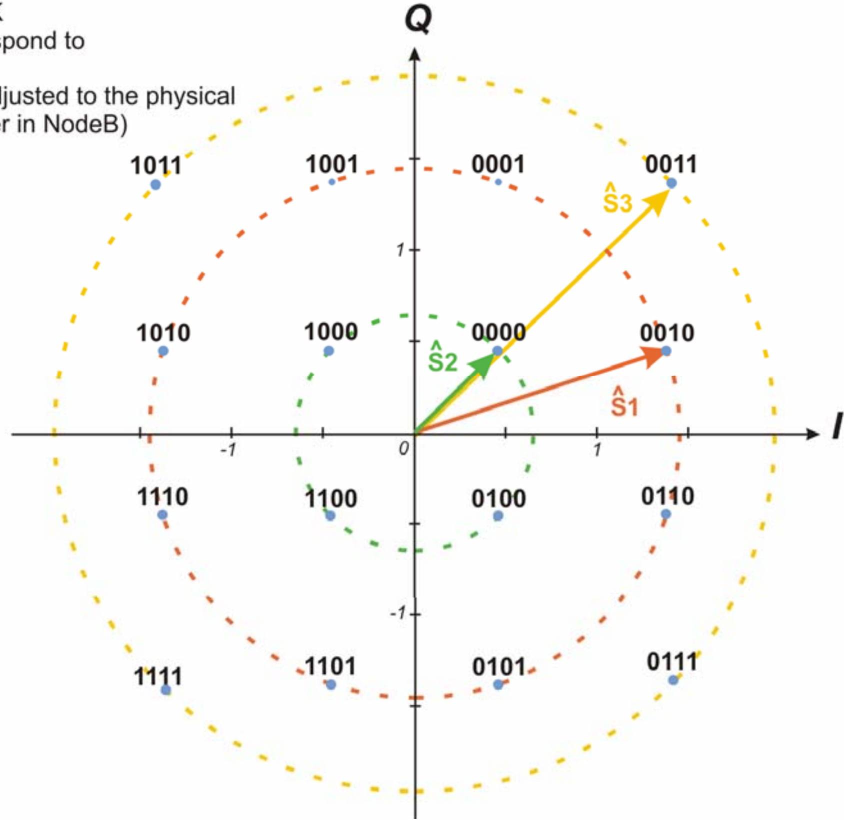
The increasing demand for capacity in order to provide high data rate multimedia services in wireless environments necessitates enhanced radio transmission techniques and network protocol functionality. Such techniques have to be added to already existing mobile cellular networks. For 3rd generation UMTS networks based on WCDMA, the HSDPA is being introduced to meet this demand and improve spectral efficiency by higher order modulation using 16-QAM.

Note: HSDPA achieves gross data rates in downlink up to 14 Mbit/s under ideal conditions. The reverse link (uplink) may remain on 64 kbit/s until at a later stage new features are introduced with HSUPA (High Speed Uplink Packet Access). However, HSUPA will require new mobile terminals and PC-cards to operate with. Except where otherwise indicated, the description of this course only applies to the FDD mode of UMTS.

QPSK versus 16-QAM Modulation

Note:
- 16-QAM requires about 3dB more power in average than QPSK
- I-branch and Q-branch correspond to normalised values
- The normalised values are adjusted to the physical conditions (available Tx-power in NodeB) via multiplication





QPSK versus 16-QAM Modulation

The figure illustrates the I/Q Plane for QPSK and 16-QAM modulation technique. The bit to symbol mapping is done according to the Gray Code. In case of wrong estimation of the symbol, only one bit is wrong. However 16-QAM requires a more accurate phase estimation in the first place.
An increase of the transmission rate in bandwidth limited frequency spectrum can be achieved through digital transmission systems where both the amplitude and the phase of a high frequency carrier are modulated ⇔ amplitude-phase-keying ⇔ 16-QAM.
16-QAM combines phase and amplitude keying ==> quadrature amplitude modulation

QPSK

Each symbol corresponds to 2 consecutive input bits. The four symbols are represented by different phase shifts in the I/Q plane.

⇒ Spectrum efficiency: 2 bits / (modulation symbol and Hz)

⇒ All constellation points lie on the same circle, thus a constant amplitude for all 4 modulation symbols.

16-QAM

Each symbol corresponds to four consecutive input bits. Thus the data rate can be doubled with 16-QAM compared to QPSK. The 16 symbols are represented in the I/Q plane by different phase shifts and amplitudes.

⇒ Spectrum efficiency: 4 bits / (modulation symbol and Hz)

⇒ The amplitude-phase keying 16-QAM requires compared e.g. 16-PSK less power in order to achieve the same BER probability. However this is compromised by increased complexity due to the amplitude modulation information.

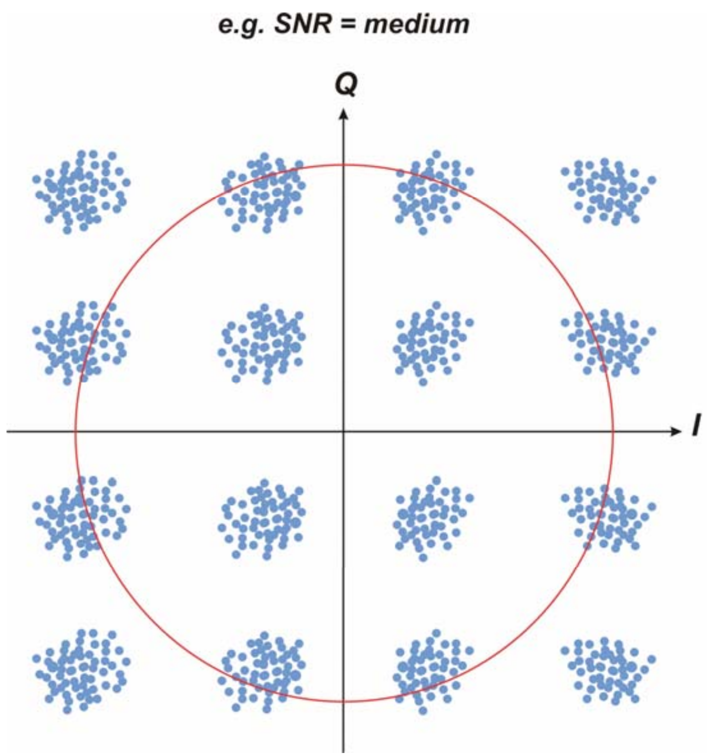
⇒ 16-QAM achieves the same BER probability like 16-PSK but needs about 3.5 dB less power because in 16-QAM the constellation points are further apart in the I-Q-plane compared to 16-PSK.

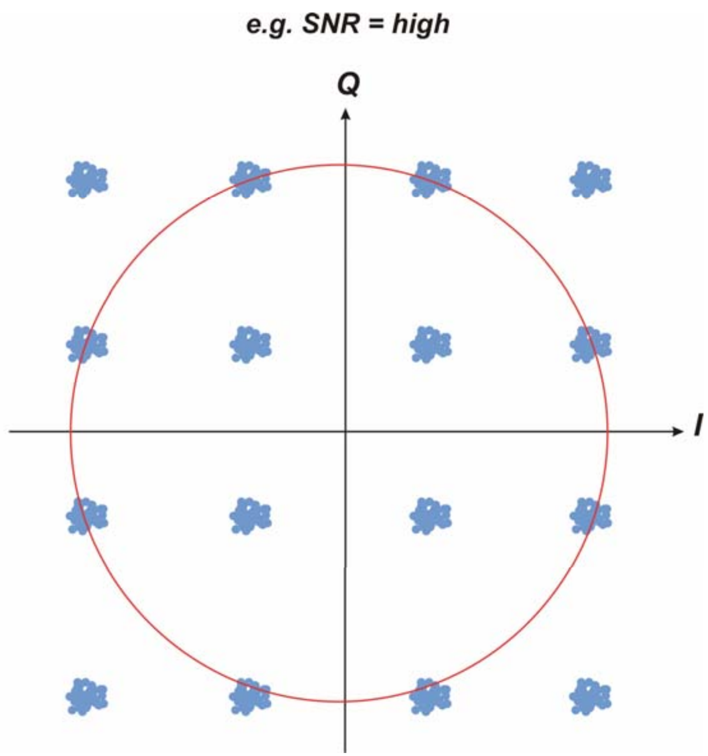
In 16-QAM modulation the symbol value is determined by phase and amplitude. Compared to that, in QPSK the phase is only modulated and variation in amplitude have only minor influence on the decision space in the I/Q diagram. However with 16-QAM the decision space is heavily influenced by amplitude variations, thus higher constraints are put on the transmitter linearity. Note, a more accurate phase estimate is necessary with 16-QAM since constellation points have smaller differences in phase domain compared to QPSK.

Note: The number of constellation points in the I/Q-diagram can be calculated with 2^m, where m represents the number of bits or chips per modulation symbol. QPSK modulation has four constellation points in the I/Q-diagram: 2^m = 4 ⇔ m = 2. 16-QAM modulation has 16 constellation points in the I/Q-diagram: 2^m = 16 ⇔ m = 4

[3GTS 25.213 (5.1), Erich Pehl (digitale und analoge Nachrichtenübertragung)]

16-QAM Sensitivity and SNR



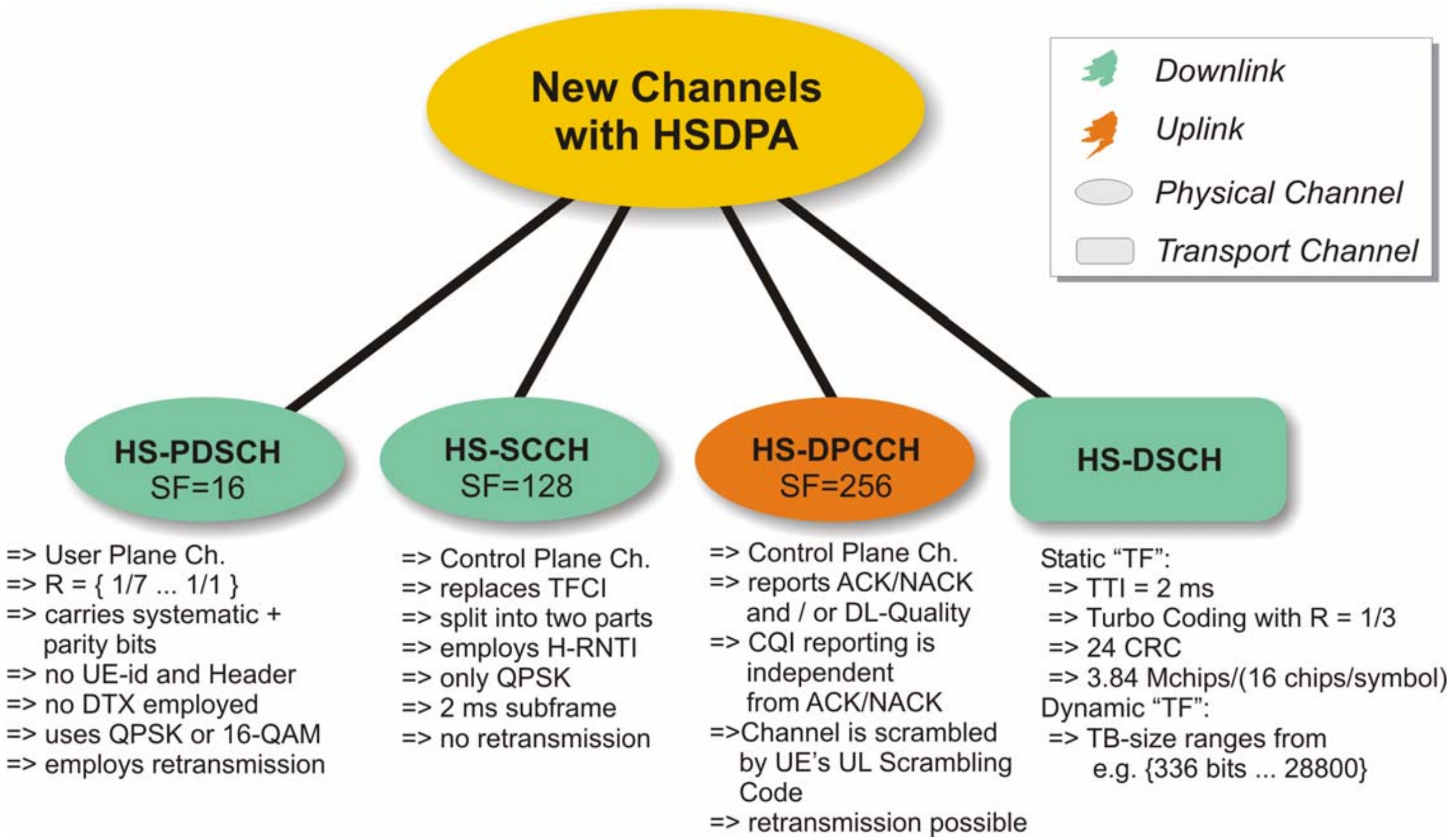


16-QAM Sensitivity and SNR

The figure above should demonstrate how the decision space shrinks for a 16-QAM receiver with lower SNR (signal to noise ratio). It is therefore reasonable to claim that 16-QAM usage is quite limited to low mobility and quite static radio conditions, e.g. radio conditions with little fading effects. Such good radio conditions can be expected from indoor environments where a good coverage exists and the mobility of the subscriber is very low.

Note: We from Inacon intentionally do not provide studies on 16-QAM required SNR versus achievable throughput. Such diagrams are subject to radio network planning which is out of the scope of this course.

New Channels with HSDPA



New Channels with HSDPA

The support of HSDPA is based on several new physical channels and one new transport channel.

Physical Channels

HS-PDSCH (High Speed Physical Downlink Shared Channel)

The HS-PDSCH has a **fixed** spreading factor of value '16'. Thus, it provides for multicode operation using up to 15 channelization codes in parallel. Of course the UE must support the use of up to 15 channelization codes which depends on its category. The HS-PDSCH adopts the shortened TTI of 2 ms.

HS-SCCH (High Speed Shared Control Channel)

The HS-SCCH has a fixed spreading factor of value '128' and is configured only in the downlink direction. It also adopts the shortened TTI of 2 ms. In theory, up to 127 HS-SCCH's can be configured in a cell. However, the UE is required only to be able to listen to up to four HS-SCCH in parallel.
The HS-SCCH allows the efficient sharing of one or more HS-PDSCH's among different users. Nevertheless every UE needs to be informed on the DCCH via RRC messages about the specific HS-SCCH-set that it shall monitor in order to receive data via the HS-PDSCH's.

HS-DPCCH (High Speed Dedicated Physical Control Channel)

The HS-DPCCH has a fixed spreading factor of value '256' and is only configured in uplink direction. The HS-DPCCH also follows the shortened TTI of 2 ms. Its purpose is to provide feedback information about the downlink receive quality and whether the packet data received by the UE are error-free or need to be retransmitted. Thus the NodeB is quickly notified of unsuccessful transmissions and/or changing radio conditions in downlink direction.

Transport Channel

HS-DSCH (High Speed Downlink Shared Channel)

The HS-DSCH is the actual transport resource carrying the packet data of the user applications. As it also follows the shortened TTI of 2 ms, it allows for short round trip delay in the operation between NodeB and UE. The 2 ms TTI is short when compared to 10, 20, 40 or 80 ms TTI's supported by Rel. '99 and Rel. 4 transport channels. HS-DSCH describes the physical layer processing by MAC-hs of a HSDPA transport block.

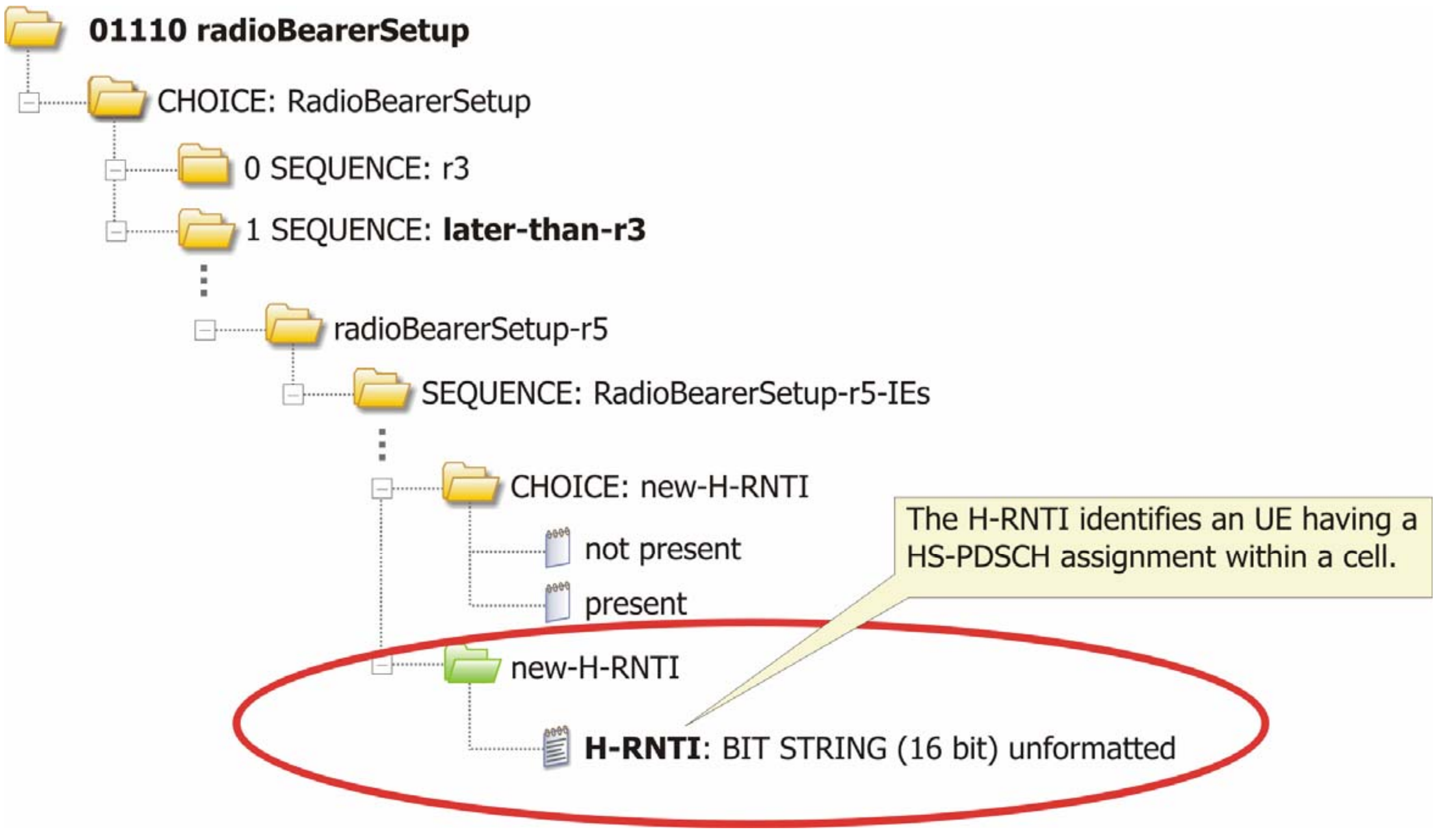
⇒ Dynamic part: TB size = TBS size {1 to 200 000 bits with 8 bit granularity}; modulation scheme {QPSK, 16-QAM}; redundancy / constellation version {1 … 8}.

⇒ Static part: TTI {2 ms for FDD}; type of channel coding {turbo coding}; mother code rate {1/3}, CRC size {24 bits}

⇒ No semi-static attributes are defined for HS-DSCH.

[3GTS 25.211 (4.1.2.7, 5.2.1, 5.3.3.12, 5.3.3.13), 3GTS 25.213 (4.2.1, 4.3.1.2), 3GTS 25.302 (7.1.6a)]

HSDPA High Speed Information



HSDPA High Speed Information

When the UE is in CELL_DCH state, RRC-messages are exchanged e.g. for setting up radio bearers. If the UE has indicated beforehand its HSDPA capability, the RB_SETUP-message may contain HSDPA related information such as:

H-RNTI

The H-RNTI (High Speed Radio Network Transaction Identifier) is firstly used to identify the very UE which shall receive data from a HS-DSCH. Therefore the UE's H-RNTI is **implicitly** encoded in the HS-SCCH. Implicitly encoded means that part 1 of HS-SCCH uses H-RNTI as input for UE specific masking. For part 2 of HS-SCCH, the H-RNTI is used for UE specific CRC attachment. Thus the UE is able to distinguish which out of a max. of four HS-SCCH's contains decoding information for the following HS-PDSCH's in the sub-sequent HS-DSCH subframe. This means on the other hand, that the actual HS-DSCH TB does not contain any UE-id.

⇒ Thus the HS-DSCH resource allocation in HSDPA is entirely done without higher layer involvement. The reasons for this are twofold. Leaving the resource assignment at layer 1 speeds up the entire process (avoiding higher layer processing delays) and avoids to transmit UE specific RNTI's and sequence numbers.

⇒ The timely relationship between HS-SCCH and HS-DSCH avoids the need of attaching an UE-id within HS-DSCH transport block to identify the recipient.

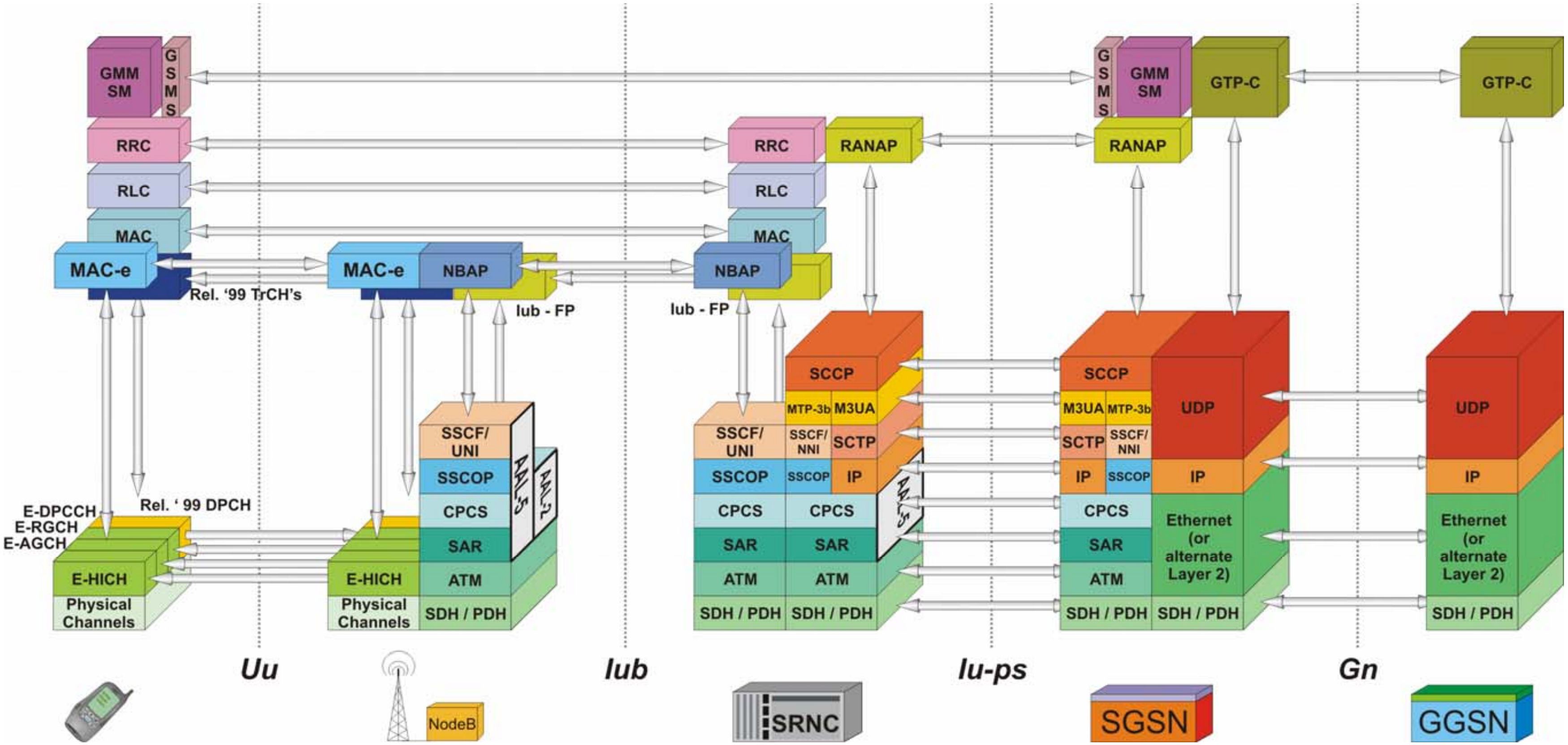
For each HS-DSCH TTI of 2 ms, each related HS-SCCH occurring 2 slots ahead of HS-DSCH carries HS-DSCH related downlink signaling for one UE only. The H-RNTI encoded in the HS-SCCH identifies therefore an UE having a HS-PDSCH assignment within a cell. Therefore the UE needs at first to decode the very HS-SCCH (part 1) before it can attempt to demodulate the allocated HS-PDSCH's.

The HS-SCCH signaling message is divided into two parts, with part 1 containing the time critical information on channelization code set and modulation scheme. Part 2 of HS-SCCH consists of transport block size and HARQ-related (indicating new transmission or retransmission, HARQ process id, redundancy and constellation version). A 16-bit UE specific CRC is computed over part 1 and part 2 and attached to part 2. The UE ID is only implicitly included in the CRC. In order to allow the very UE quickly to determine whether HS-PDSCH's are going to be allocated, the part 1 alone of HS-SCCH is scrambled with the H-RNTI as well.

⇒ If more than one UE shall be served within a subframe, more than one HS-SCCH need to be transmitted as one HS-SCCH can only allocate HS-DSCH resources for one UE only. However code multiplexing may be limited between 2-3 users per subframe as it becomes less efficient and processing is quite high for NodeB.

[3GTS 25.213 (4.3.1.2), 3GTS 25.331 (8.6.3.1b, 8.6.6.32, 10.3.6.23a, 10.3.6.36a, 10.3.6.40a)]

HSUPA Control Plane



HSUPA Control Plane

The figure shows the protocol model for the E-Uplink when the CRNC and SRNC are co-incident. Please note that since Rel. 5 the transport network can be entirely based on IP.

MAC Architecture Change in HSUPA

The overall UTRAN MAC architecture includes a new MAC-e entity and a new MAC-es (only user plane) entity. For each UE that uses E-DCH, one MAC-e entity per NodeB and one MAC-es entity in the SRNC are configured. MAC-e, located in the Node B, controls access to the E-DCH and is connected to MAC-es, located in the SRNC. MAC-es is further connected to MAC-d. For control information, new connections are defined between MAC-e and a MAC Control SAP in the Node B, and between MAC-es and the MAC Control SAP in the SRNC.

There is one Iub transport bearer per MAC-d flow (i.e. MAC-es PDUs carrying MAC-d PDUs from the same MAC-d flow)

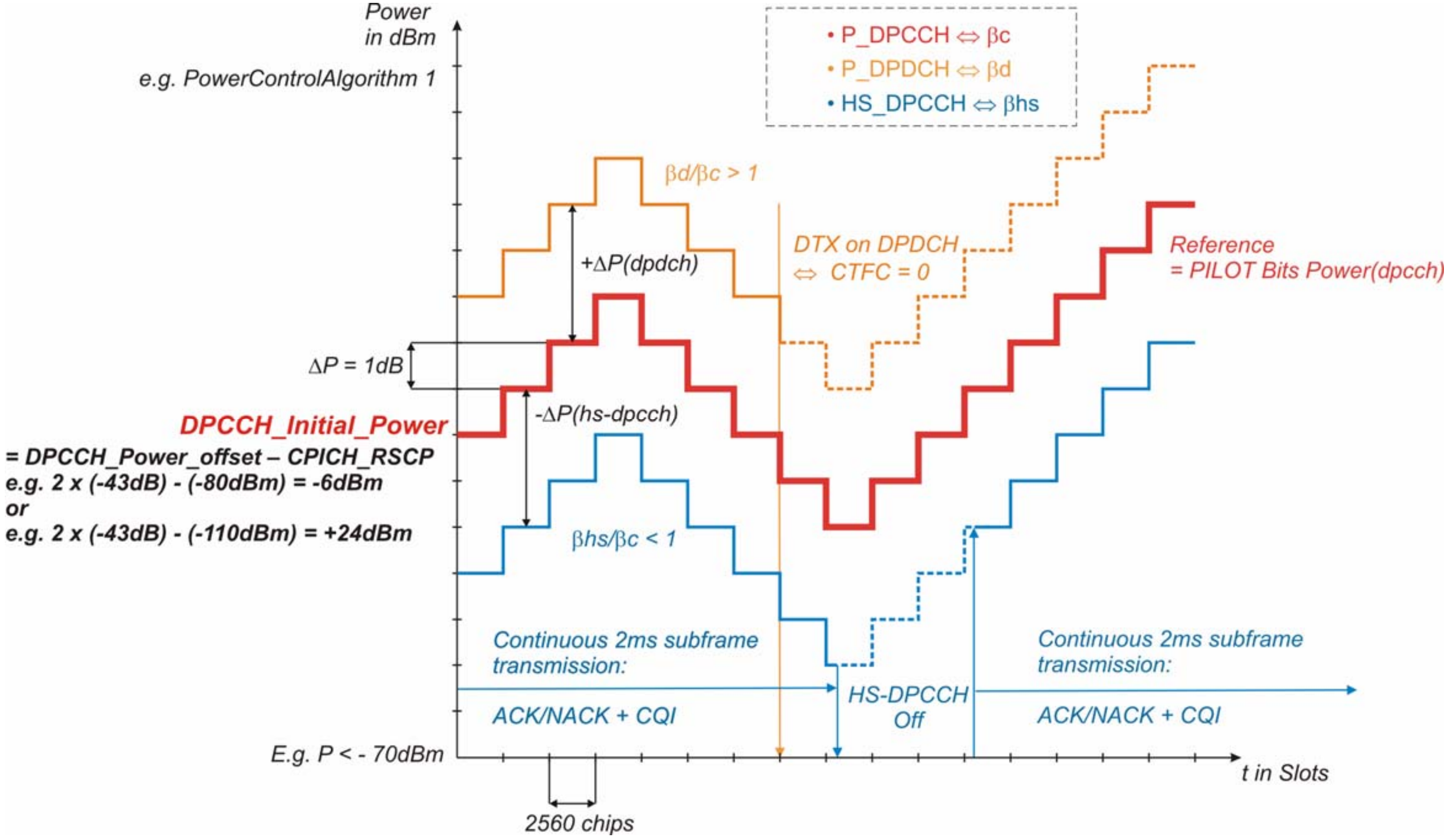
- ⇒ The important changes in the control plane for HSUPA are the MAC-e in NodeB and UE and the new physical channels in uplink and downlink controlling the data transmission in uplink and providing feedback in form of ACK/NACK for retransmission.
- ⇒ The protocol stack above MAC remains unchanged.
- ⇒ In order to setup HSUPA in UE via RRC signaling the legacy release TrCH DCH has to be used to configure MAC-e and E-TFC's in UE. This is indicated with "Rel. '99 TrCH's".
- ⇒ There is one MAC-e entity in Node B for each UE and one E-DCH scheduler function in the Node-B. The MAC-e and E-DCH scheduler handle HSUPA specific functions in Node B, e.g. E-DCH control ⇔ E-AGCH, E-RGCH, E-DPCCH, E-HICH.

The table below describes a possible combination of FDD physical channels that needs to be supported in the downlink on the same frequency by one UE simultaneously:

Physical Channel Combination	Transport Channel Combination	Mandatory dependent on UE radio access capabilities	Comment
PCCPCH (neighbour cell) + DPCCH + one or more DPDCH + one or more HS-SCCH + zero, one or more HS-PDSCH + one or more E-HICH + E-AGCH + one or more E-RGCH	BCH (neighbour cell) + one or more DCH's + one HS-DSCH	Depending on UE radio access capabilities	This combination is required by a UE in CELL_DCH state to be able to read the SFN of a neighbouring cell and support "SFN-CFN observed time difference" and "SFN-SFN observed time difference" measurements while HS-DSCH(s) are configured. In this combination E-DCH is configured in uplink.

[3GTS 25.301 (5.6.10), 3GTS 25.302 (8.2), 25.309 (6.1)]

Uplink Power Control including HS-DPCCH



Uplink Power Control including HS-DPCCH

The initial uplink DPCCH transmit power is set by higher layers: DPCCH_Initial_power = DPCCH_Power_offset – CPICH_RSCP. Subsequently the uplink transmit power control procedure simultaneously controls the power of a DPCCH and its corresponding DPDCHs and HS-DPCCH (if present). The relative transmit power offset between DPCCH and DPDCHs or DPCCH and HS-DPCCH is determined by the UTRAN and is computed using the gain factors signalled to the UE using higher layer signaling, e.g. RADIO BEARER SETUP message or any other Radio Bearer Control message.
The operation of the inner power control loop adjusts the power of the DPCCH, HS-DPCCH and DPDCHs by the same amount, provided there are no changes in gain factors.

Note: Additional adjustments to the power of the DPCCH associated with the use of compressed mode are not described in here. Neither the details of fast inner loop power control are described, being out of the scope of this course. For details, the reader is kindly referred to [4].

Any change in the uplink DPCCH transmit power shall take place immediately before the start of the pilot field on the DPCCH. The change in DPCCH power with respect to its previous value is derived by the UE and is denoted by Δ_{DPCCH} (in dB).
The uplink inner-loop power control adjusts the UE transmit power in order to keep the received uplink signal-to-interference ratio (SIR) at a given SIR target, SIR_{target}. The SIR_{target} is updated by the SRNC's Outer Loop Power Control algorithm (OLPC) which tries to reach a certain BLER value for the applications.
The serving cell(s) (cells in the active set) should estimate signal-to-interference ratio SIR_{est} of the received uplink DPCH (based on the Pilot bits of DPCCH). The serving cell(s) should then generate TPC commands and transmit the commands once per slot according to the following rule:

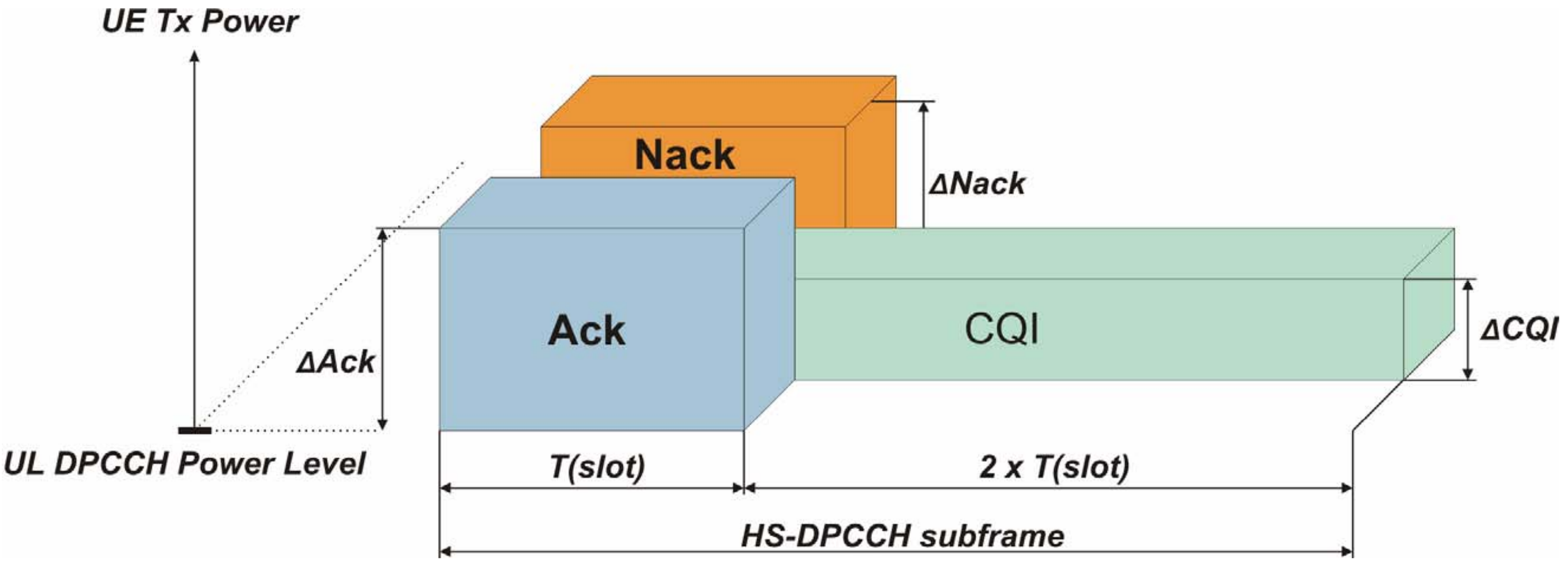
⇒ if $SIR_{est} > SIR_{target}$ then the TPC command to transmit is "0"; e.g. 1dB power down.

⇒ if $SIR_{est} < SIR_{target}$ then the TPC command to transmit is "1", e.g. 1dB power up.

Two algorithms shall be supported by the UE for deriving a TPC_cmd. Which of these two algorithms is used is determined by a UE-specific higher-layer parameter, "PowerControlAlgorithm", and is under the control of the UTRAN.
It can be seen in the figure that HS-DPCCH can be switched off and on within a slot whereas DPDCH is only switched off and on a TTI bases which is a multiple of 10 ms. The fact that HS-DPCCH is turned off and on within a slot, it puts a greater constrained on UE's power amplifier linearity and the peak to average power ration increases with on/off of HS-DPCCH of course.
The gain factor ratio ßd/ßc and ßhs/ßc express the power increase (<=> ßd/ßc > 1; ßhs/ßc > 1) of DPDCH and/or HS-DPCCH or power decrease (<=>ßd/ßc < 1; ßhs/ßc < 1) relative to uplink DPCCH.

[3GTS 25.214 (5.1.2)]

Delta Ack / Nack and CQI Power



Delta Ack / Nack and CQI Power

When an HS-DPCCH is active, the power offset Δ(HS-DPCCH) for each HS-DPCCH slot shall be set as follows.
For HS-DPCCH slots carrying HARQ Acknowledgement:

⇒ Δ(HS-DPCCH) = Δ(ACK) if the corresponding HARQ Acknowledgement is equal to 1

⇒ Δ(HS-DPCCH) = Δ(NACK) if the corresponding HARQ Acknowledgement is equal to 0

For HS-DPCCH slots carrying CQI:

⇒ Δ(HS-DPCCH) = Δ(CQI)

Note: The values for Δ(ACK), Δ(NACK) and Δ(CQI) are set by RRC signaling.

In non-compressed frames β(hs) is the gain factor which is calculated according to

$$ß(hs) = ß(c) \times 10^{[\Delta(\text{HS-DPCCH})]/20}$$

where ß(c) value is signaled by higher-layer, e.g. through RRC or calculated based on TFCI selection.
With the exception of the start and end of compressed frames, any DPCCH power change shall not modify the power ratio between the DPCCH and the HS-DPCCH.

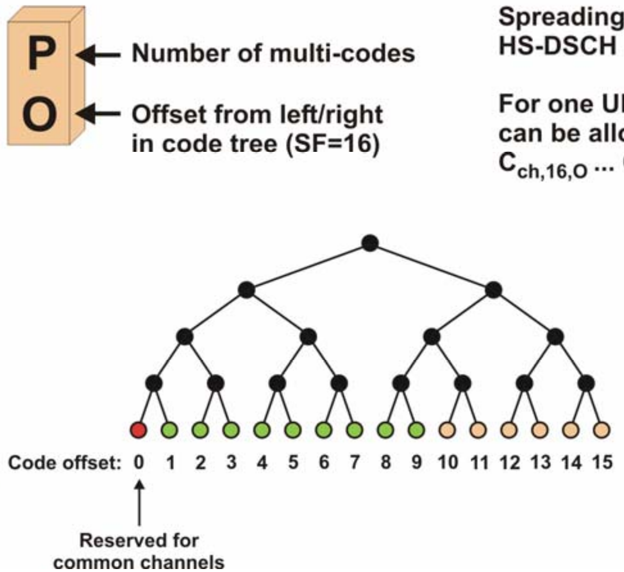
Signaling Values for Δ(ACK), Δ(NACK) and Δ(CQI)	Quantisized Amplitude ratios for $10^{[\Delta(\text{HS-DPCCH})]/20}$	Non-Compressed HS-DPCCH frames P(HS-DPCCH) = P(DPCCH) + Δ(HS-DPCCH)
8	30/15	P(DPCCH) + 6 dB
7	24/15	P(DPCCH) + 4 dB
6	19/15	P(DPCCH) + 2 dB
5	15/15	P(DPCCH) + 0 dB
4	12/15	P(DPCCH) – 1.9 dB
3	9/15	P(DPCCH) – 4.4 dB
2	8/15	P(DPCCH) – 5.5 dB
1	6/15	P(DPCCH) – 8 dB
0	5/15	P(DPCCH) – 9.5 dB

[3GTS 25.214 (5.1.2.5A)]

HS-PDSCH Code Allocation through HS-SCCH Part 1

Cluster code indicator (3 bits)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0 (1/15)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	1
1 (2/14)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	14	14
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	2	1
2 (3/13)	3	3	3	3	3	3	3	3	3	3	3	3	3	13	13	13
	1	2	3	4	5	6	7	8	9	10	11	12	13	3	2	1
3 (4/12)	4	4	4	4	4	4	4	4	4	4	4	4	12	12	12	12
	1	2	3	4	5	6	7	8	9	10	11	12	4	3	2	1
4 (5/11)	5	5	5	5	5	5	5	5	5	5	5	11	11	11	11	11
	1	2	3	4	5	6	7	8	9	10	11	5	4	3	2	1
5 (6/10)	6	6	6	6	6	6	6	6	6	6	10	10	10	10	10	10
	1	2	3	4	5	6	7	8	9	10	6	5	4	3	2	1
6 (7/9)	7	7	7	7	7	7	7	7	7	9	9	9	9	9	9	9
	1	2	3	4	5	6	7	8	9	7	6	5	4	3	2	1
7 (8/8)	*Redundant*								8	8	8	8	8	8	8	8
									8	7	6	5	4	3	2	1

Decoding Notation



Spreading factor of the HS-DSCH is fixed SF = 16

For one UE a cluster of codes can be allocated $C_{ch,16,O} \ldots C_{ch,16,O+P-1}$

HS-PDSCH Code Allocation through HS-SCCH Part 1

For HSDPA, a NodeB needs to signal to the UE exactly how many multi-codes have been allocated and at which offset the set of codes begin (all defined at spreading factor 16 level). It is specified that only clusters of consecutive codes are allocated to one user at a time. In general, up to 15 multi-codes may be supported by the most capable UE's and for the single-code case there is up to 15 different code offsets possible since a single code (offset 0) is reserved to the common channels P-CPICH/P-CCPCH.
Commonly, 4 bits are used in order to represent number of multi-codes and 4 bits are used in order to represent the code tree offset. Hence, altogether 2x4=8 bits are needed to make full-flexibility signaling. Some combinations of multi-code number and code offsets are not possible. For example, if 15 multi-codes are allocated to a user there is only one possible offset combination. In total there is only 120 combinations. By building a lookup table with the possible combinations, 120 combinations can be represented using 7 bits. However, the major drawback of the lookup table method is that it requires additional memory at the UE side to decode the received information. Therefore a need exists for reducing the signaling overhead using bit-efficient ways of signaling while maintaining performance and flexibility. The figure presents a method for compact representation of multi-code signaling that includes: determining a number of multi-codes, determining a code offset, and formulating a codeword that includes a code group indicator and an offset indicator. The codeword represents a compact representation of multi-code signaling and is formulated and may be decoded without the need for a look-up table.

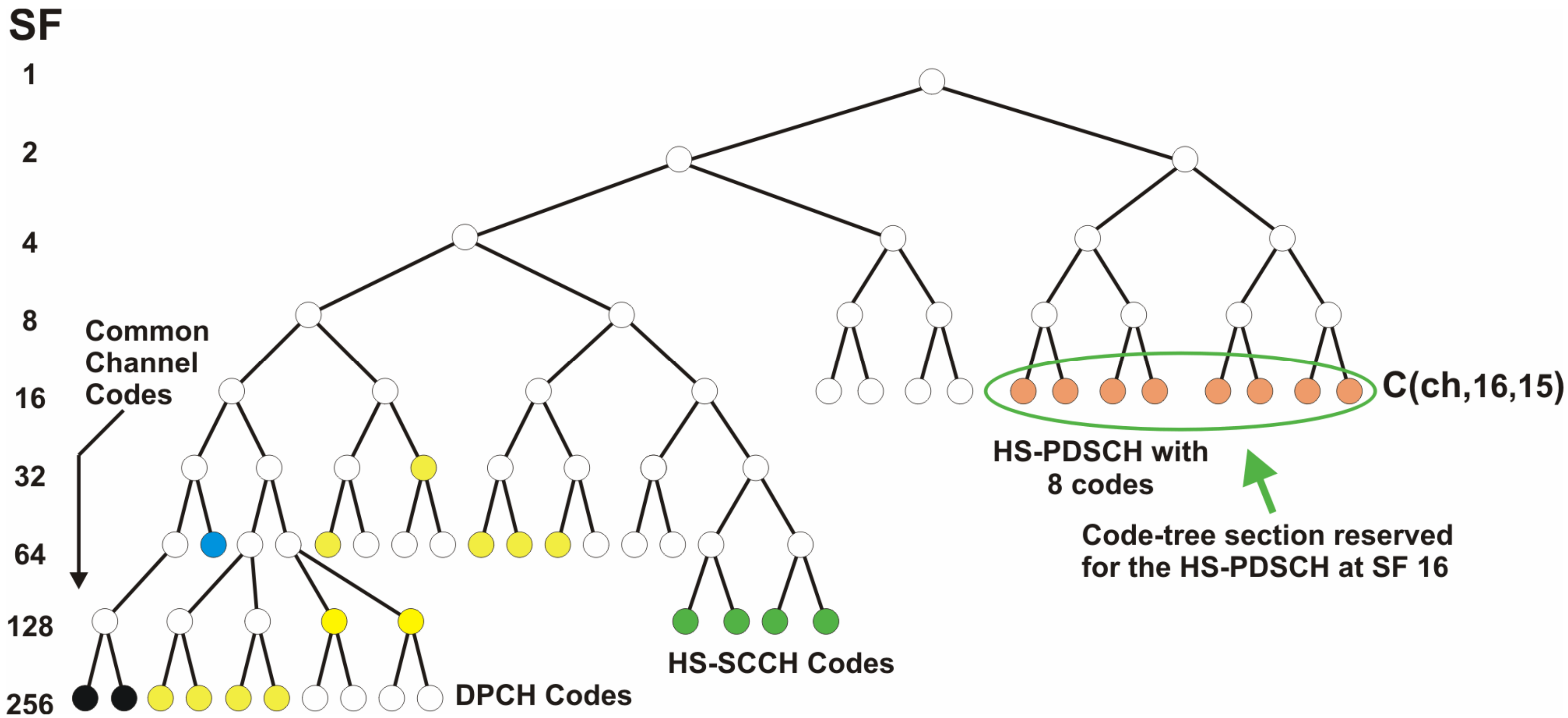
The channelization code set information is sent over a HS-SCCH for a HS-DSCH. OVSF codes are allocated in such as way that they are positioned in sequence in the code tree. Therefore, a number of multi-codes P starting at an offset O may be allocated for a given HS-DSCH and signaled on the HS-SCCH where P may be encoded using only three bits for the code group indicator and four bits for the code offset indicator O for a total of seven bits, one less than conventional methods.

Code group indicator: X(ccs,1); X(ccs,2), X(ccs,3) = min (P - 1, 15 - P)

Code offset indicator: X(ccs,4); X(ccs,5), X(ccs,6), X(ccs,7) = |O - 1 - Floor [P / 8] x 15|

[3GTS 25.212 (4.6.7), (NOKIA)]

HS-DSCH Channelization Code Tree



HS-DSCH Channelization Code Tree

The figure gives an example how the available channelization codes under the primary scrambling code may be shared between HSDPA and Rel. '99 or Rel. 4 users.

⇒ In HSDPA, every HS-PDSCH uses a fixed spreading factor of SF = 16
⇒ Up to 15 codes in parallel may be allocated to a UE.
⇒ The OVSF channelization code tree is allocated by the CRNC.
⇒ The HSDPA codes are autonomously managed by NodeB's MAC-hs scheduler function.

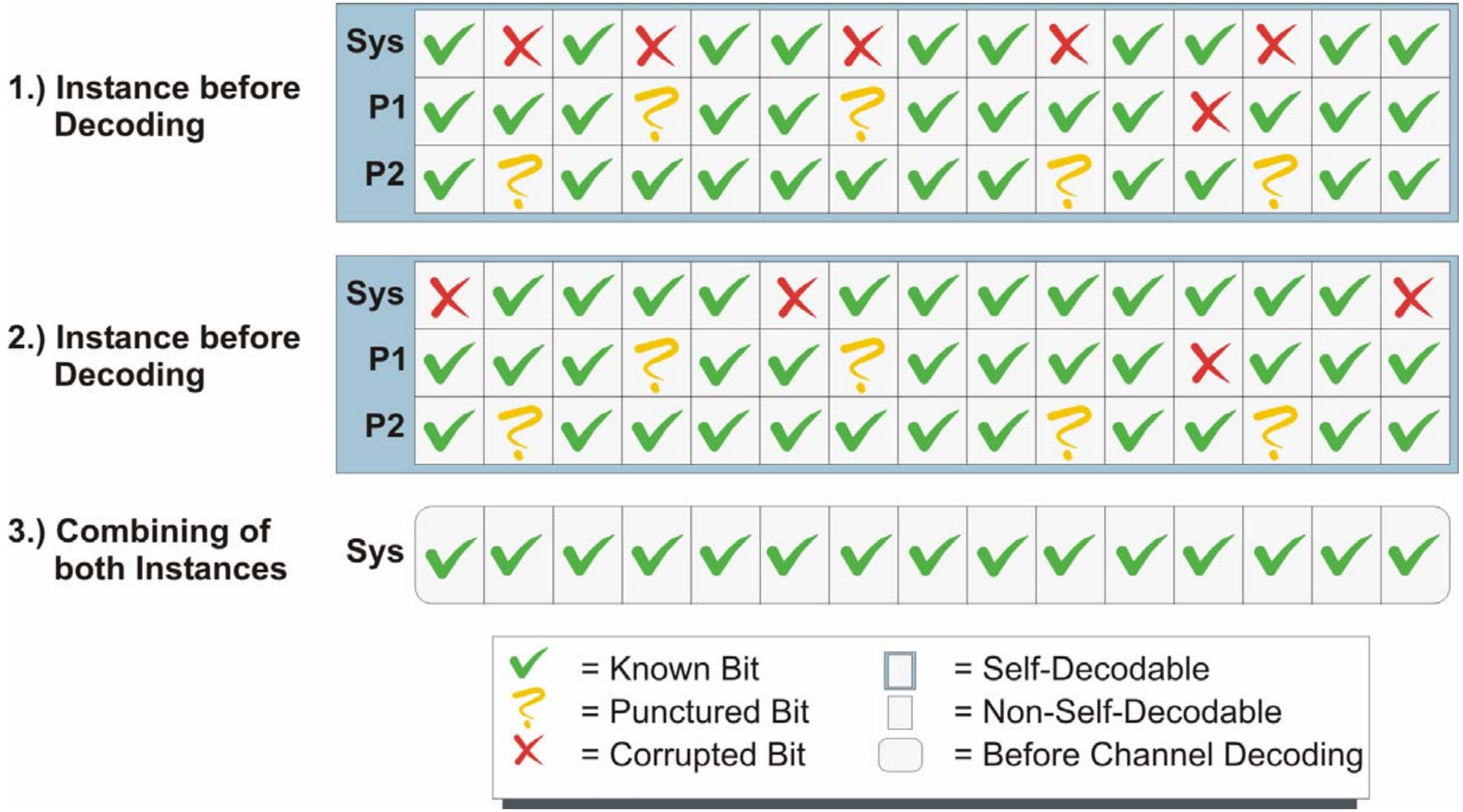
- **Example:**
  The picture shows 8 consecutive codes reserved for HS-PDSCH, starting at C(ch,16,8) and ending with C(ch16,15).

  Additionally, HS-SCCH codes with SF = 128 need to be allocated for the HS-SCCH-set. The HS-SCCH-set can comprise up to 4 HS-SCCH's thus giving the C-RNC a wider flexibility in sharing the OVSF tree between Rel. 5 and legacy release UE's.

⇒ Remember: The HS-DSCH channelization-code-set information signaled over HS-SCCH is mapped the following: The OVSF codes shall be allocated in such a way that they are positioned in sequence in the code tree. That is, for p multicodes at offset y the following codes are allocated:
⇒ C(ch,16,y) … C(ch, 16,y+p-1)
⇒ For the example presented here, the parameter y and p have to be set like this: y = 8 and p =8.

[3GTS 25.213 (5.2.1)]

Operation of Chase Combining



Operation of Chase Combining

The receiver comprises a demodulator and a channel decoder. The demodulator generates soft decision bits for every received bit. The soft decision bits represent likelihood of the real bit value. Thus the demodulator tries to find out all possible combinations of bit values for unknown bits targeting the maximum probability of the bit sequence. The demodulator stores, therefore after each packet has been demodulated, the highest probability values for each bit in soft decision bits. When the channel decoder performs the decoding and the CRC check indicates a block error, retransmission is requested from the sender.

Note: The HS-DSCH is turbo encoded with a rate of 1/3. The turbo coder delivers 3 output bit streams.

⇒ Systematic bits
⇒ Parity P1 bits
⇒ Parity P2 bits

The systematic bits are always needed to decode the original transport block. Transmission or retransmissions containing the systematic bits are therefore also called self-decodable transmissions. The parity bits add redundancy to the encoded block and are not sufficient to decode the transport block without systematic bits.

- **Chase Combining Performance – Hybrid ARQ type III**

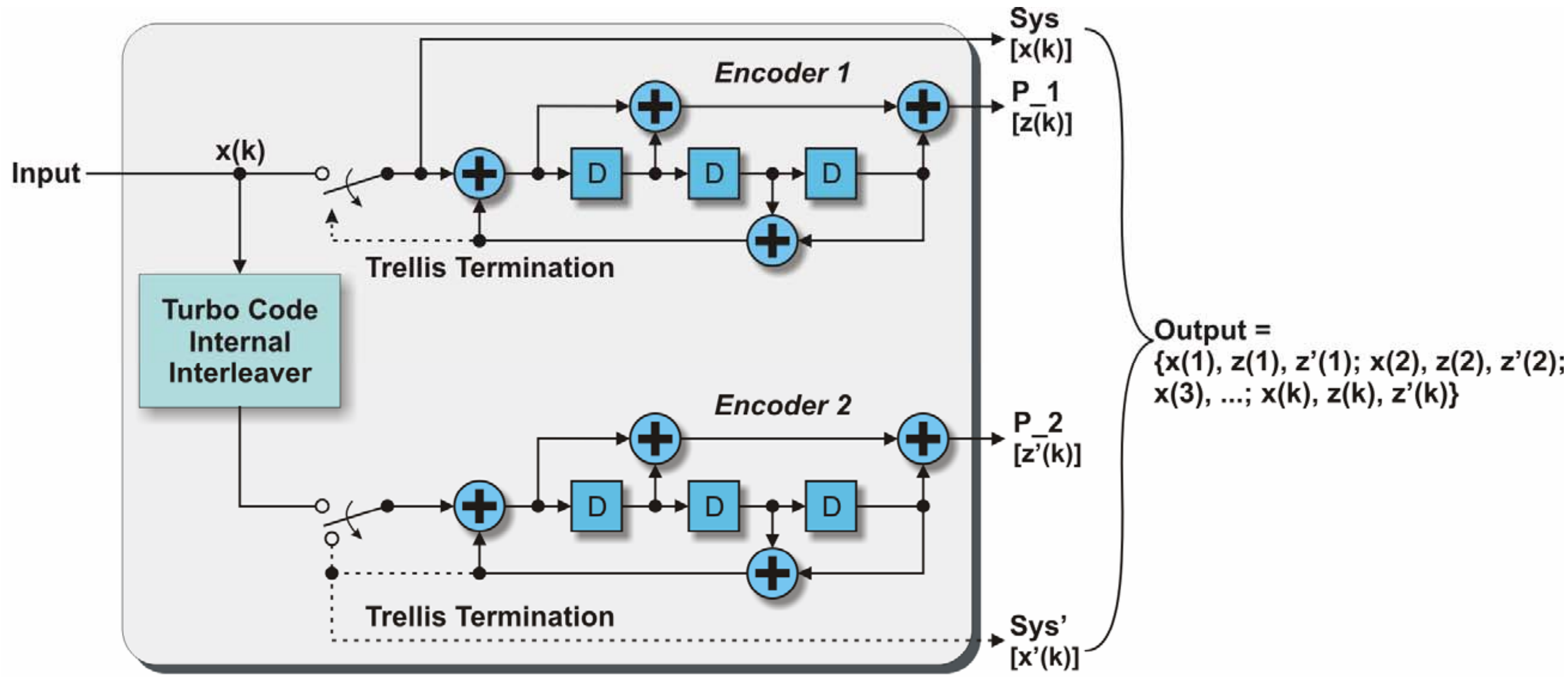
The retransmission of the same packet occurs always with the same puncturing scheme. Every transmission and retransmission contains systematic bits. The same puncturing scheme is indicated by the same two question marks in each packet. Thus chase combining makes use of time diversity gain. Not every transmission or re-transmission is affected by the same interference or fading. Thus errors occur on different bit positions as indicated by the red 'cross'. After the first instance of a packet has been received the demodulator keeps the soft decision values in a buffer as the CRC check indicated block error and a second instance of the same packet is requested.

Once the second instance has been received, the demodulator can add up the soft decision values of each transmission based on their SNR value and so achieve a more reliable demodulation result. By adding up the soft decision values after every instance of a retransmission, the buffer capacity for the soft decision bits is modest compared to IR.

Note: In chase combining, multiple retransmissions, so called full retransmissions, are sent with the same puncturing scheme. Every transmission is self-decodable as it contains the systematic bits. The amount of data in the receiver buffer remains the same.

[3GTR 25.848 (6.8.1.1)]

Turbo Coder Structure



Trellis Termination: {x(k+1), z(k+1); x(k+2), z(k+2); x(k+3), z(k+3); x'(k+1), z'(k+1); x'(k+2), z'(k+2); x'(k+3), z'(k+3)}

Turbo Coder Structure

The scheme of a Turbo coder is a Parallel Concatenated Convolutional Code (PCCC) with two 8-state constituent encoders and one turbo code internal interleaver. Coding rate of a turbo coder is =1/3 (if the tail bits are not included)
Turbo coding is block encoding suitable and efficient for code blocks. If turbo coding is selected and the number of input bits in the code block is less than 40, then filler bits are added to the beginning of the code block. The filler bits are transmitted and they are always zero.
Note: After CRC attachment of the transport block, the block is called coded block. After turbo coding the block is called encoded block.

The maximum code block size K for turbo coding is: $40 <= K <= 5114$

If the number of coded bits exceeds 5114, code block segmentation is performed. The code blocks after segmentation are of the same size.

Trellis Termination for Turbo coder

Trellis termination is done in order to reset the turbo coder after the coded block has been entirely encoded. Due to the recursive function in the RSC, an endless output bit sequence is generated even when the input sequence has ended. Therefore it is not possible to simply terminate the turbo coder by clocking in zero bits as it is done for convolutional coders. Trellis termination is performed by proper selection of tail bits. Unlike conventional convolutional codes which can be always terminated with a tail of zeros, the tail bits of an RSC will depend on the state of the encoder. Because the states of the two RSC encoders will be usually be different after the data has been encoded, the tails for each encoder must be separately calculated and transmitted. The tail bits are generated for each encoder by throwing the two switches into the down position, thus causing the inputs to the two encoders to be indicated by the dotted lines. The tail bits are then transmitted at the end of the encoded frame according to x(k+1), z(k+1); x(k+2), z(k+2); x(k+3), z(k+3); x'(k+1), z'(k+1), x'(k+2), z'(k+2), x'(k+3), z'(k+3)
The first three tail bits are used to terminate the first constituent encoder (upper switch of figure in lower position) while the second constituent encoder is disabled. The last three tail bits are used to terminate the second constituent encoder (lower switch of figure in lower position) while the first constituent encoder is disabled. As each RSC is a form of 1/2 convolutional coder, 2 times 6 output bits are generated by tail bits.

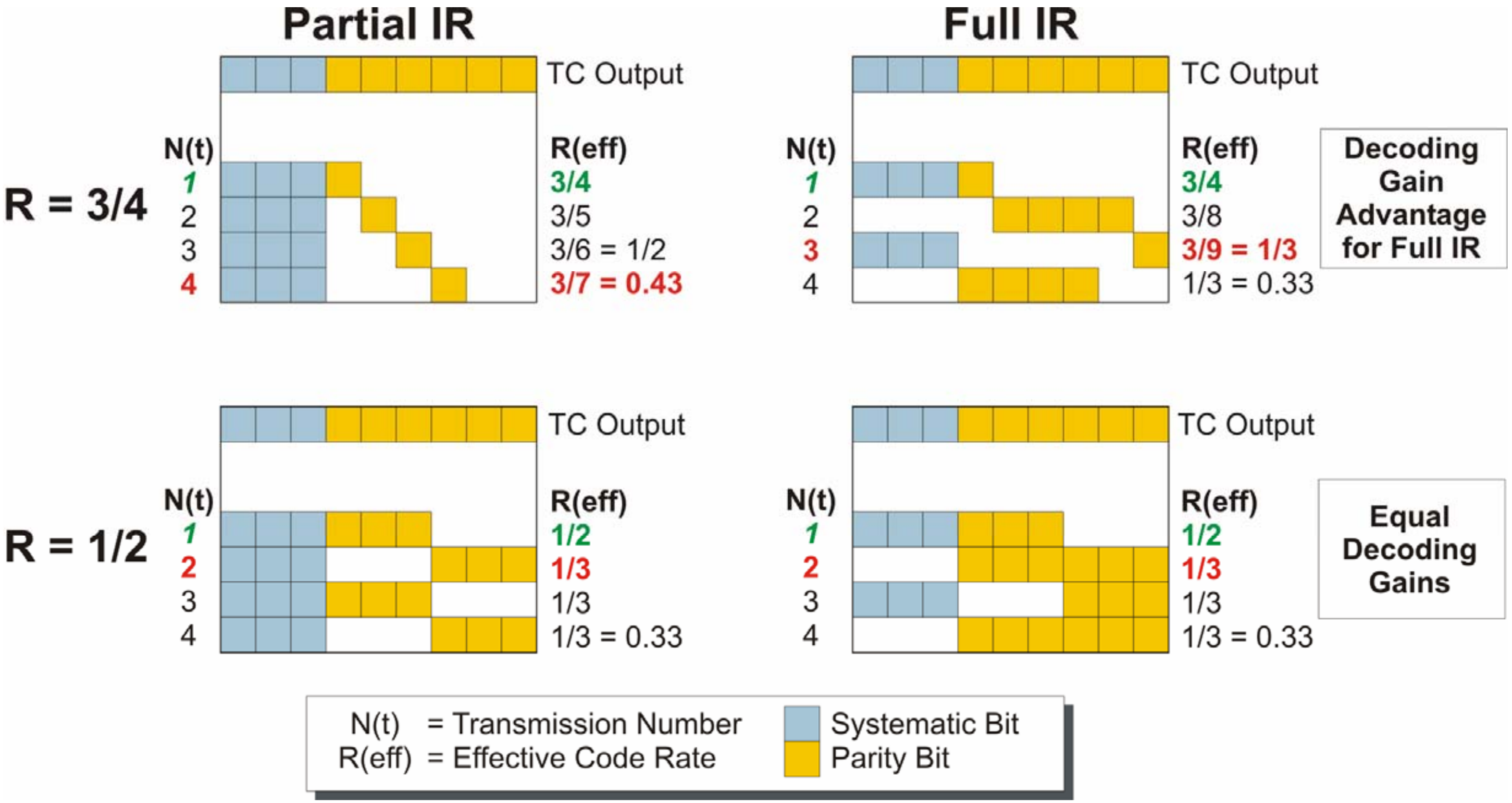
When tail bits are taken into account the number of encoded bits is: $3K + 12 \Leftrightarrow \text{code rate} = K / (3K + 12)$

Turbo Code internal Interleaver

The interleaver is a matrix with 5, 10 or 20 rows and between 8 and 256 column, depending on the size of the input word K. Data is read into the interleaver in a row-wise fashion. Intra-row permutations are performed on each row of the matrix. Next, inter-row permutations are performed. After that the data is read out from the interleaver in a column-wise fashion.

[25.212 (4.2.2.2, 4.2.3.2)]

Comparison between Full and Partial IR



Comparison between Full and Partial IR

The code rate R expresses the ratio of protection, and how much redundancy is added to the user bits respectively. A code rate close to "1" means that there is actually almost no redundant information added. Thus such aggressive transmissions are performed under good ratio conditions and high user data rate requests. Full and Partial IR allow to reduce the code rate compared to chase combining. However, chase combining requires minimum complexity and buffer size. Initial transmission and retransmissions are identical when using chase combining method. Chase combining offers time diversity and soft combining gain taking the SNR of each (re-) transmission into account (i.e. the energy accumulation effect for each bit). The code rate r is defined as:

R = (number of bits before channel coding) / (number of bits after channel coding & puncturing)

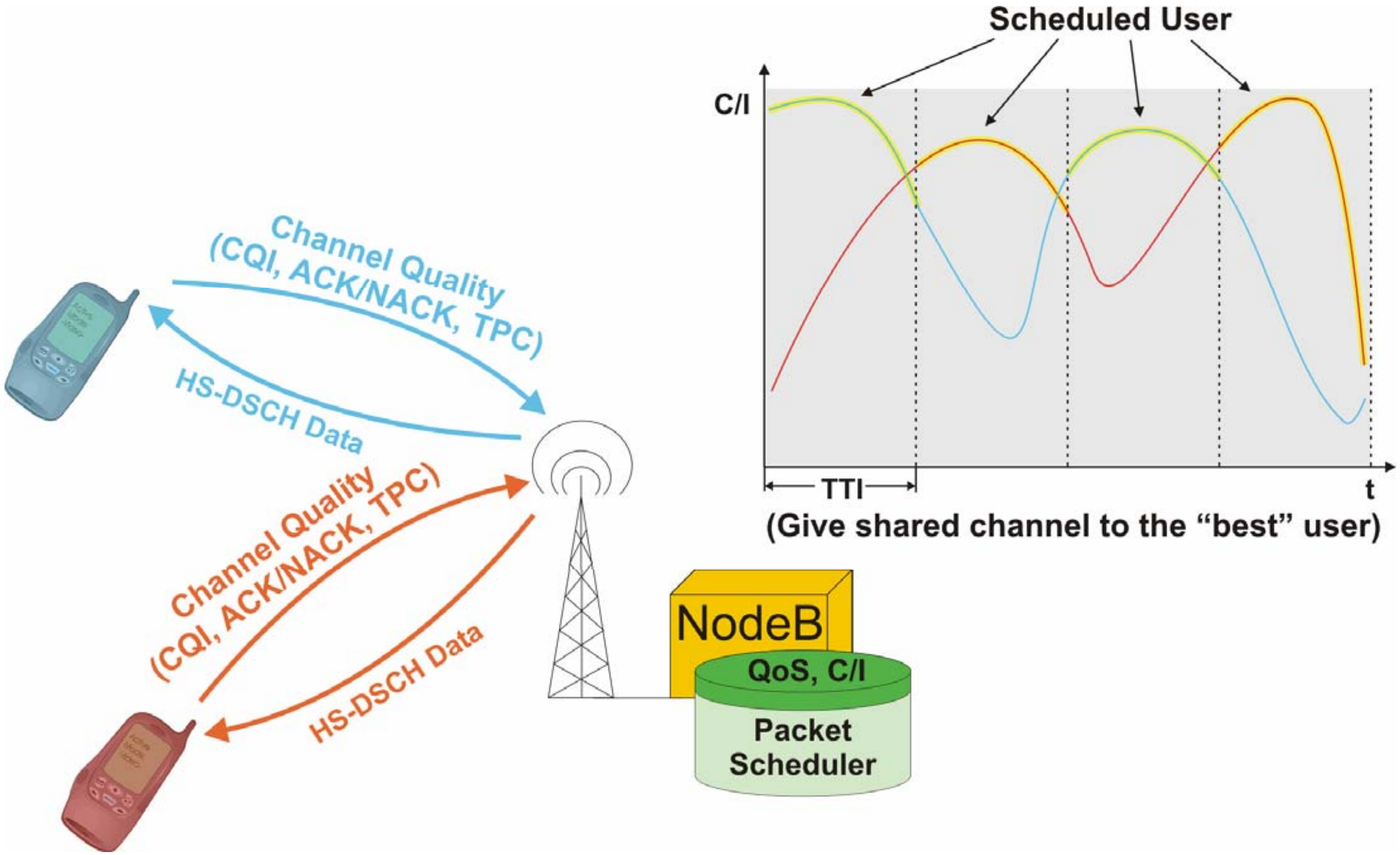
Note: The number of bits before channel coding (turbo coding) matches the systematic bits (in our example: 3 bits (blue color))
As an example, the figure compares partial and full IR for code rates R = 3/4 and R = 1/2 in a pictorial way. The code rate is re-calculated after each retransmission.
The first row in each block signifies the total number of bits after turbo coding with R = 1/3. Due to the turbo coder code rate of 1/3, twice as much parity bits (yellow) are available than systematic bits (blue).
The following four rows show which bits are sent in each transmission N(t). For partial IR the systematic bits are always repeated, simply different parity bits are sent.

- **R = 3/4**
  For high initial code rates it is obvious that it takes partial IR several retransmissions until all parity bits have been sent once. R(eff) is slowly decreasing and only after six transmissions all bits have been sent ⇔ (3/4, 3/5, 3/6, 3/7, 3/8, 3/9)
  Full IR allows decreasing the effective code rate more rapidly. As depicted in the figure, all bits have been sent once already after three transmissions.

- **R = 1/2**
  For R = 1/2, however, there is no longer a decoding gain advantage for full IR, since partial IR allows also to send all available bits within two transmissions. Detailed investigations have shown, that for HSDPA full IR is favorable for initial code rates R > 1/2, while partial IR should be used for lower initial code rates, e.g. R =< 1/2.

  [3GTR 25.848 (Annex A), (SAG)]

Multi-User Selection Diversity – Dynamic Scheduling



Multi-User Selection Diversity – Dynamic Scheduling

The PS is located in the NodeB. This opens up for "fast scheduling" at nearly every TTI (2 ms) in HSDPA. The scheduling algorithm may be optimized according to the current channel conditions (⇔ RICQ) which can yield large gain at cell and user levels.
Basic diversity mechanism utilized is multi-user diversity = selection diversity among the active users.

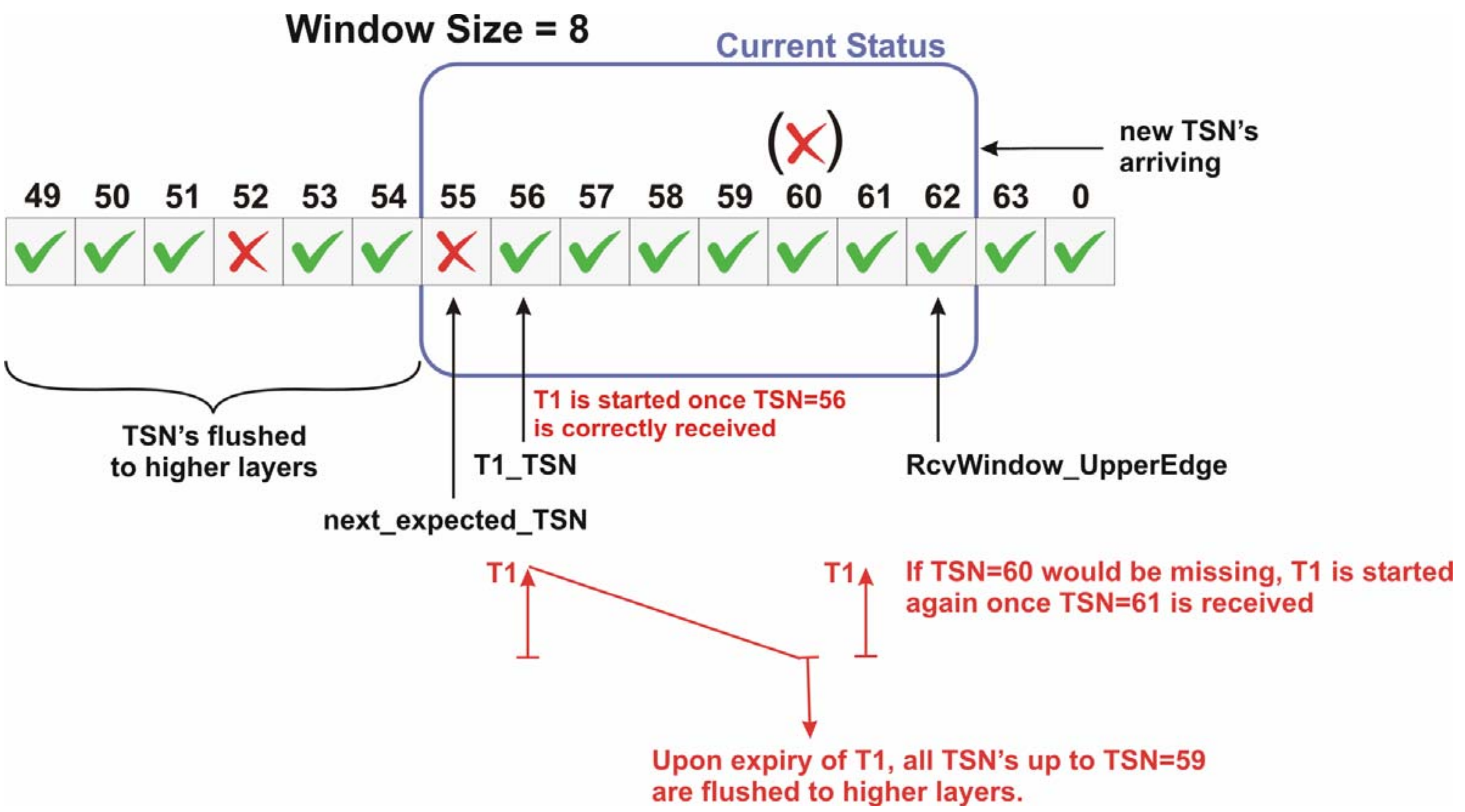
- **Dynamic Scheduling according to best C/I**
  Dynamic scheduling at the NodeB provides optimized usage of radio resources and exploits the short-term variations on the radio channels. It allows for a certain degree of QoS. There is a closed loop due to the physical feedback on HS-DPCCH about reception quality and Ack/Nack.

  There is a "statistical multiplexing" of data packets from different data flows (here from UE's) over one shared medium, namely HS-DSCH.
  ➔ Optimized usage of radio resources
  ➔ Exploitation of the short-term variations on the radio channels
  ➔ Provides certain degree of QoS

- **Scheduler Resources include:**
  ⇒ Transmission power for HS-SCCH's and HS-PDSCH's
  ⇒ Channelization codes for HS-PDSCH's
  ⇒ Transport block size must be one out of a predefined set or at least compatible with UE category
  ⇒ Number and codes for HS-SCCH's
  ⇒ NodeB hardware/processing boards configured for HS-PDSCH's and HS-SCCH's
  ⇒ NodeB hardware/processing boards configured for reception of HS-DPCCH per user individually

- **MAC-hs Scheduler should not allocate any HSDPA Resources to a User which:**
  ⇒ Has no data for transmission
  ⇒ Has no free capacity in any reordering buffer
  ⇒ Has no ready-to-transmit HARQ process
  ⇒ Has not completed the minimum inter-TTI interval after the last HSDPA transmission (see chapter 3 page "HSDPA Category and Reference Combinations"
  ⇒ Has reported a too low/bad CQI or CQI is "out of range"
  ⇒ Has not reported any CQI or is physically out of sync in UL

Timer and / or Window Based Stall Avoidance



Timer and / or Window Based Stall Avoidance

- **Window Based Scheme**
  The diagram graphically illustrates the window maintained for a particular priority queue. To resolve ambiguity in the TSN number space caused by the fact that the TSN field has a finite size, the receiver uses a window. The max. size of this window is typically set at less than half of the TSN number space (i.e., < 32) and may be set even smaller according to higher layer requirements. Since the window size is smaller than the TSN number space, the order of the packets within the window is unambiguous. In determining the size of the window, there is a tradeoff. If the window is small, the stall avoidance performance at the receiver increases and the receiver buffer size requirement in UE is reduced. However, the stall probability at the transmitter or the probability of needing to interrupt retransmissions (depending on the transmission strategy) is increased.
  The window is advanced forward as new packets are received. For the receiver, the leading edge of the window is set equal to the "latest" TSN of all recovered packets (RcvWindow_UpperEdge). Packets toward the left of the window have successively "earlier" TSN's. Since the TSN value can wrap around, the latest TSN value may actually be smaller than an earlier TSN whenever the TSN wraps around. Missing packets with TSN's earlier than the trailing edge of the window may be assumed to be lost. Thus, as the window is advanced forward, packets earlier than the trailing window edge are "flushed" and sent to higher layers. This window mechanism may therefore be used to flush out missing packets at the receiver. However, since the size of the window would need to be large to allow for a large number of retransmissions, a large amount of data would be needed to flush out the missing packets. Consequently, the window-based scheme is marginally effective at the end of data bursts, which are frequent in the case of bursty closed loop traffic such as what is generated by web browsing.

- **Timer Bases Scheme**
  In order to address the limitations of the window-based scheme, a timer-based mechanism was also introduced. For the timer-based scheme, each time a missing packet stalls the delivery of packets to higher layers at the receiver, a timer T1 is started. If no other missing packets are thereafter detected then, once T1 expires, the missing packet is assumed to have been recovered, and all packets stalled by this missing packet are then delivered to higher layers. This mechanism requires the maintenance of one timer per re-ordering queue. To ensure proper HARQ operation, the timer needs to be set longer than the longest amount of time it takes to complete all retransmissions for a given packet. A large number of retransmissions may need to be performed to recover the missing packet. Moreover, in a system that asynchronously schedules retransmissions and where the amount of resources (e.g., as quantified by channelization codes and transmit power) available for HSDPA can change dynamically, the amount of time it takes to complete all retransmissions for a missing packet can vary widely. Consequently, the value of this timer would need to be long. Otherwise, the retransmissions for the missing packet may be prematurely terminated by the expiration of the T1, in which case the missing packet would need to be retransmitted by higher layers, which is highly undesirable. The re-ordering entity may need to wait a significant amount of time for the long timer to expire or until all the retransmissions for the missing payload are completed.

HS-PDSCH and DL TrCH Information

Activation Time [CFN]				**MD**	0...255; Default value is "now"
H-RNTI				**OP**	16 bit string (unformatted)
Downlink HS-PDSCH Information				**OP**	
	HS-SCCH Info			OP	
		DL Scrambling Code		MD	Default is Primary Scrambling Code
		HS-SCCH Channelization Code Information		MP	
		1 to maxHSSCCHcodes	HS-SCCH Channelization Code	MP	0 ... 127
	Measurement Feedback Info			OP	
		Measurement Power Offset Γ		MP	-6 .. 13 dB by step of 0.5
		CQI Feedback Cycle k		MP	(0, 2, 4, 8, 10, 20, 40, 80, 160) ms
		CQI Repetition Factor		MP	1 ... 4
		Δ CQI		MP	0 ... 8
Added or Reconfigured DL TrCH Information				MP	
	Downlink Transport Channel Type			**HS-DSCH**	
	HARQ Info			OP	
	CHOICE	Memory Partitioning		MP	
		Implicit			
		Number of Processes		MP	1 ... 8
		Explicit			
		1 to MaxNoHARQProcesses	Process Memory Size	MP	800 .. 16000 by step of 800, 17600 .. 32000 by step of 1600, 36000 .. 80000 by step of 4000, 88000 .. 160000 by step of 8000, 176000 .. 304000 by step of 16000

HS-PDSCH and DL TrCH Information

The table shows what are the values and their need for following IE's 'Activation Time', 'H-RNTI', 'Downlink HS-PDSCH Information and 'Added or Reconfigured DL TrCH Information'. Note, that only the IE's which have not yet been covered in the previous chapters will be explained here.

Activation Time

If the UE receives an RRC message where the IE "Activation time" has a value other (e.g. CFN) than the MD value "Now", the UE shall:

⇒ in the case of HS-DSCH, let the CCTrCH including the associated DCH be the "reference CCTrCH",

⇒ if the frame boundary immediately before the frame with the CFN value indicated by the IE "Activation Time" is at the TTI boundary common to all the transport channels that are multiplexed onto the reference CCTrCH:

⇒ select that frame boundary as the activation time T.

else:

⇒ select the next TTI boundary, which is common to all the transport channels that are multiplexed onto the reference CCTrCH, after the frame with the CFN value indicated by the IE "Activation Time", as the activation time T.

For an HS-DSCH related reconfiguration caused by the received RRC message:

⇒ select the HS-SCCH subframe boundary immediately before the first HS-SCCH subframe, which entirely falls within the 10 ms frame following T;

⇒ start using at that HS-SCCH subframe boundary the new HS-DSCH configuration in the received RRC message, replacing any old HS-DSCH configuration.

Note: In FDD an "HS-DSCH related reconfiguration" includes, in particular, reconfigurations that need to be time-aligned with the 2ms subframe of the HS-SCCH, HS-PDSCH and/or HS-DPCCH. For example, start and stop of HS-SCCH reception and serving HS-DSCH cell change.

If the UE receives a RRC message where the IE "Activation time" has the default value "Now", the UE shall:

⇒ choose an activation time T as soon as possible after the reception of the message, respecting the performance requirements in 3GTS 25.331 (13.5.2)

at the activation time T:

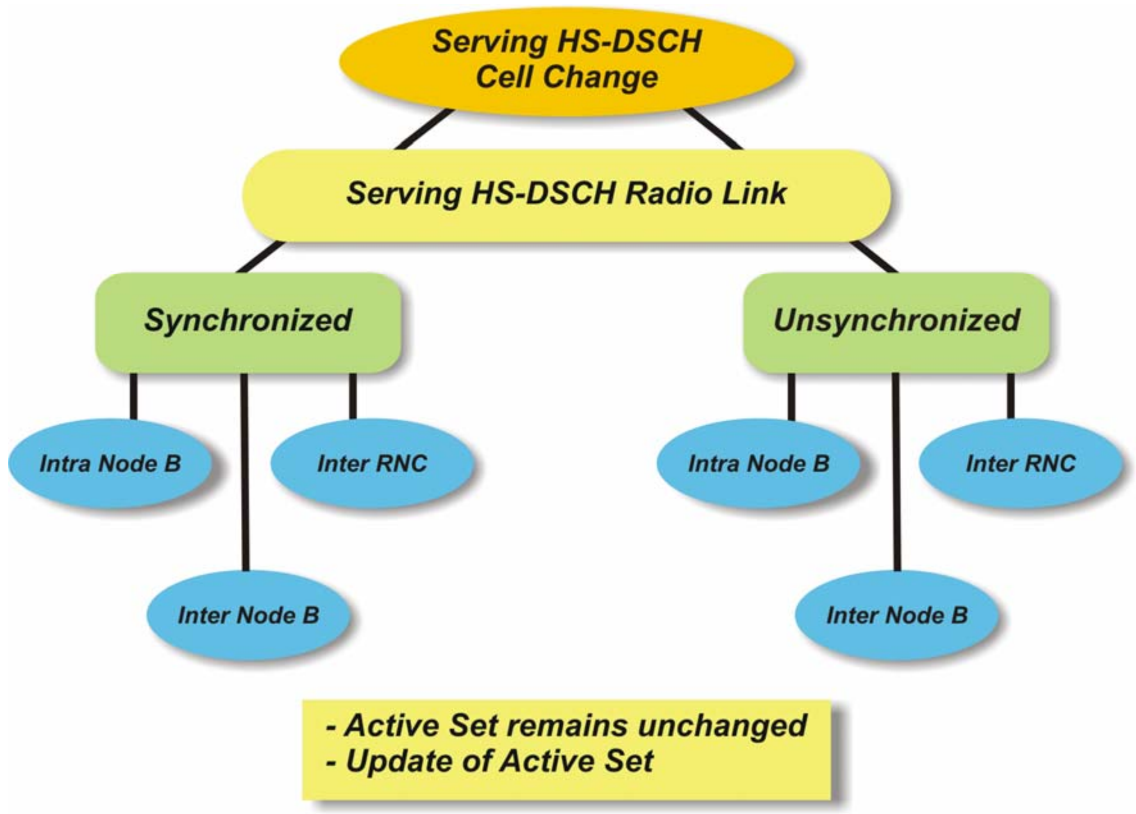
⇒ perform the actions for the information elements in the received message as specified elsewhere

Downlink Transport Channel Type

The IE "Downlink transport channel type" values "HS-DSCH" and "DCH + HS-DSCH" are not used in the RRC CONNECTION SETUP message.

[3GTS 25.331 (8.6.3.1)]

Introduction to HSDPA Mobility Procedures



Introduction to HSDPA Mobility Procedures

While in CELL_DCH state, the UE may be allocated one or more HS-PDSCH(s), allowing it to receive data on the HS-DSCH(s).
Mobile evaluated hard-handover and soft-handover mechanisms are provided by the RRC connection mobility in CELL_DCH state. The mobility procedures are affected by the fact that the HS-PDSCH allocation for a given UE belongs to only one of the radio links assigned to the UE, the serving HS-DSCH radio link. The cell associated with the serving HS-DSCH radio link is defined as the serving HS-DSCH cell. A change in the serving HS-DSCH cell is the transfer of the serving HS-DSCH radio link from the source to the target HS-DSCH cell.

Note: In Release 5, only network controlled serving HS-DSCH cell changes shall be supported.

The SRNC makes the decision of the HS-DSCH cell change and determines the target cell. The decision could be based on UE measurement reports and other information available in the network. The SRNC controlled HS-DSCH cell change is performed as an RRC layer signaling procedure and is based on the existing handover procedures in CELL_DCH state.

Serving HS-DSCH Cell Change

The following categories exist with respect to the dedicated physical channel configuration:

⇒ Serving HS-DSCH cell change while keeping the dedicated physical channel configuration and the active set;
⇒ Serving HS-DSCH cell change in combination with an establishment, release and/or reconfiguration of dedicated physical channels
⇒ Serving HS-DSCH cell change in combination with active set update in soft handover.

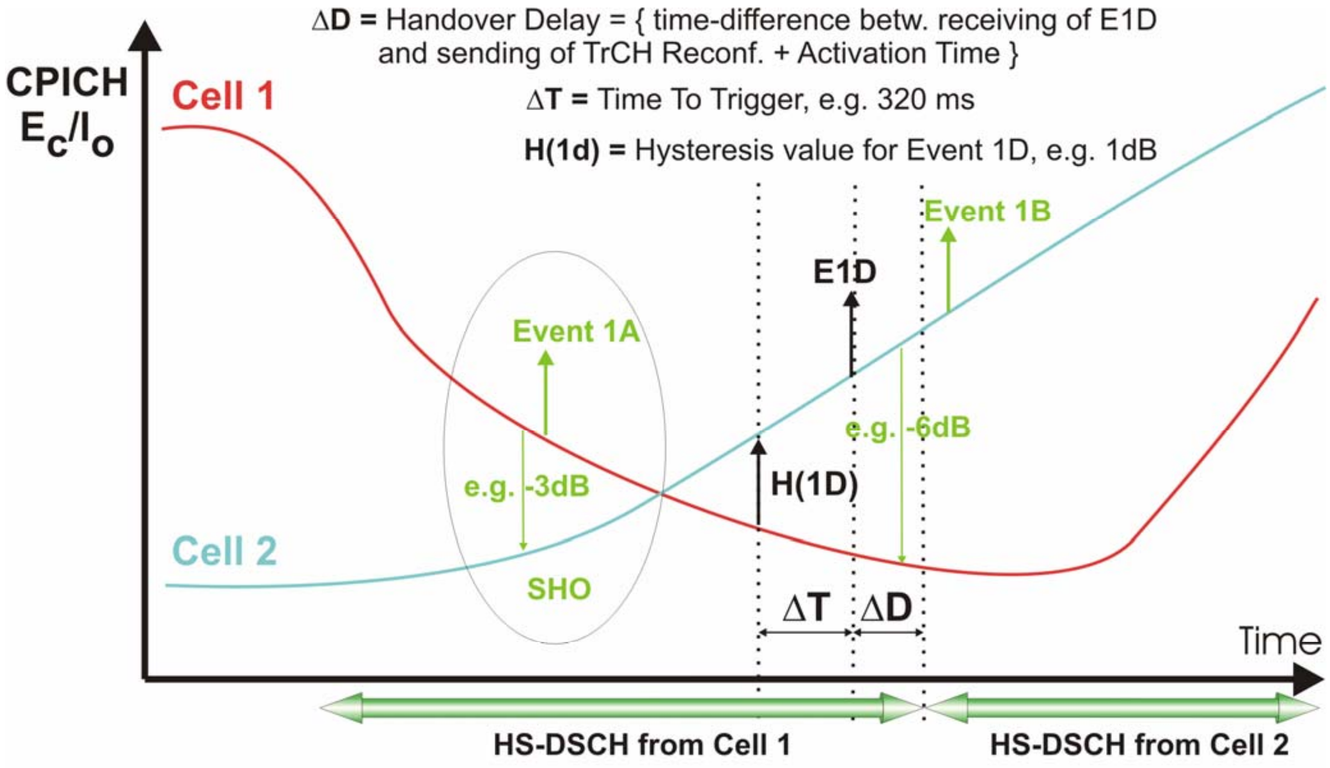
With respect to synchronization between UE and UTRAN as to when transmission and reception is stopped and re-started, two possibilities for a serving HS-DSCH cell change exist:

⇒ Synchronized serving HS-DSCH cell change: Start and stop of HS-DSCH transmission and reception is performed at a certain time typically selected by the network;
⇒ Unsynchronized serving HS-DSCH cell change: Start and stop of HS-DSCH transmission and reception is performed "as soon as possible" (stated by UE performance requirements) at either side.

Note: For traffic classes like streaming, interactive or background, the synchronized cell change is advantages as it minimizes the packet loss and therefore the jitter.

[3GTS 25.308 (9.1)]

Best Serving HS-DSCH Cell Measurement



<u>Note:</u> The SRNC must delay the ActiveSetUpdate for Event 1B until the TransportChannelReconfiguration Complete message was received on SRB 2!

Best Serving HS-DSCH Cell Measurement

The figure shows the event 1D which is used by UE to report a change of the best serving cell of the active set.
In order to support the UE's mobility, the UE needs to provide measurement reports about the quality (Ec/Io) and / or signal level (RSCP) of the configured neighbor cells. Note this measurements are obtained from the P-CPICH which is basically a beacon for the cell.

Change of best Cell

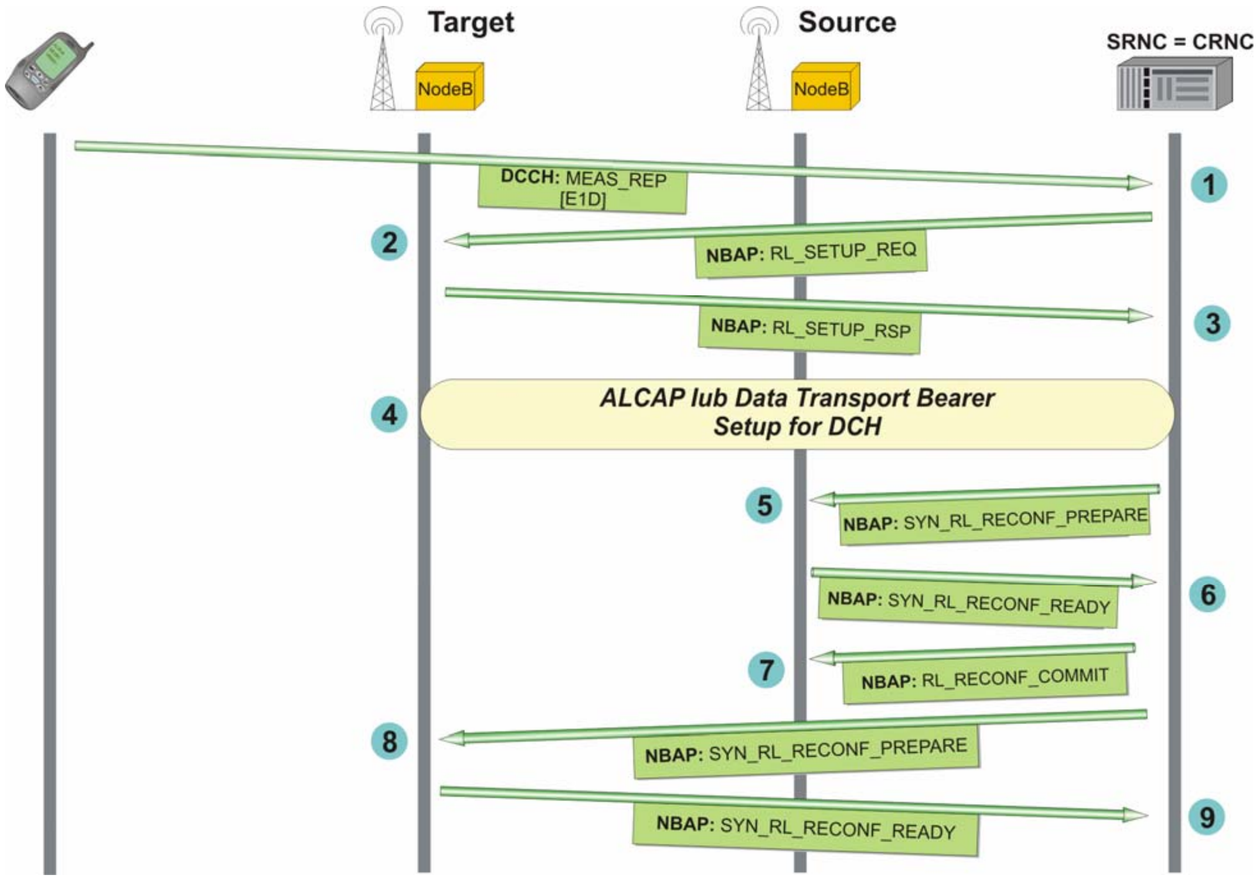
As known from legacy releases, it is the SRNC that determines the cells which should belong to the UE's active set for transmission of dedicated channels. The SRNC typically bases its decisions on requests received from UE that are triggered by measurement events (e.g. Ec/Io or RSCP) on the P-CPICH. Via RRC measurement control messages the UE is informed about the candidate set for neighbor measurements.
For HSDPA a similar measurement event 1D can be defined which is called the measurement event for best serving HS-DSCH cell. This measurement basically reports the best serving HS-DSCH cell to the SRNC based on a measurement of the P-CPICH Ec/Io or P-CPICH_RSCP. It is possible to configure this measurement event so that all cells in the UE's monitoring set are taken into account, or to restrict the measurement event so that only the current cells in the UE's active set (for dedicated channels) are considered.
The usage of a hysteresis margin avoids fast change of the serving HS-DSCH cell. Also the specification of a CIO (cell individual offset) to favor certain cells, i.e. for instance, to extend their HSDPA coverage area.

HS-DSCH Handover

As can be seen in the figure, the UE moves from cell 1 towards cell 2. At a point in time, the P-CPICH_Ec/Io of cell 2 is better compared to cell 2's P-CPICH_Ec/Io. After a safe guard time of TTT (time to trigger), the UE reports event 1D to SRNC indicating cell 2's scrambling code and P-CPICH_Ec/Io and / or P-CPICH_RSCP value in order to inform SRNC about a better cell. TTT prevents in conjunction with H(1d) too frequent measurement reports and consequently too rapid cell changes. For example, the cell 2 must exceed cell 1's P-CPICH_Ec/Io quality level by H(1d) for a minimum time of TTT. Here we assume that CIO is set to '0' and thus not delaying or speeding up event 1D measurement reports. Once the SRNC has received the event 1D measurement report it may execute the HS-DSCH cell change procedure. Thus the HS-DSCH cell change is network controlled. The SRNC specifies with the activation time when the UE has to leave the old cell and change to the new cell.
As this cell change involves RRC, NBAP and ALCAP signaling procedures in conjunction with an activation time, there is a certain delay until the serving HS-DSCH cell change is finished.

[3GTS 25.308 (9), 3GTS 25.331 (14.1.2.4)]

Inter NodeB HS-DSCH Cell Change – Hard Handover (1)



Inter NodeB HS-DSCH Cell Change – Hard Handover(1)

The figure illustrates a synchronized inter-Node B serving HS-DSCH cell change **in combination with hard handover** e.g. necessary for quick handovers of both DCH's and HS-DSCH in one shot. The reconfiguration is performed in two steps within UTRAN. On the radio interface only a single RRC procedure is used. The UE sends Measurement Report with event 1D to the SRNC. The SRNC determines the need for hard handover based on received measurement reports and/or load control algorithms (e.g. measurements may be performed in compressed mode ⇔ Inter FDD HHO).
In the first step, the SRNC establishes a new radio link in the target NodeB via a NBAP RL Setup message. In the second step this newly created radio link is prepared for a synchronized reconfiguration to be executed at a given activation time indicated in a NBAP RL Reconfiguration Commit message. After the first step, the target Node B starts transmission and reception on dedicated (logical) channels (DCH ⇔ DCCH). At the indicated activation time, transmission of HS-DSCH is started in the target HS-DSCH Node B and stopped in the source HS-DSCH Node B.
In order to trigger the hard handover SRNC then sends a Transport Channel Reconfiguration message on the old configuration. This message indicates the configuration after handover, both for DCH and HS-DSCH. The Transport Channel Reconfiguration message includes a flag indicating that the MAC-hs entity in the UE shall be reset. The message also includes an update of transport channel related parameters for the HS-DSCH in the target HS-DSCH cell.

1. UE sends Measurement Report [E1D] to SRNC via DCCH in order to indicate a better cell.
2. The SRNC decides that there is a need for a hard handover combined with a serving HS-DSCH cell change. It therefore transmit a NBAP Radio Link Setup message to the target NodeB.
3. The target NodeB allocates the resources, starts physical layer reception on the DPCH on the new radio link and responds with the NBAP message Radio Link Setup Response. Parameters provided: HS-DSCH Information Response.
4. The SRNC initiates set-up of a new Iub Data Transport Bearer for DCH using ALCAP protocol. This request contains the AAL2 Binding ID to bind the Iub Data Transport Bearer to the DPCH.
5. The SRNC requests the source HS-DSCH NodeB to perform a Synchronized Radio link Reconfiguration, removing its HS-DSCH resources for the source HS-DSCH radio link. Parameters provided: HS-DSCH Information, a CRNC (=SRNC) allocated HS-DSCH RNTI and HS-PDSCH's RL ID.
6. The source HS-DSCH NodeB returns the NBAP message Synchronized Radio Link Reconfiguration Ready. Parameters provided: HS-DSCH Information Response.
7. The SRNC transmits a NBAP Radio Link Reconfiguration Commit to the source cell indicating when the MAC-hs shall stop sending HS-DSCH data blocks. At the indicated activation time the source NodeB stops and the target HS-DSCH NodeB starts transmitting on the HS-DSCH to the UE. Parameter provided: SRNC selected activation time in the form of CFN.
8. Now the SRNC requests the target HS-DSCH NodeB to perform a Synchronized Radio Link Reconfiguration via NBAP, adding HS-DSCH resources for the target HS-DSCH radio link.
9. The target HS-DSCH NodeB returns the NBAP message Radio Link Reconfiguration Ready. Parameters provided: HS-DSCH Information Response.

[3GTS 25.308 (9.4), 3GTR 25.931 (7.11.1.3.1)]