

HSPA

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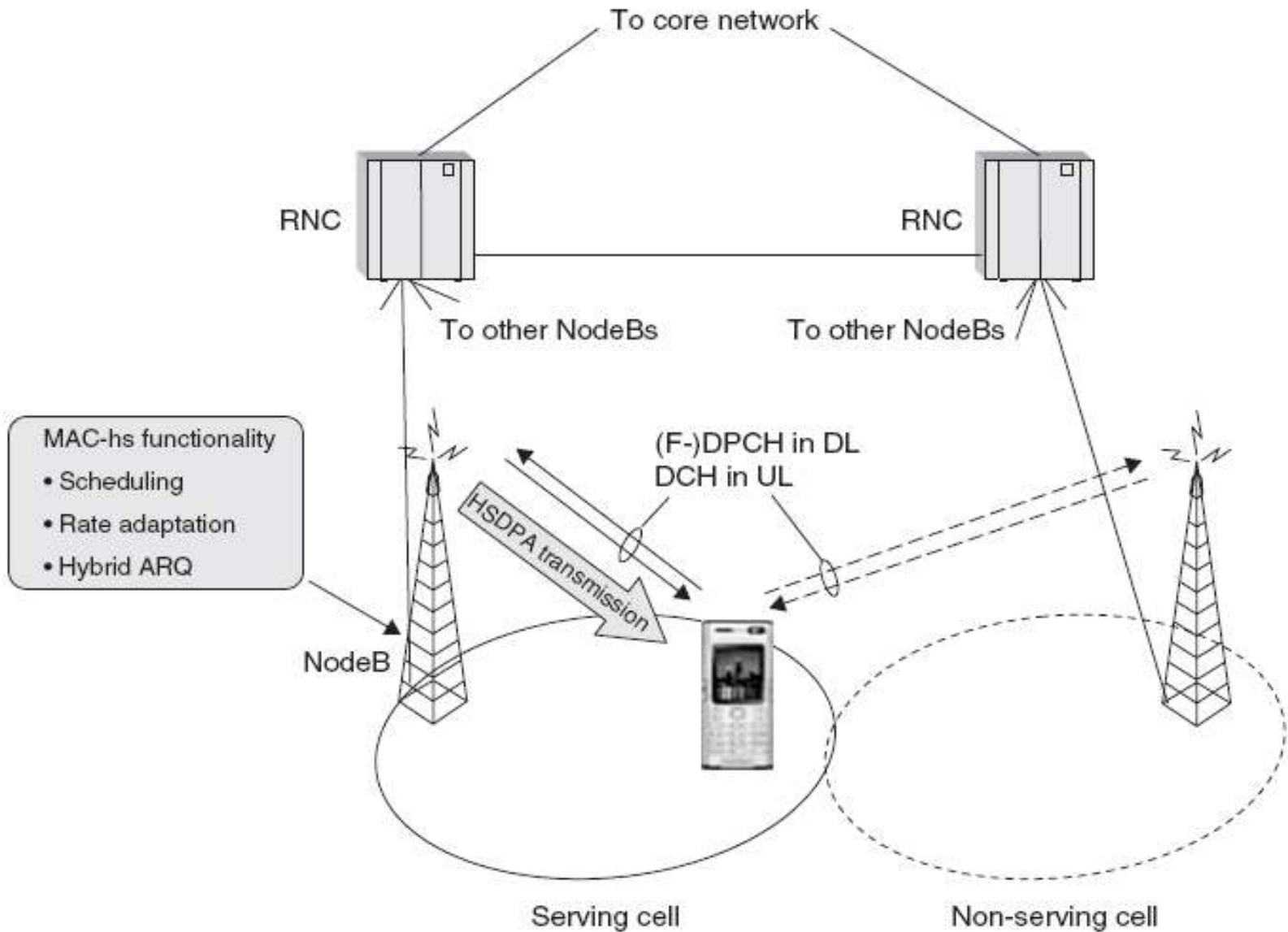
HSPA

- **HSPA** (High Speed Packet Access) consists of **HSUPA** (High Speed Uplink Packet Access) and **HSDPA** (High Speed Downlink Packet Access). It is a major extension of WCDMA radio interface.
- HSPA enhances the Uplink/downlink packet data performance and capabilities in terms of higher peak data rate, reduce latency and increase capacity using techniques including higher-order modulation, rate control, channel-dependent scheduling, and hybrid ARQ with soft combining.
- The key feature for HSPA is the use of shared channel transmission in which a certain fraction of total radio resources are dynamically shared among all users in the time domain.
- In the downlink, the shared resources is transmission power and code space, both are located in one central NodeB. In the uplink, the shared resources are the amount of allowed interference, which depends on the transmission power of multiple distributed nodes, the UEs.

HSDPA

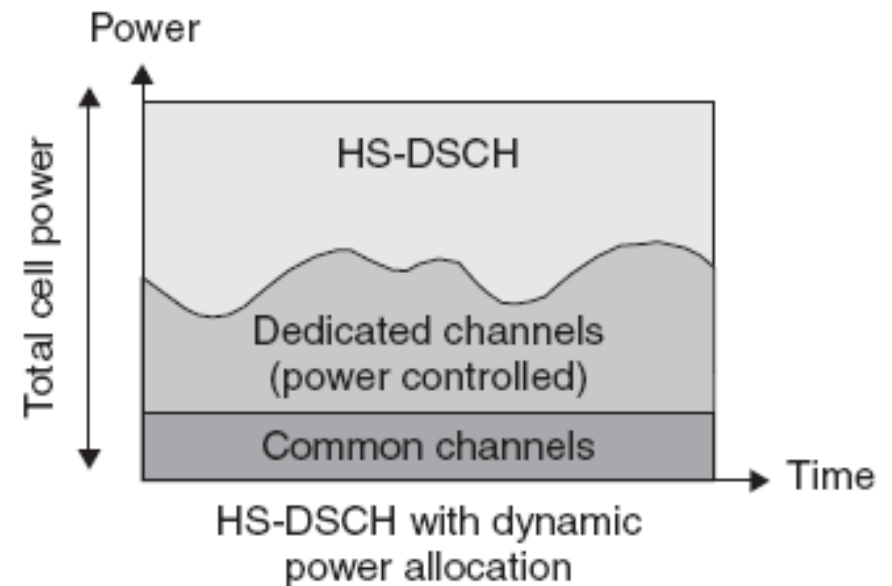
- In HSDPA, the shared channel transmission is implemented in WCDMA through the High-Speed Downlink Shared Channel (HS-DSCH) which make possible the rapid allocation of a large fraction of downlink resources for data transmission to a specific user.
- The dynamic allocation of HS-DSCH code resource for transmission to a specific user is done on a 2ms TTI (transmission Time Interval) basis to reduces the overall delay and improves the tracking of fast channel variations exploited by the rate control and the channel-dependent scheduling.
- In each TTI, the scheduler decides to which user(s) the HS-DSCH should be transmitted and in cooperation with the rate-control mechanism, at what data rate. The scheduler is the key element that determines the overall system performance, especially in a highly loaded network.
- HS-DSCH is not power controlled but rate controlled. This allows the remaining cell power, after serving other channels, to be used for HS-DSCH transmission.
- For HSDPA, rate control is implemented by dynamically adjusting the channel coding rate and dynamically selecting between QPSK and 16QAM modulation. 16QAM, which requires higher received E_b/N_0 and allows for higher bandwidth utilization than QPSK, is used in advantageous channel conditions. The data rate is selected independently for each 2 ms TTI by the NodeB to track rapid channel variations.

HSDPA Architecture



High Speed Downlink Shared Channel (HS-DSCH)

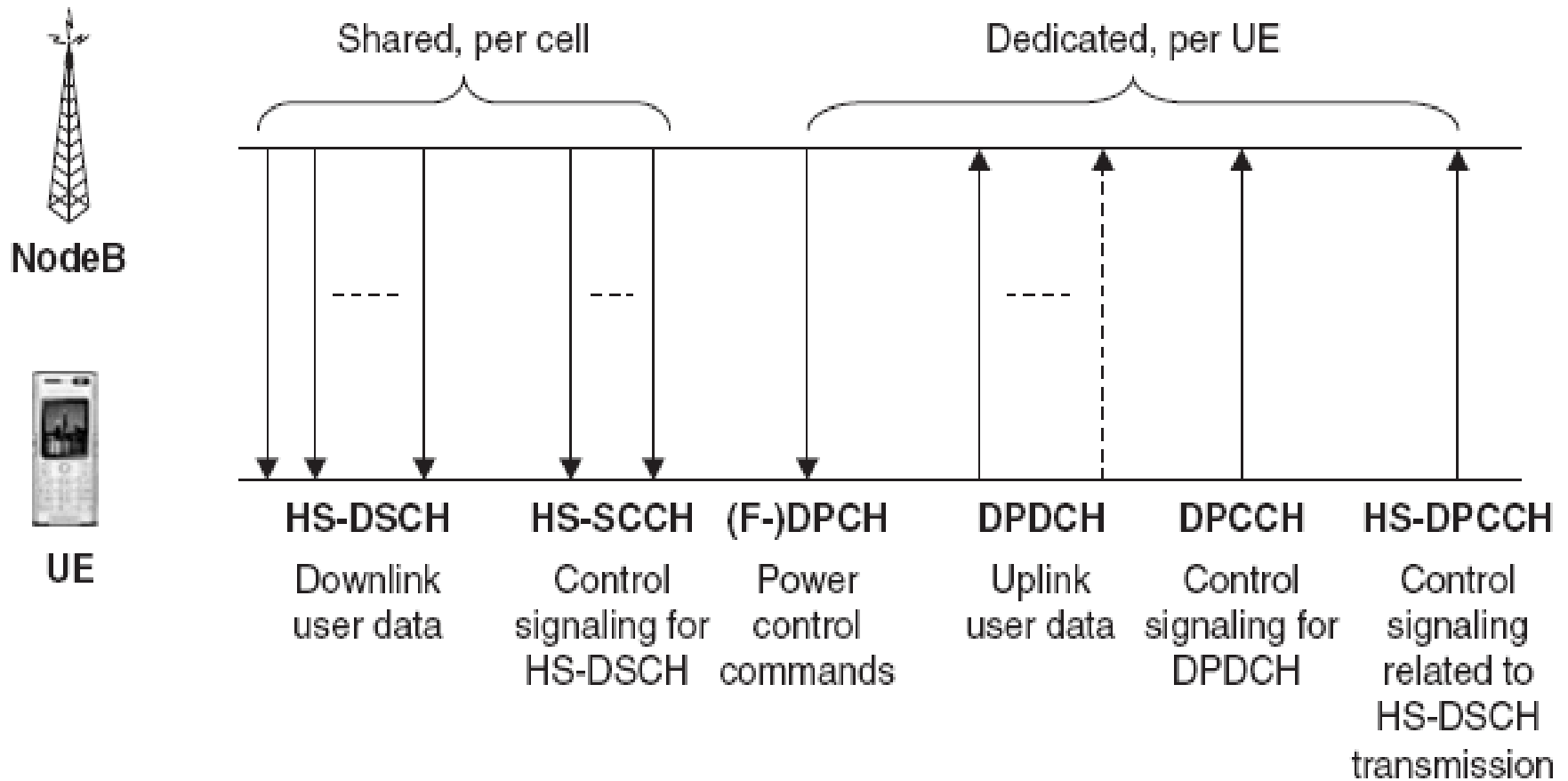
- HS-DSCH corresponds to a set of channelization codes, each with spreading factor 16. Each such channelization code is also known as an HS-PDSCH – *High-Speed Physical Downlink Shared Channel*.
- The number of channelization codes available for HS-DSCH ranging from 1 to 15 codes. Codes not reserved for HS-DSCH transmission are used for control signaling and circuit-switched services. The first node in the code tree is only used for mandatory physical channels such as the common pilot.
- Sharing of the HS-DSCH code resource should primarily take place in the time domain. Sharing of the HS-DSCH code resource in the code domain is also supported.
- A certain part of the total available cell power is used for HS-DSCH transmission. To maximize the utilization of power resource in the base station, the remaining power after serving other, power-controlled channels, should be used for HS-DSCH transmission. This results in a constant transmission power in a cell.
- To obtain rapid allocation of the shared resources and a small end-user delay, the TTI should be selected as small as possible. A 2 ms TTI is selected to prevent excessive overhead as control signaling is required for each transmission.



High Speed Shared Control Channel (HS-SCCH)

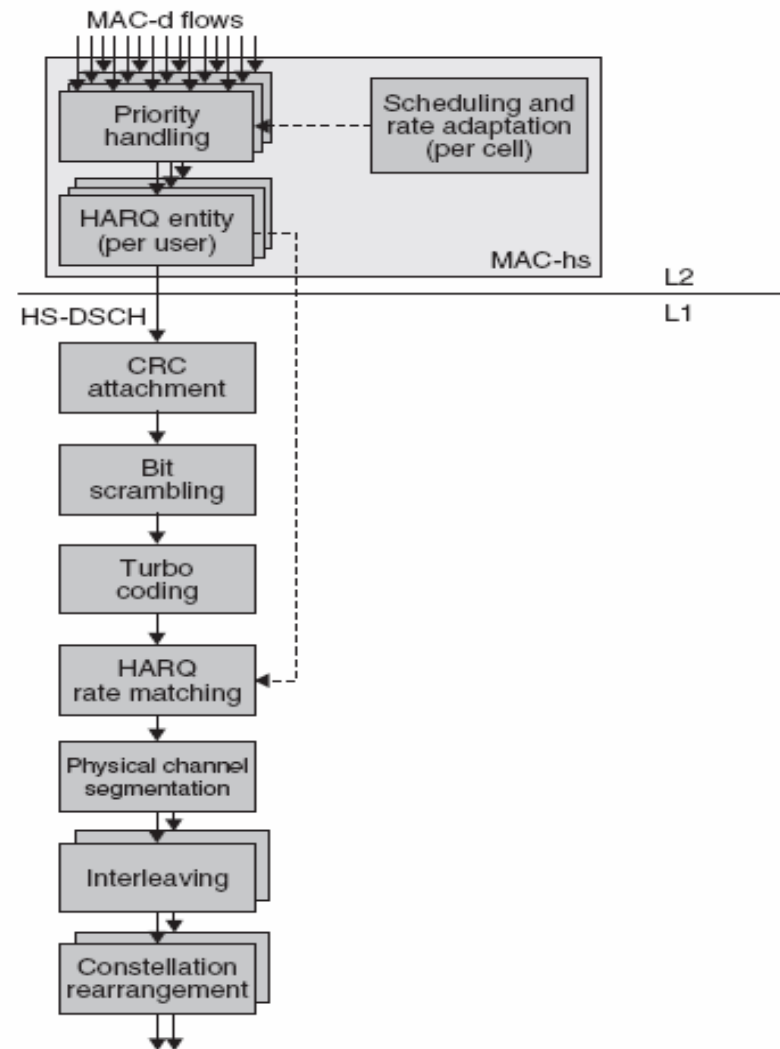
- Downlink control signaling (such as identity of the UE(s) currently being scheduled, physical resources, transport format, modulation scheme and transport block size) is necessary for the operation of HS-DSCH in each TTI.
- The downlink control signaling is carried on the *High-Speed Shared Control Channel* (HS-SCCH), transmitted in parallel to the HS-DSCH using a separate channelization code. The HS-SCCH is a shared channel, received by all UEs for which an HS-DSCH is configured to find out whether the UE has been scheduled or not.
- HS-DSCH is shared mainly in the time domain and only the currently scheduled terminal needs to receive the HS-SCCH. there is typically only one or, if code-domain sharing is supported in the cell, a few HS-SCCHs configured in each cell. Each HS-DSCH-capable terminal is required to be able to monitor up to four HS-SCCHs.
- HSDPA transmission also requires uplink control signaling as the hybrid-ARQ mechanism must be able to inform the NodeB if the downlink transmission was successfully received (decoded). This information (ACK, NAK) is carried on the uplink *High-Speed Dedicated Physical Control Channel* (HS-DPCCH).
- Each UE also measures the instantaneous downlink channel conditions and transmits a *Channel-Quality Indicator* (CQI), on the HS-DPCCH for the purpose of channel-dependent scheduling and rate control.
- For each HSDPA UE, a downlink dedicated physical channel - DPCH is used to receive power control commands for fast closed loop power control of the uplink. This channel can also be used for user data not carried on the HS-DSCH, for example circuit-switched services.
- *Fractional DPCH*, F-DPCH, is added to allow multiple UEs to share a single downlink channelization code.
- Neither the HS-PDSCH, nor the HS-SCCH, are subject to downlink macro diversity or soft handover. However, the uplink channels, as well as any dedicated downlink channels, can be in soft handover.

Channel Structure of HSDPA



Mac-hs and Physical Layer Processing

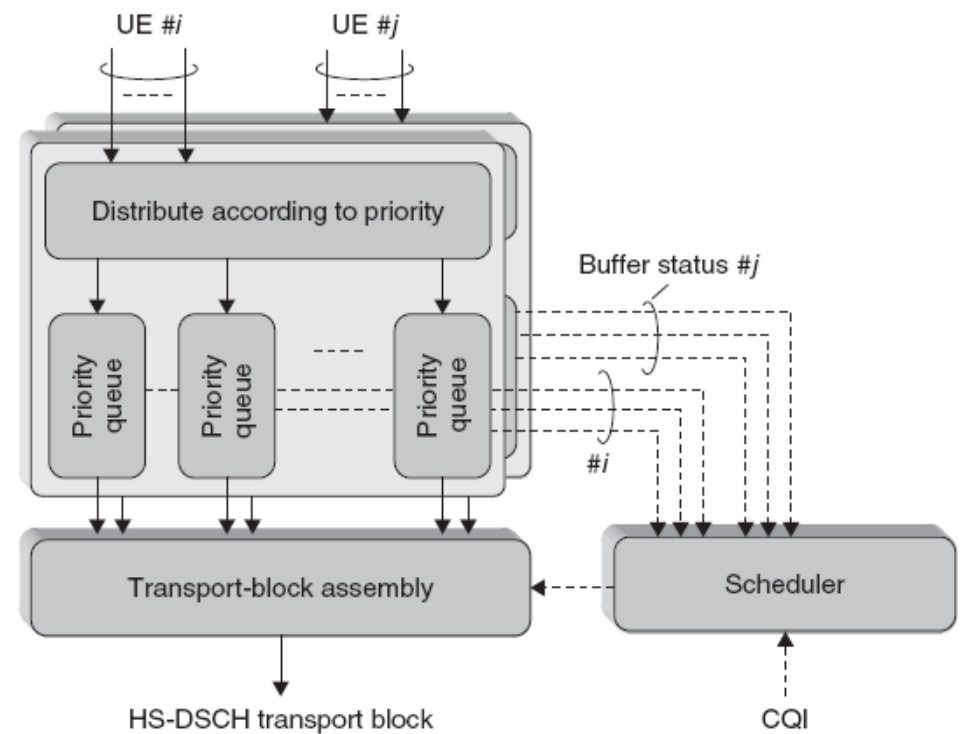
- MAC-hs is a new sub-layer located in the NodeB consists of scheduling, priority handling, transport-format selection (rate control), and the protocol parts of the hybrid-ARQ mechanism. Data, in the form of a single transport block passes from the MAC-hs via the HS-DSCH transport channel to the HS-DSCH physical-layer processing.
- A 24-bit CRC is used by the UE to detect errors in the received transport block. To ease the estimation of the amplitude reference in the receiver, the bits after CRC attachment are scrambled.
- The coding scheme in HSDPA is rate-1/3 Turbo coding. To obtain the code rate, rate matching, that is, puncturing or repetition, is used to match the number of coded bits to the number of physical-channel bits available.
- Constellation rearrangement is used only for 16QAM.



MAC-hs and physical-layer processing.

Scheduling

- HSDPA uses channel-dependent scheduling. The scheduler in the MAC-hs controls what part of the shared code and power resource is assigned to which user in a certain TTI.
- the goal of most schedulers is to take advantage of the channel variations between users and preferably schedule transmissions to a user when the channel conditions are advantageous.
- efficient scheduling strategies require at least: 1) information about the instantaneous channel conditions at the UE, 2) information about the buffer status and priorities of the data flows.
- the instantaneous channel quality at the UE is obtained through a 5-bit Channel-Quality Indicator (CQI), which each UE feeds back to the NodeB at regular intervals. The CQI is calculated at the UE based on the signal-to-noise ratio of the received common pilot. CQI is expressed as a recommended transport-block size, taking into account the instantaneous data rate a terminal can support rather than the channel quality alone.
- To support priority handling, a set of priority queues is defined in which the scheduler selects data from these priority queues for transmission based on the channel conditions, the priority of the queue, maximum delay and minimum average data rate.

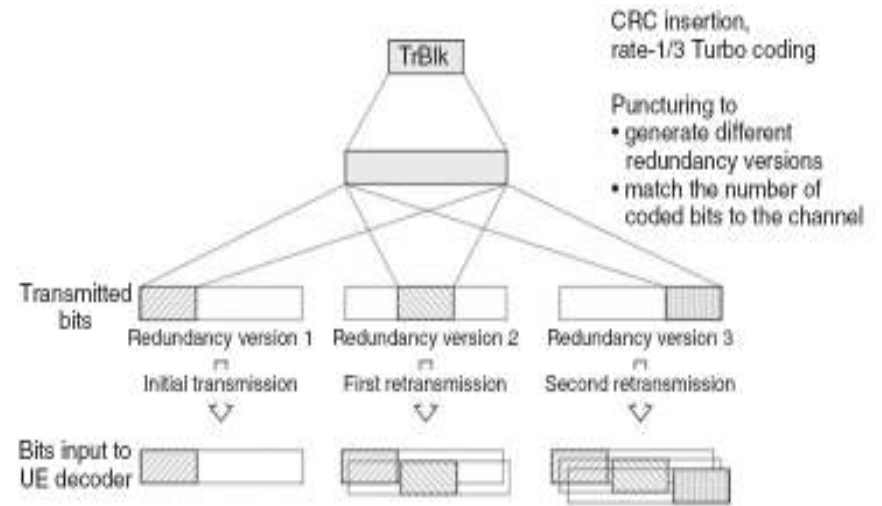


Rate Control

- rate control denotes the process of adjusting the data rate to match the instantaneous radio conditions. The data rate is adjusted by changing the modulation scheme and the channel-coding rate. For each TTI (2 ms), the rate-control mechanism in the scheduler selects, for the scheduled user(s), the transport format(s) and channelization-code resources to use. The transport format consists of the modulation scheme (QPSK or 16QAM) and the transport-block size.
- The HS-DSCH transport-block size can take one of 254 values. Transport-block sizes are in the range of 137–27 952 bits with channel-coding rates ranging from 1/3 up to 1.
- The primary way of adapting to rapid variations in the instantaneous channel quality is rate control as no fast closed-loop power control is specified for HS-DSCH. A dynamic HS-DSCH power allocation scheme is that the HS-DSCH uses all power not used by other channels. The overall interference created in the cell must be taken into account when allocating the amount of HS-DSCH power. The radio-resource control in the RNC sets an upper limit on the power used by the NodeB for the HS-DSCHs and all HS-SCCHs.
- The target for the rate control is to select a transport format resulting in transmitting an as large transport block as possible with a reasonable error probability, given the instantaneous channel conditions typically obtained from the CQI.

Hybrid ARQ with Soft Combining

- The hybrid-ARQ functionality spans both the MAC-hs and the physical layer. As the MAC-hs is located in the NodeB, erroneous transport blocks can be rapidly retransmitted. Hybrid-ARQ retransmissions are therefore significantly less costly in terms of delay compared to RLC-based (WCDMA) retransmissions.
- In HSDPA, the hybrid ARQ operates per transport block or, equivalently, per TTI, whenever the HS-DSCH CRC indicates an error, the content of the whole TTI is retransmitted in case of an error. This reduces the amount of uplink signaling as a single ACK/NAK bit per TTI is sufficient.
- Incremental redundancy is the basic scheme for soft combining, that is, retransmissions may consist of a different set of coded bits than the original transmission. Different redundancy versions, that is, different sets of coded bits, are generated as part of the rate-matching mechanism.
- The UE receives the coded bits and attempts to decode them. If decoding attempts fails, the UE buffers the received soft bits and requests a retransmission by sending a NAK. Once the retransmission occurs, the UE combines the buffered soft bits with the received soft bits from the retransmission and tries to decode the combination.

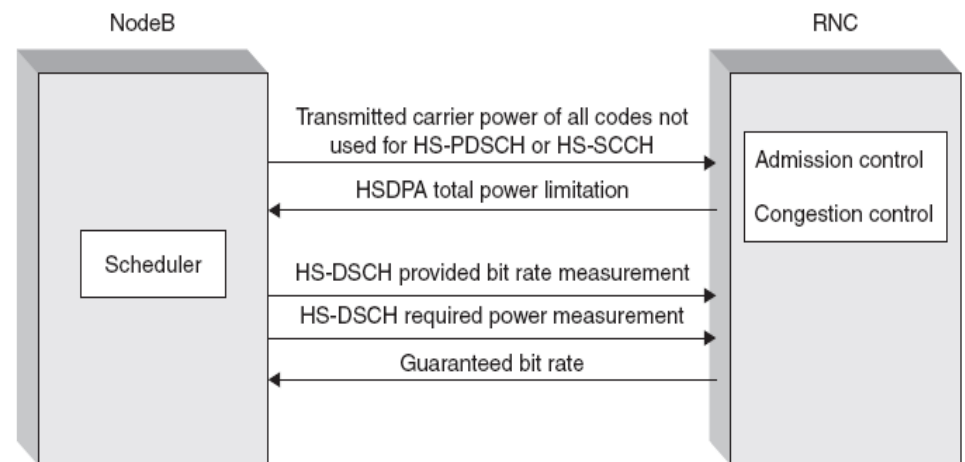


Generation of redundancy versions.

The downlink control signaling includes a new-data indicator, used by the UE to control whether the soft buffer should be cleared (the current transmission is new data) or whether soft combining of the soft buffer and the received soft bits should take place (retransmission).

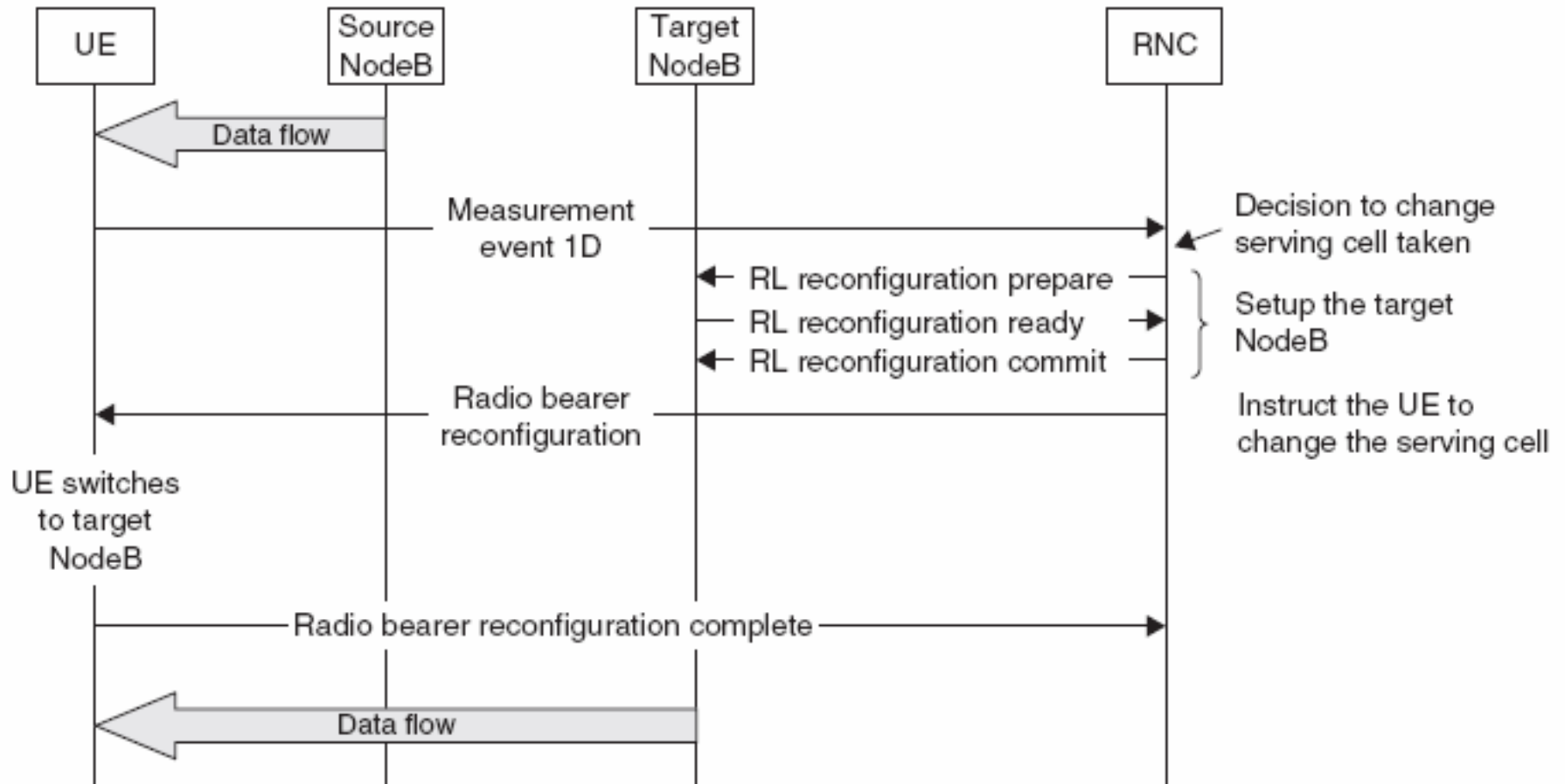
HS-DSCH Resource Control

- A result of introducing channel-dependent scheduling and rate control in the NodeB in order to exploit rapid channel variations, parts of the radio resource management are handled by the NodeB instead of the RNC.
- New measurement reports from the NodeB to the RNC are added, as well as mechanisms for the RNC to set the limits within which the NodeB are allowed to handle the HSDPA resources in the cell.
- To ensure that the RNC has control of the maximum amount of interference a cell may generate to neighboring cells, the RNC can set the maximum amount of power the NodeB is allowed to use for HSDPA-related downlink transmissions.
- Admission control in the RNC needs to take into account the amount of power available in the NodeB. Only if there is a sufficient amount of transmission power available in the NodeB can a new user be admitted into the cell. The *Transmitted carrier power* measurement is available for this purpose.



Measurements and resource limitations for HSDPA

Change of Serving cell in HSPA



It is assumed that both the source and target NodeB are part of the active set.

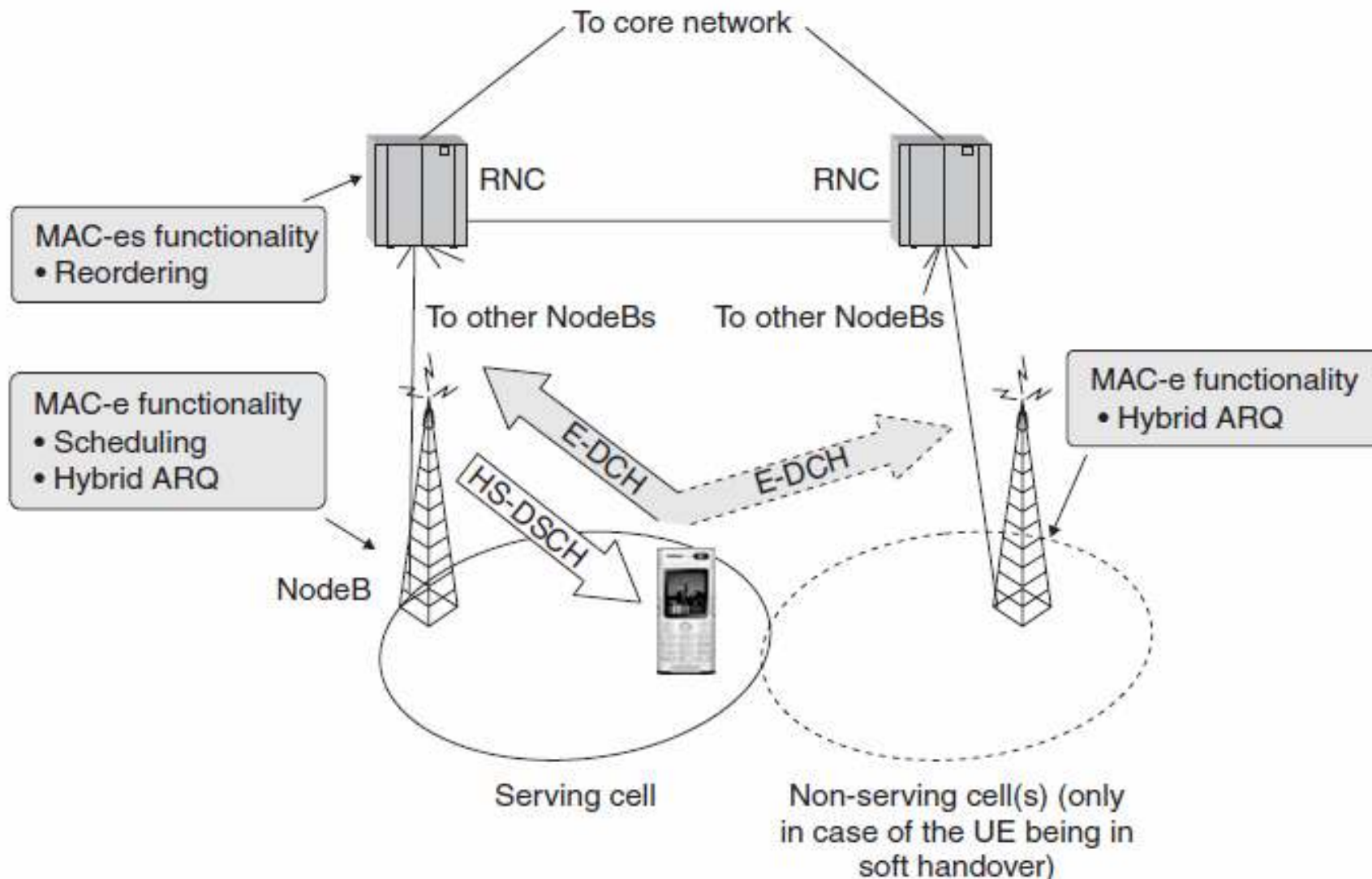
Mobility

- Mobility for HSDPA, that is, change of serving cell, is handled through RRC signaling using similar procedures as for dedicated channels. The basics for mobility are network-controlled handover and UE measurement reporting. Measurements are reported from the UE to the RNC, which based on the measurements, reconfigures the UE and involved NodeBs, resulting in a change of serving cell.
- Several measurement mechanisms are specified already in the first release of WCDMA, for example, active set update, hard handover, and intra-frequency measurements.
- Measurement Event 1D, 'change of best cell,' which is reported by the UE whenever the common-pilot strength from a neighboring cell becomes stronger than for the current best cell. This is used to determine when to switch the HS-DSCH serving cell.
- The reconfiguration of the UE and involved NodeBs can be either synchronous or asynchronous. With synchronous reconfiguration (typically used), an activation time is defined in the reconfiguration message, ensuring that all involved parties change their reconfiguration at the same time. Asynchronous reconfiguration implies that the involved nodes obey the reconfiguration message as soon it is received, which would result in some data loss that has to be retransmitted by the RLC protocol.

HSDPA UE Categories

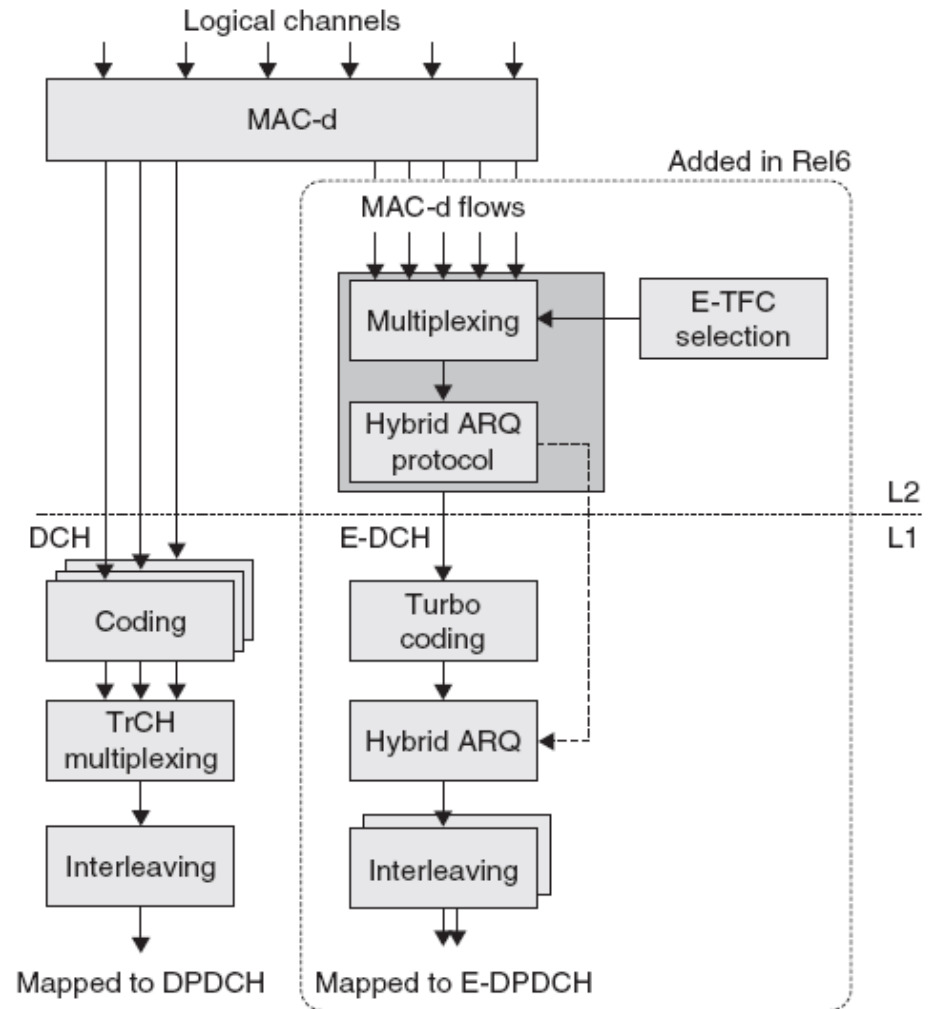
HS-DSCH category	Maximum number of HS-DSCH codes received	Minimum inter-TTI interval	Maximum transport-block size	Maximum number of soft bits	Supported modulation schemes
1	5	3	7298 (3.6 Mbit/s)	19200	16QAM, QPSK
2	5	3	7298 (3.6 Mbit/s)	28800	16QAM, QPSK
3	5	2	7298 (3.6 Mbit/s)	28800	16QAM, QPSK
4	5	2	7298 (3.6 Mbit/s)	38400	16QAM, QPSK
5	5	1	7298 (3.6 Mbit/s)	57600	16QAM, QPSK
6	5	1	7298 (3.6 Mbit/s)	67200	16QAM, QPSK
7	10	1	14411 (7.2 Mbit/s)	115200	16QAM, QPSK
8	10	1	14411 (7.2 Mbit/s)	134400	16QAM, QPSK
9	15	1	20251 (10.1 Mbit/s)	172800	16QAM, QPSK
10	15	1	27952 (14 Mbit/s)	172800	16QAM, QPSK
11	5	2	3630 (1.8 Mbit/s)	14400	QPSK
12	5	1	3630 (1.8 Mbit/s)	28800	QPSK

HSUPA Architecture with HSDPA Configured



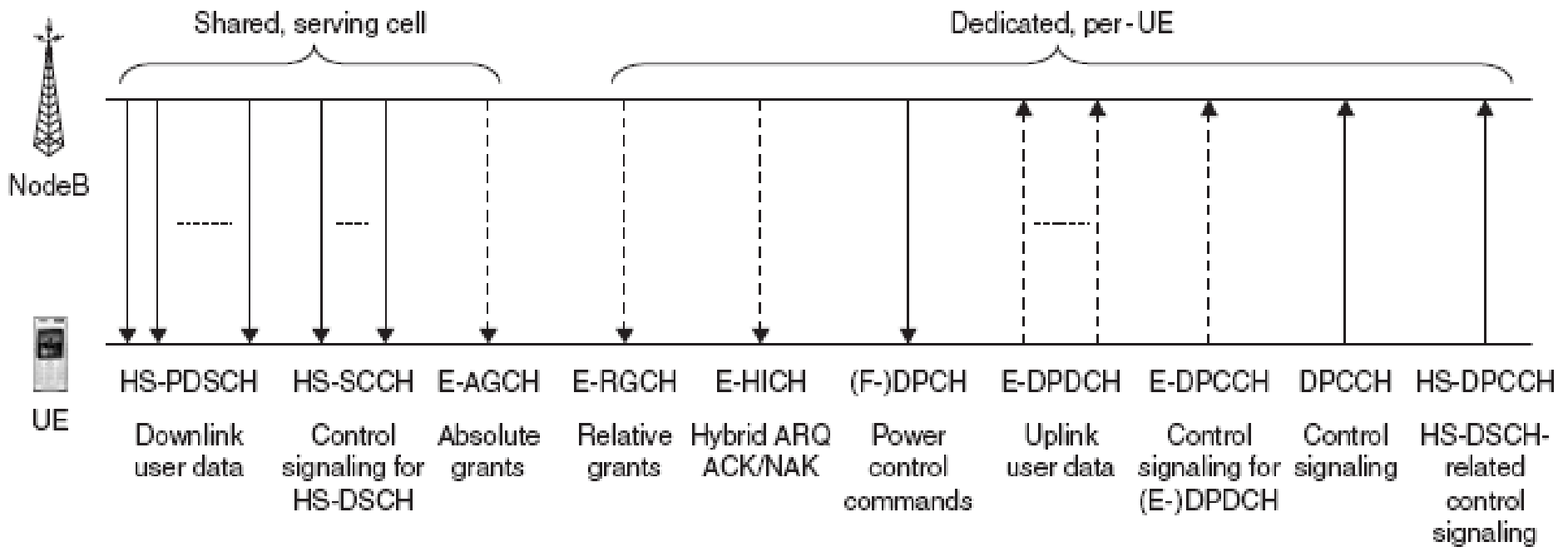
Enhanced Dedicated Channel (E-DCH)

- HSUPA is also known as Enhanced Uplink. The core of Enhanced Uplink are two basic technologies used also for HSDPA – fast scheduling and fast hybrid ARQ with soft combining. These enhancements are implemented in WCDMA through a new transport channel, the *Enhanced Dedicated Channel* (E-DCH).
- The E-DCH can be configured simultaneously with one or several DCHs. Thus, high-speed packet-data transmission on the E-DCH can occur at the same time as services using the DCH from the same UE.
- E-DCH supports two TTI lengths, 2 and 10 ms, and the network can configure the appropriate value. In principle, different UEs can be configured with different TTIs.
- The E-DCH is mapped to a set of uplink channelization codes known as *E-DCH Dedicated Physical Data Channels* (E-DPDCHs). Backward compatibility requires the E-DCH processing to be invisible to a NodeB not supporting Enhanced Uplink. This is solved by separate processing of the DCH and E-DCH.



Separate processing of E-DCH and DCH.

Channel Structure of Enhanced Uplink with HSDPA



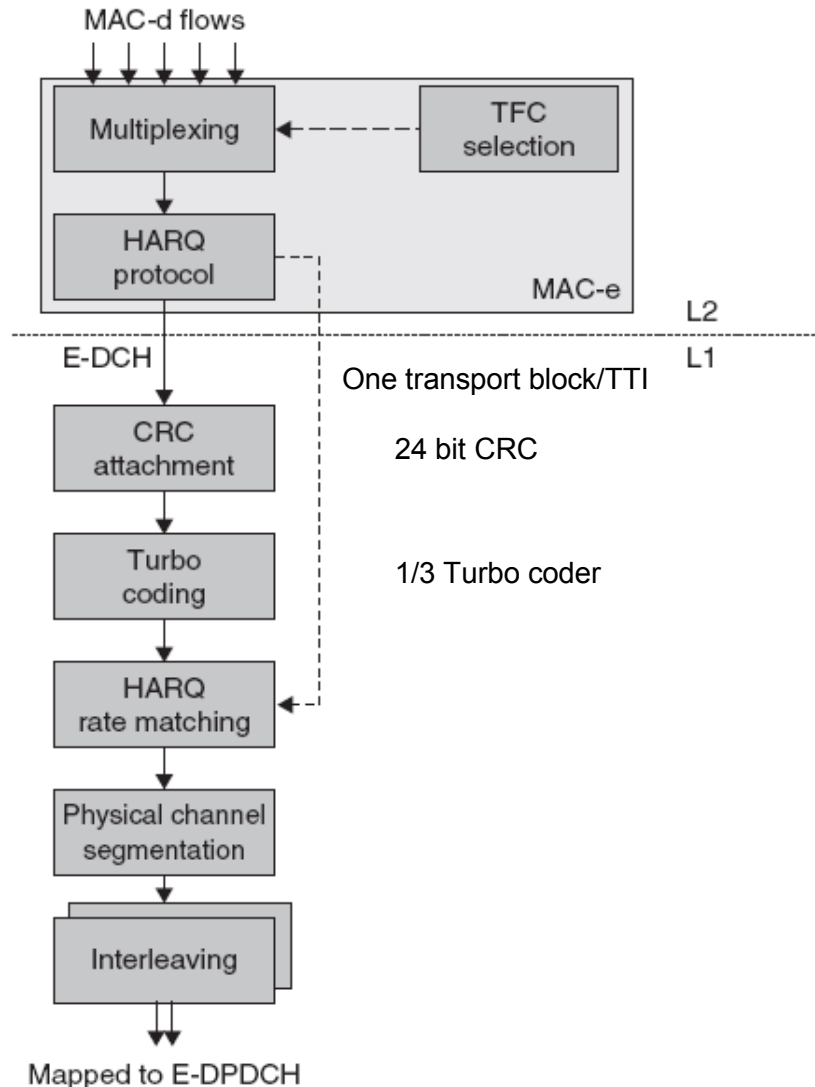
The new channels introduced as part of Enhanced Uplink are shown with dashed lines.

Enhanced Uplink Channels

- Downlink control signaling is necessary for the operation of the E-DCH. NodeB needs to request retransmissions from the UE as part of the hybrid ARQ mechanism. This information, the ACK/NAK, is sent on a new downlink dedicated physical channel, the *E-DCH Hybrid ARQ Indicator Channel* (E-HICH). Each UE with E-DCH configured receives one E-HICH of its own from each of the cells which the UE is in soft handover with.
- Scheduling grants, sent from the scheduler to the UE to control when and at what data rate the UE is transmitting, are sent to the UE using the shared *E-DCH Absolute Grant Channel* (E-AGCH). E-AGCH is sent from the serving cell only as this is the cell having the main responsibility for the scheduling operation and is received by all UEs with an E-DCH configured. Scheduling grant information can also be conveyed to the UE through an *E-DCH Relative Grant Channel* (E-RGCH). E-AGCH is typically used for large changes in the data rate, while the E-RGCH is used for smaller adjustments during an ongoing data transmission.
- Power control commands for E-DCH can be transmitted from NodeB to UE using DPCH or, to save channelization codes, the fractional DPCH, F-DPCH.
- In the uplink, control signaling is required to provide the NodeB with the information to demodulate and decode the data transmission. The *E-DCH Dedicated Physical Control Channel* (E-DPCCH) is used for this purpose in non scheduled transmission or non serving cell in soft handover.

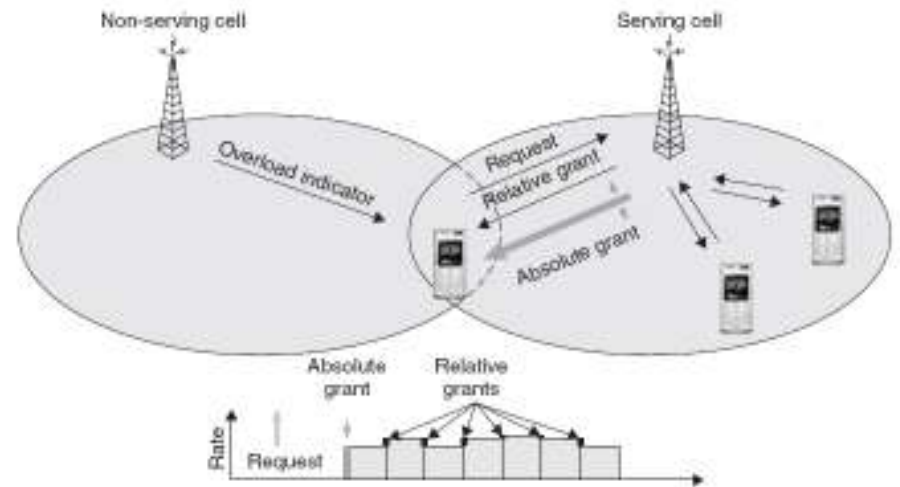
MAC-e and Physical Layer Processing

- Similar to HSDPA, short delays and rapid adaptation are important aspects of the Enhanced Uplink. This is implemented by introducing the MAC-e, a new entity in the NodeB responsible for scheduling and hybrid ARQ protocol operation. The physical layer is also enhanced to provide the necessary support for a short TTI and for soft combining in the hybrid ARQ mechanism.
- In soft handover, uplink data can be received in multiple NodeBs. Hence, there is a need for a MAC-e entity in each of the involved NodeBs to handle the hybrid ARQ protocol. The MAC-e in the serving cell is, in addition, responsible for handling the scheduling operation.
- To handle the Enhanced Uplink processing in the terminal, there is also a MAC-e entity in the UE. The MAC-e in the UE consists of MAC-e multiplexing, transport format selection, and the protocol parts of the hybrid ARQ mechanism.
- Only the UE has accurate knowledge about the buffer situation and power situation in the UE at the time of transmission of a transport block in the uplink. Hence, the UE is allowed to autonomously select the data rate or, the *E-DCH Transport Format Combination (E-TFC)*. The UE needs to take the scheduling decisions into account in the transport format selection; the scheduling decision is an upper limit of the data rate the UE is not allowed to exceed.



E-DCH Scheduling

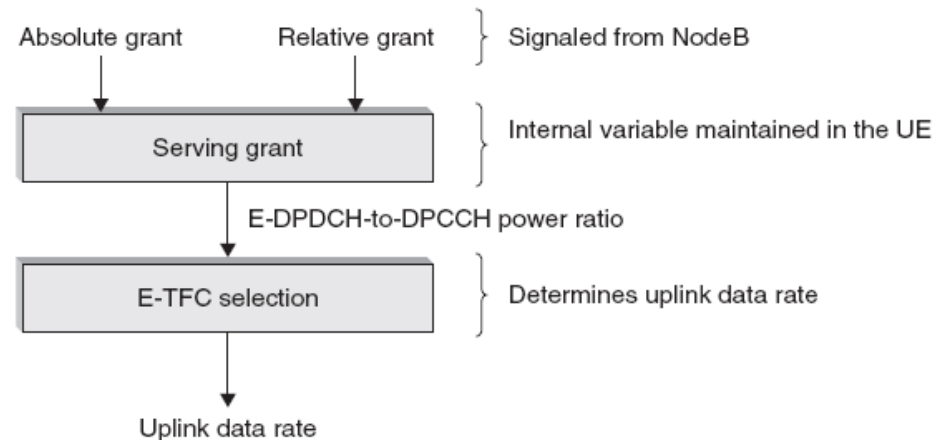
- The responsibility of the scheduler is to control *when* and *at what data rate* a UE is allowed to transmit, thereby controlling the amount of interference affecting other users at the NodeB. This can be seen as controlling each UE's consumption of common resources, which in case of Enhanced Uplink is the amount of tolerable interference, that is the total received power at the base station. The higher the data rate, the larger the required transmission power.
- Noise rise, defined as $(I_0 + N_0)/N_0$ where N_0 and I_0 are the noise and interference power spectral densities, respectively, is a measure of the increase in interference in the cell due to the transmission activity. Channel dependent scheduling will result in a lower noise rise in the system, thereby improving capacity and/or coverage.
- In Enhanced Uplink, the scheduler is located in the NodeB to control the transmission activity of different UEs, while the buffer status information and the UE available transmission power are distributed among the UEs. Hence, a specific signaling is needed to convey buffer status and power availability information from the UE to the NodeB.



The basis for the scheduling framework is *scheduling grants* sent by the NodeB to the UE and limiting the E-DCH data rate and *scheduling requests* sent from the UE to the NodeB to request permission to transmit (at a higher rate than currently allowed). The scheduling grant does not set the E-DCH data rate, but rather an *upper limit* of the resource usage. The UE select the data rate or, more precisely, the *E-DCH Transport Format Combination* (E-TFC) within the restrictions set by the scheduler.

E-DCH Serving Grant

- The *-serving grant* is expressed as a maximum E-DPDCH-to-DPCCH power ratio used to control the maximum transmission power of the UE.
- The NodeB can update the serving grant in the UE by sending an *absolute grant* or a *relative grant* to the UE. Absolute grants are transmitted on the shared E-AGCH and are used for absolute changes of the serving grant. Typically, these changes are relatively large, for example to assign the UE a high data rate for an upcoming packet transmission.
- Relative grants are transmitted on the E-RGCH and are used for relative changes of the serving grant. These changes are small; the change in transmission power due to a relative grant is typically in the order of 1 dB. Relative grants can be sent from both serving and, in case of the UE being in soft handover, also from the non-serving cells.

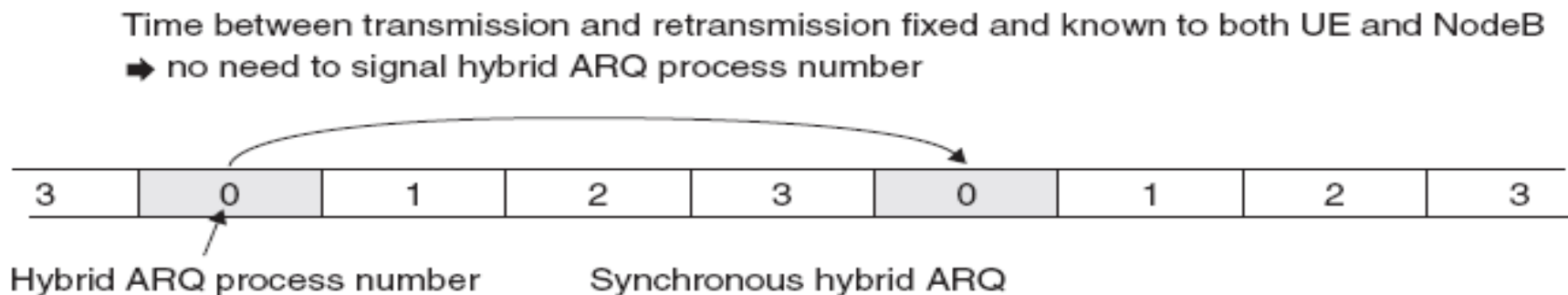


Relative grants from the serving cell are dedicated for a single UE. A relative grant from the serving cell can take one of the three values: 'UP', 'HOLD', or 'DOWN.' The 'up' ('down') command instructs the UE to increase (decrease) maximum allowed E-DPDCH-to-DPCCH power ratio compared to the previous TTI in the same hybrid ARQ process.

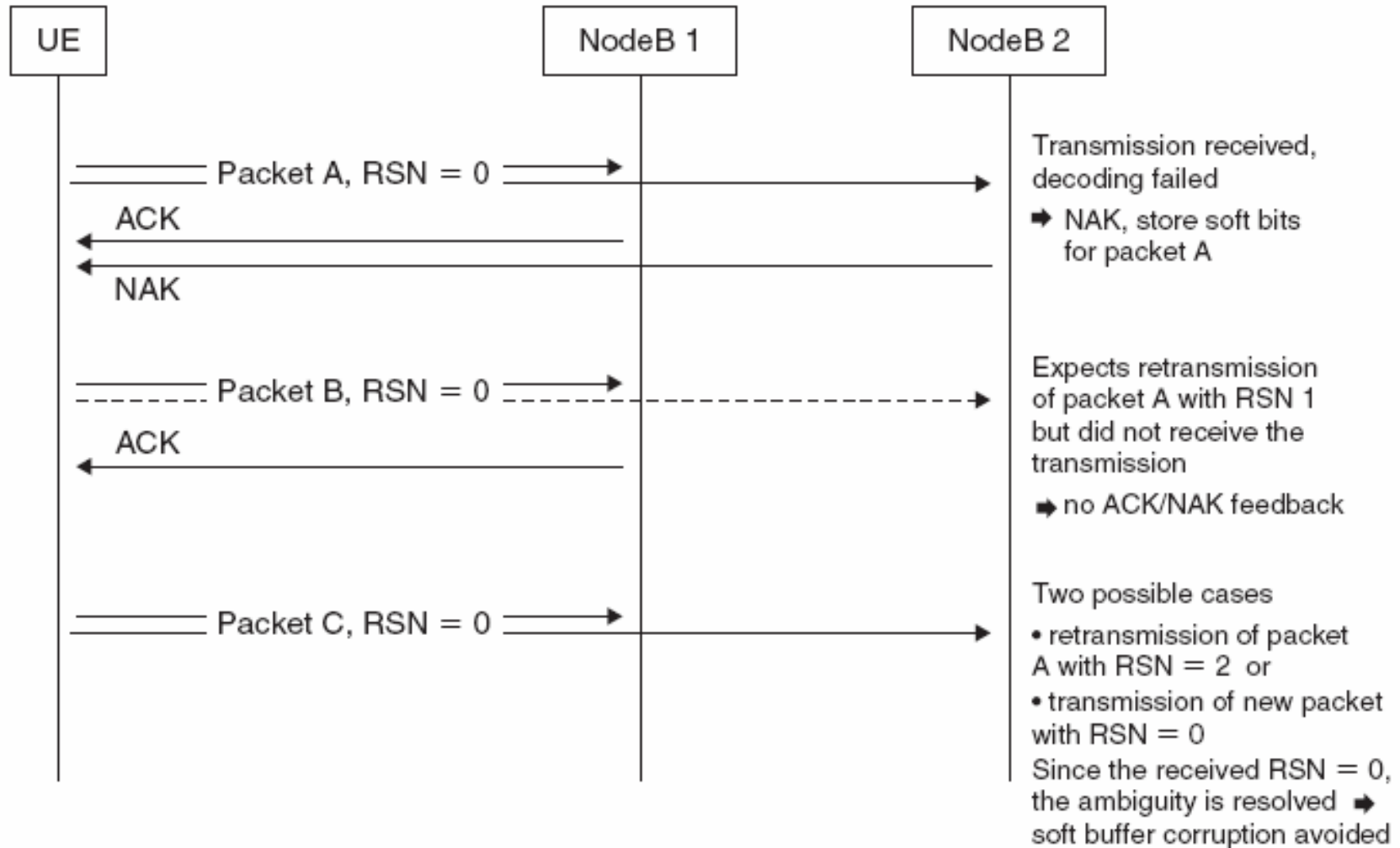
Relative grants from non-serving cells are used to control inter-cell interference. This is an 'overload indicator,' commanding non-served UEs to lower their data rate. The overload indicator is a common signal received by all UEs and only takes two values – 'DTX' and 'down,' where the former does not affect the UE operation.

E-DCH Hybrid ARQ with Soft Combining

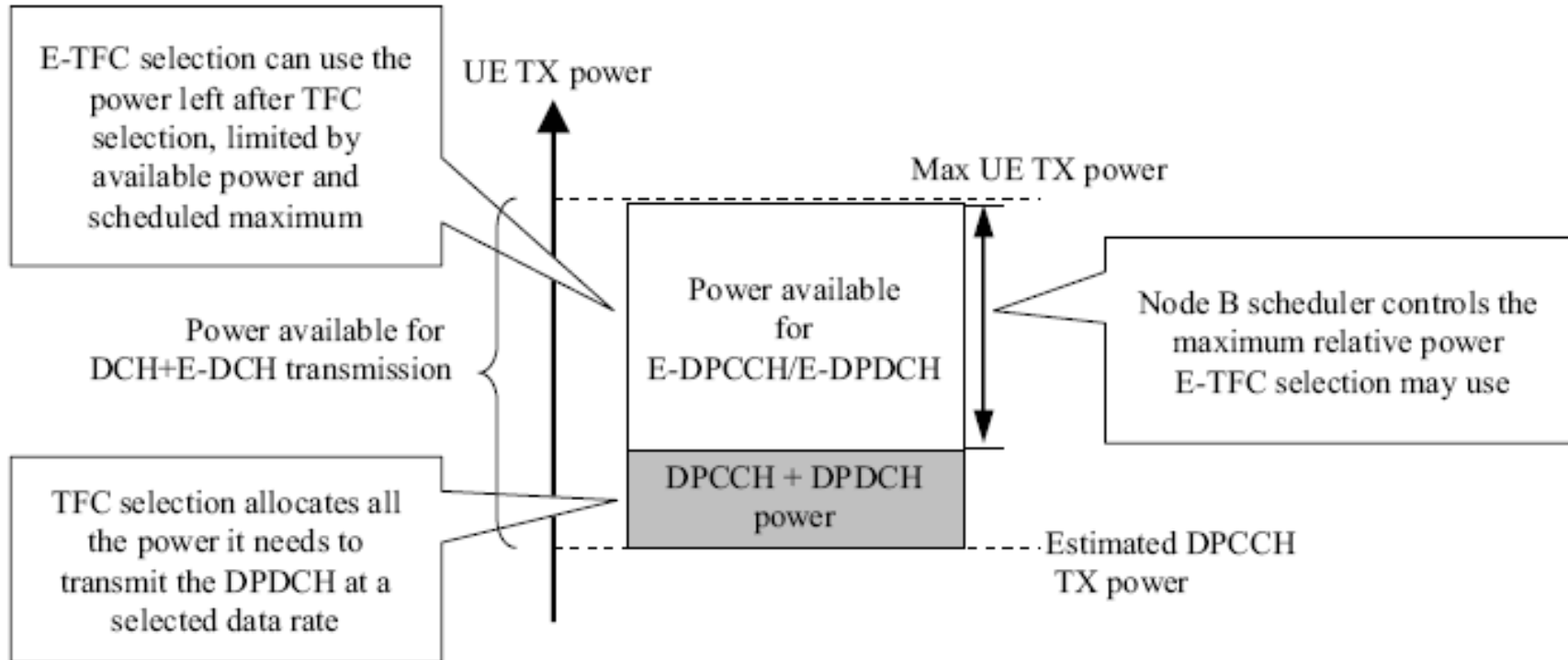
- Hybrid ARQ with soft combining for Enhanced Uplink serves the purpose to provide robustness against transmission errors and enhanced capacity/link efficiency. As hybrid ARQ allows for retransmissions, combined with incremental redundancy, this forms an implicit rate control mechanism.
- Enhanced Uplink hybrid ARQ spans both the MAC layer and the physical layer. NodeB sends a ACK/NAK to the UE indicating the decoding outcome of the received transport block transmitted in a certain TTI. Upon reception of a NAK, the UE performs a retransmission and the NodeB performs soft combining using incremental redundancy.
- For the uplink, a synchronous, non-adaptive hybrid ARQ operation is used. Hence, retransmissions occur a predefined time after the initial transmission, that is they are not explicitly scheduled. Likewise, the non-adaptive operation implies the transport format and redundancy version to be used for each of the retransmissions is also known from the time of the original transmission. The main benefit of synchronous operation of the hybrid ARQ – minimizing the control signaling overhead.
- In Enhanced Uplink, the UE needs to receive ACK/NAK from all involved NodeBs in soft handover. The use of multiple parallel hybrid ARQ processes cannot itself provide in-sequence delivery and a reordering mechanism is required and it is located in the RNC.
- In Enhanced Uplink, a 2-bit *Retransmission Sequence Number* (RSN) is used. The initial transmission sets RSN to zero and each subsequent transmission the RSN is incremented by one. The RSN only can take values in the range of 0 to 3. The RSN simply remains at 3 for the third and later retransmissions. Together with the synchronous protocol operation, the NodeB knows when a retransmission is supposed to occur and with what RSN.



E-DCH Retransmission in Soft Handover



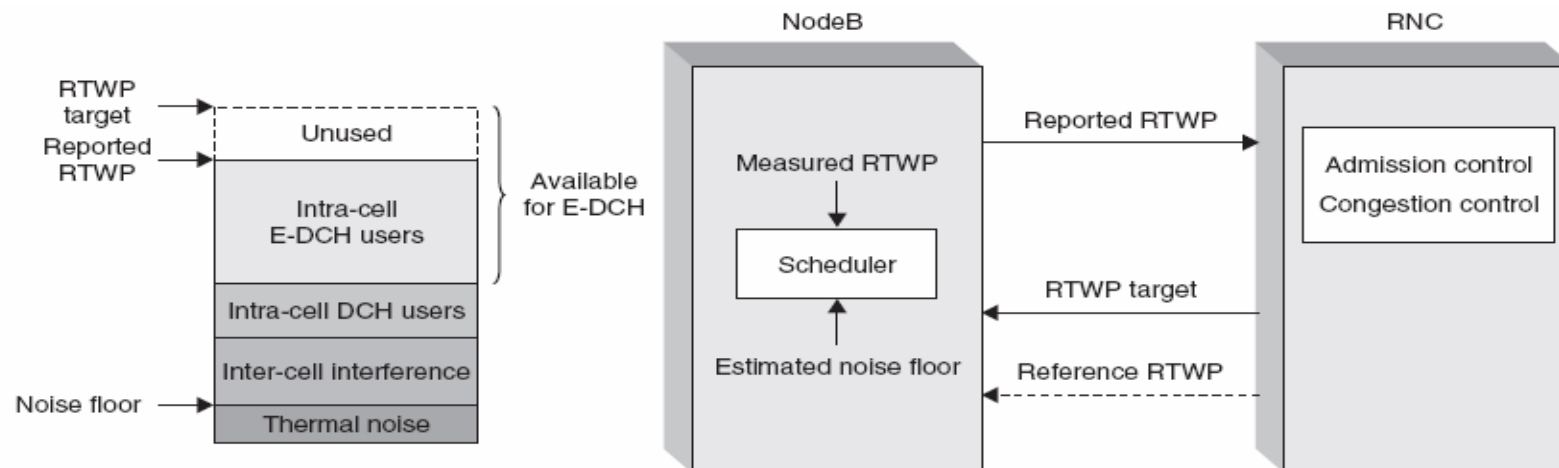
E-DCH and DCH power resource sharing



The maximum DCH data rate allowed by the specification is 64 kbps when configured parallel to the E-DCH.

E-DCH Resource Control

- Enhanced Uplink implies that a part of the radio resource management is handled by the NodeB instead of the RNC. However, the RNC still has the overall responsibility for radio resource management, including admission control and handling of inter-cell interference. Thus, there is a need to monitor and control the resource usage of E-DCH channels to achieve a good balance between E-DCH and non-E-DCH users.
- For admission control purposes, the RNC relies on the *Received Total Wideband Power* (RTWP) measurement, which indicates the total uplink resource usage in the cell. To control the load in the cell, the RNC may signal an RTWP target to the NodeB in which case the NodeB should schedule E-DCH transmissions such that the RTWP is within this limit.
- To provide the RNC with a possibility to control the ratio between inter-cell and intra-cell interference, the RNC may signal a *Target Non-serving E-DCH to Total E-DCH Power Ratio* to the NodeB. The scheduler must obey this limitation when setting the overload indicator and is not allowed to suppress non-serving E-DCH UEs unless the target is exceeded.



E-DCH UE Categories

E-DCH category	Max # E-DPDCHs, min SF	Supports 2 ms TTI	Max transport block size	
			10 ms TTI	2 ms TTI
1	1 × SF4	–	7110 (0.7 Mbit/s)	–
2	2 × SF4	Y	14484 (1.4 Mbit/s)	2798 (1.4 Mbit/s)
3	2 × SF4	–	14484 (1.4 Mbit/s)	–
4	2 × SF2	Y	20000 (2 Mbit/s)	5772 (2.9 Mbit/s)
5	2 × SF2	–	20000 (2 Mbit/s)	–
6	2 × SF4 + 2 × SF2	Y	20000 (2 Mbit/s)	11484 (5.74 Mbit/s)