3. Packet Data Transfer across EGPRS and WCDMA networks

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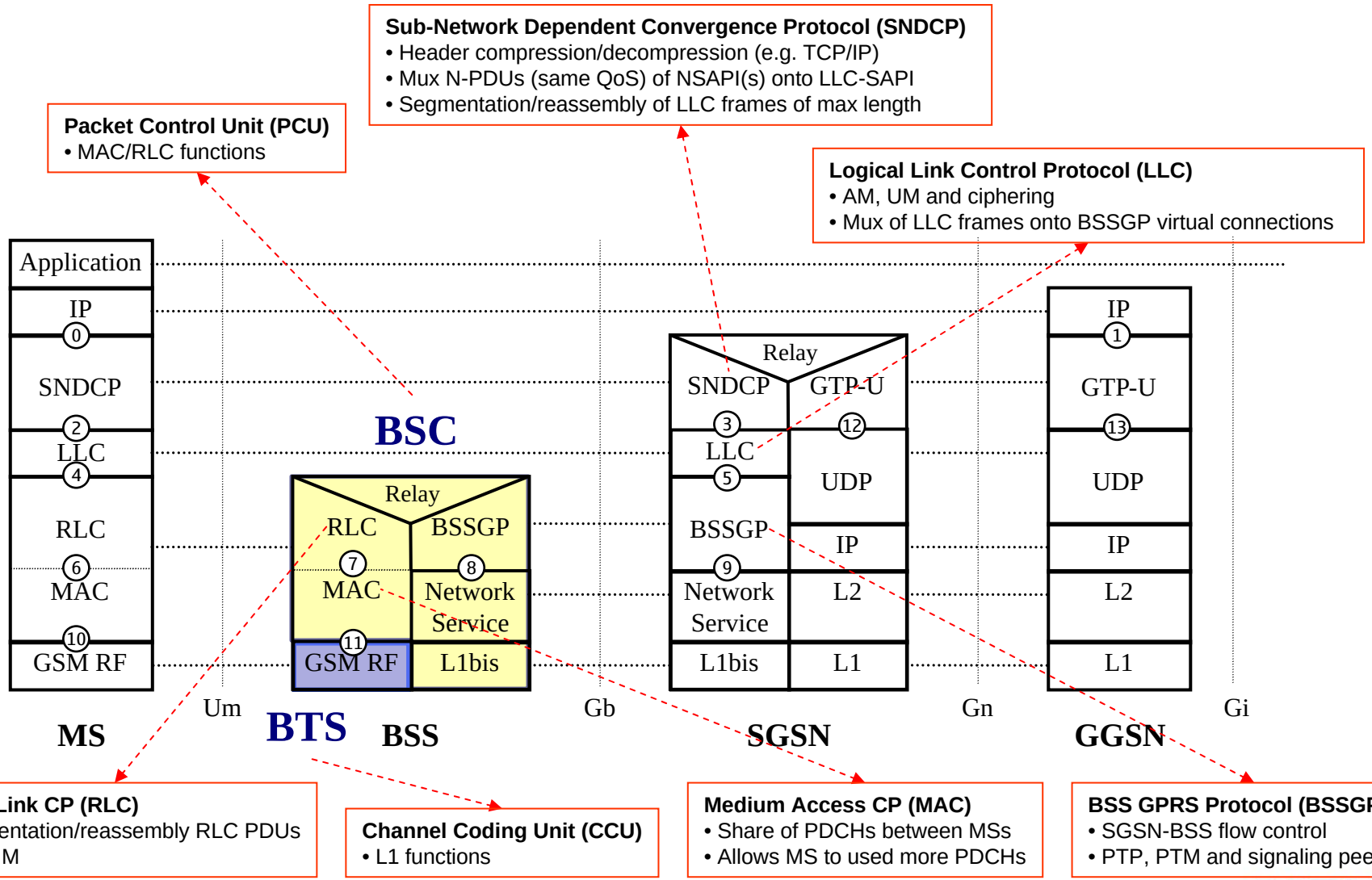
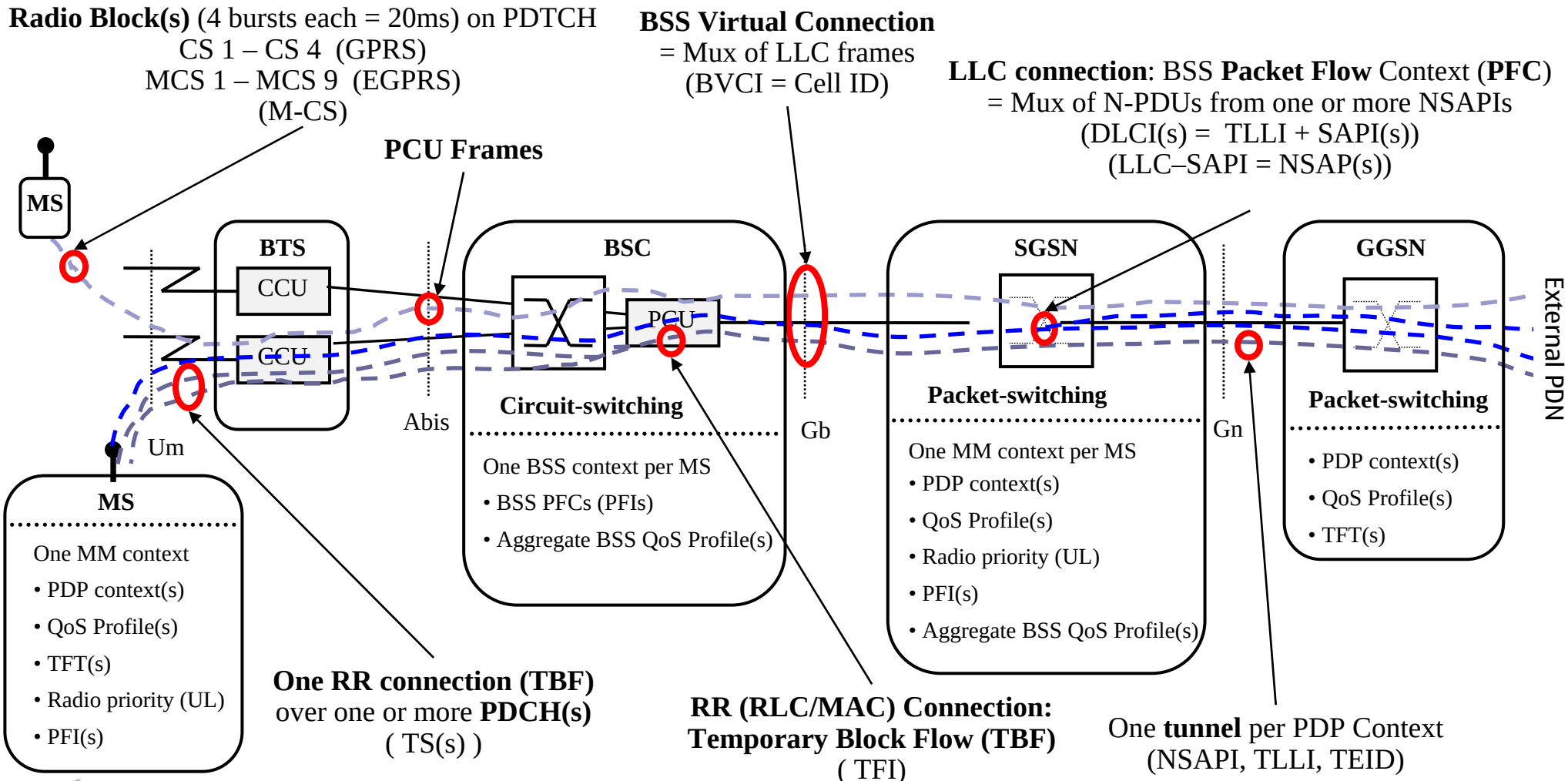
Outline

- Packet data through EGPRS networks
  - User plane protocols
  - Control plan protocols
  - Radio channels and frame structure
- Packet data through (enhanced) WCDMA networks
  - User plane protocols
  - Control plan protocols
  - Radio channels and timing
  - HSPA fundamentals

EGPRS: UP protocol stacks



EGPRS: End-to-end data transmission



R98: GPRS channel coding

- For a Radio Block (RB) carrying a RLC data block, where 1 Radio Block = 4 bursts (20 ms)

Scheme	Code rate	Radio block size (Bytes)	Modulation	Data rate (kb/s)	Data rate excluding RLC/MAC headers (kb/s)
CS-1	½	23	GMSK	9.05	8
CS-2	≈ 2/3	34	GMSK	13.4	12
CS-3	≈ 3/4	39	GMSK	15.6	14.4
CS-4	1	54	GMSK	21.4	20

Note: 1 GMSK symbol = 1 bit

R99: EGPRS channel coding

- For RB carrying one or more RLC data blocks

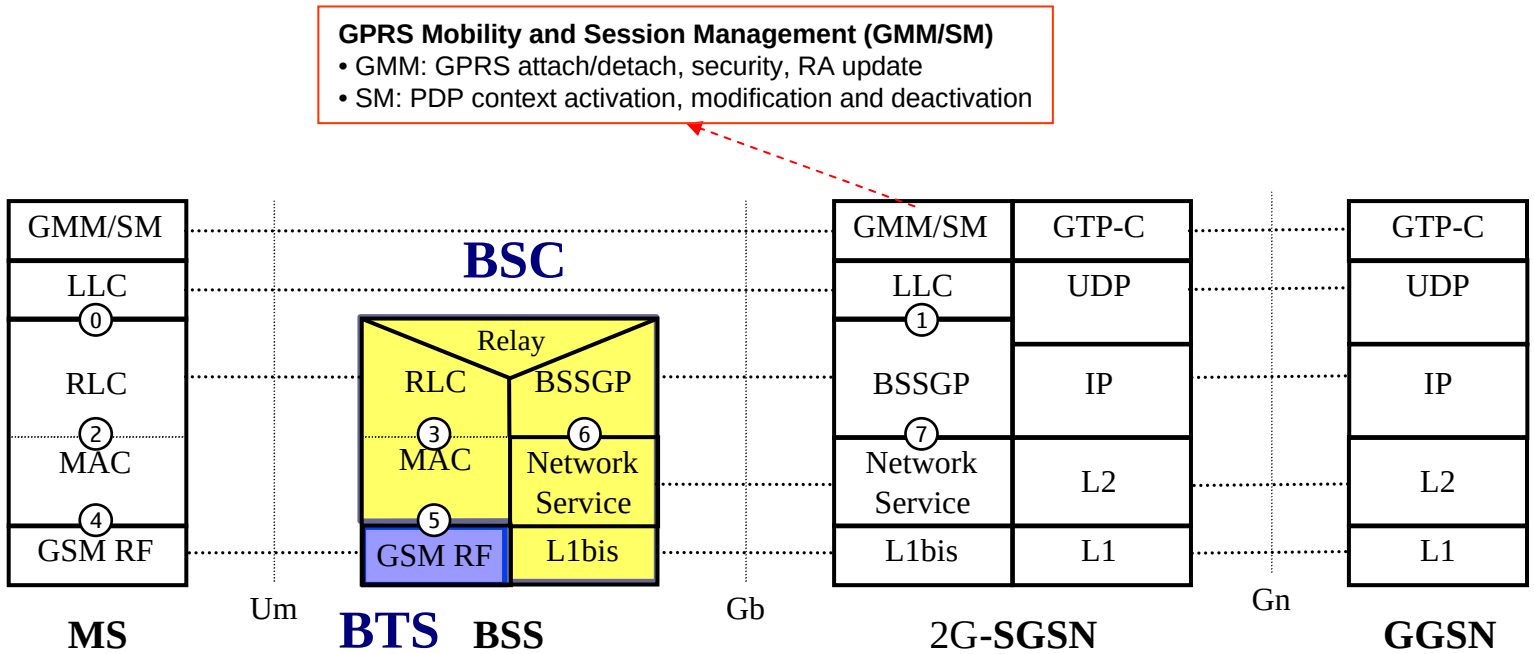
Scheme	Code rate	Header Code rate	Modulation	RLC blocks per Radio Block (20ms)	Raw Data within one Radio Block	Data rate (kb/s)
MCS-9	1.0	0.36	8PSK	2	2x592	59.2
MCS-8	0.92	0.36		2	2x544	54.4
MCS-7	0.76	0.36		2	2x448	44.8
MCS-6	0.49	1/3		1	592 *48*+544	29.6 27.2
MCS-5	0.37	1/3		1	448	22.4
MCS-4	1.0	0.53	GMSK	1	352	17.6
MCS-3	0.85	0.53		1	296 *48*+248 and 296	14.8 13.6
MCS-2	0.66	0.53		1	224	11.2
MCS-1	0.53	0.53		1	176	8.8

NOTE: The italic captions indicate the 6 octets (48 bits) of padding when retransmitting an MCS-8 block with MCS-3 or MCS-6. For MCS-3, the 6 octets of padding are sent every second block.

Note: 1 8PSK symbol = 3 bits

EGPRS: CP protocol stacks

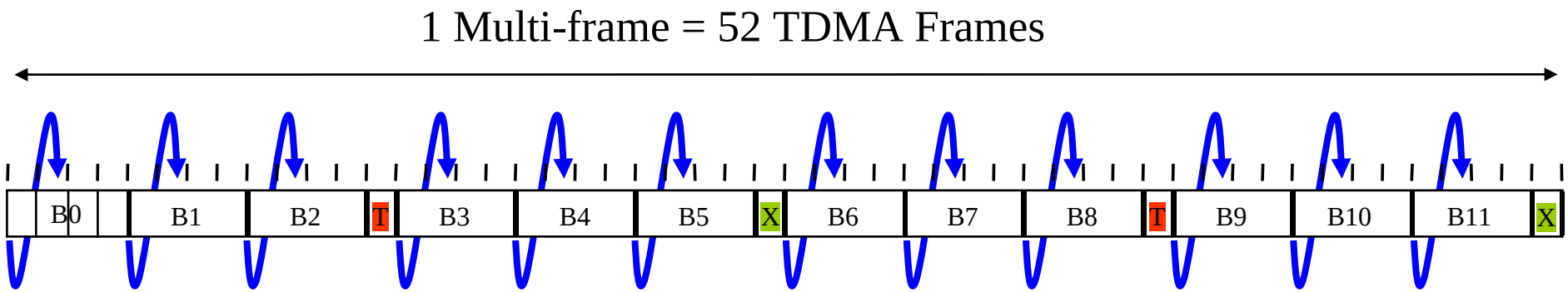
- For controlling and supporting UP functions



Radio channels and frame structure

- A **physical channel** is defined as a **sequence of TDMA frames**, a **time slot** (TS or TSL) number (modulo 8) and a **frequency hopping sequence** (FHS)
- **Logical channels** are defined based on the **type of information** carried over the air interface
  - Dedicated channels (allocated to an MS)
  - Common channels

Multi-frame structure for PDCH



= 1 TDMA Frame (8 Time Slots, 4.615 ms)

X = Idle frame, used by the MS for signal measurements and BSIC identification

T = Frame used for PTCCH (Packet Timing advance Control Channel)

B0 - B11 = Radio blocks

Mapping of packet data channels (1/2)

Downlink

- **B0**: **PBCCH** when allocated, and if required up to 3 more blocks on the same PDCH can be used as additional PBCCHs
- On any PDCH **with a PCCCH** (with or without PBCCH), **up to the next 12 blocks** in the ordered list of blocks are used for the **PPCH, PAGCH, PNCH, PDTCH or PACCH**
- On a PDCH that does not contain a PCCCH, **all blocks** can be used as the **PDTCH or PACCH**

Uplink

- On an uplink PDCH that contains a **PCCCH**, all blocks in the multi-frame can be used as the **PRACH, PDTCH or PACCH**

Mapping of packet data channels (2/2)

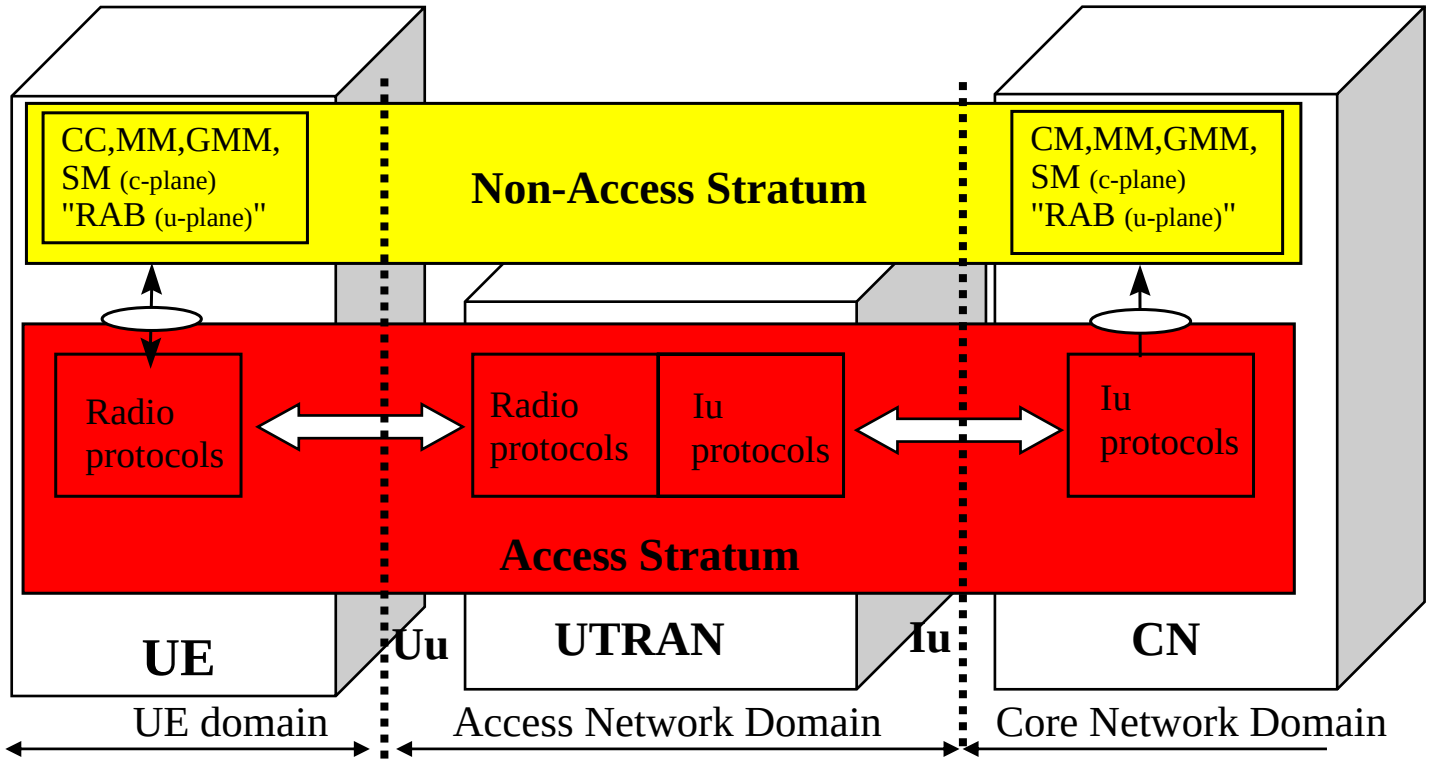
- **Possible channel combinations are**
  - **PBCCH + PCCCH + PDTCH + PACCH + PTCCH**
  - BCCH + **PCCCH + PDTCH + PACCH + PTCCH**
  - BCCH + CCCH + **PDTCH + PACCH + PTCCH**

  Where PCCCH = PNCH, PAGCH, PPCH and PRACH

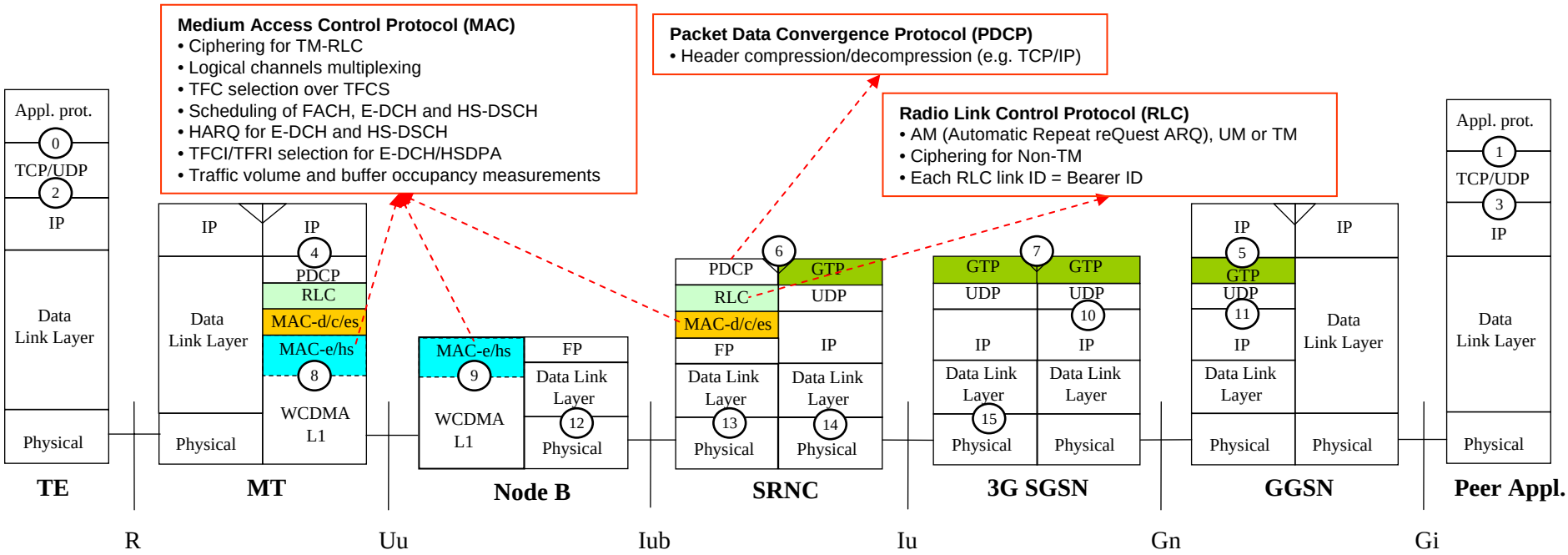
  CCCH = NCH, AGCH, PCH and RACH
- **Multi-slot configuration**
  - Multiple CS or PS traffic channels together with associated control channels, allocated to the same MS
  - Up to 8 basic physical channels, with different TS numbers, but with same frequency parameters (ARFCN or MA, MAIO and HSN) and TSC

3G: Functional grouping of protocols

- Access (AS) and Non-Access Stratum (NAS)



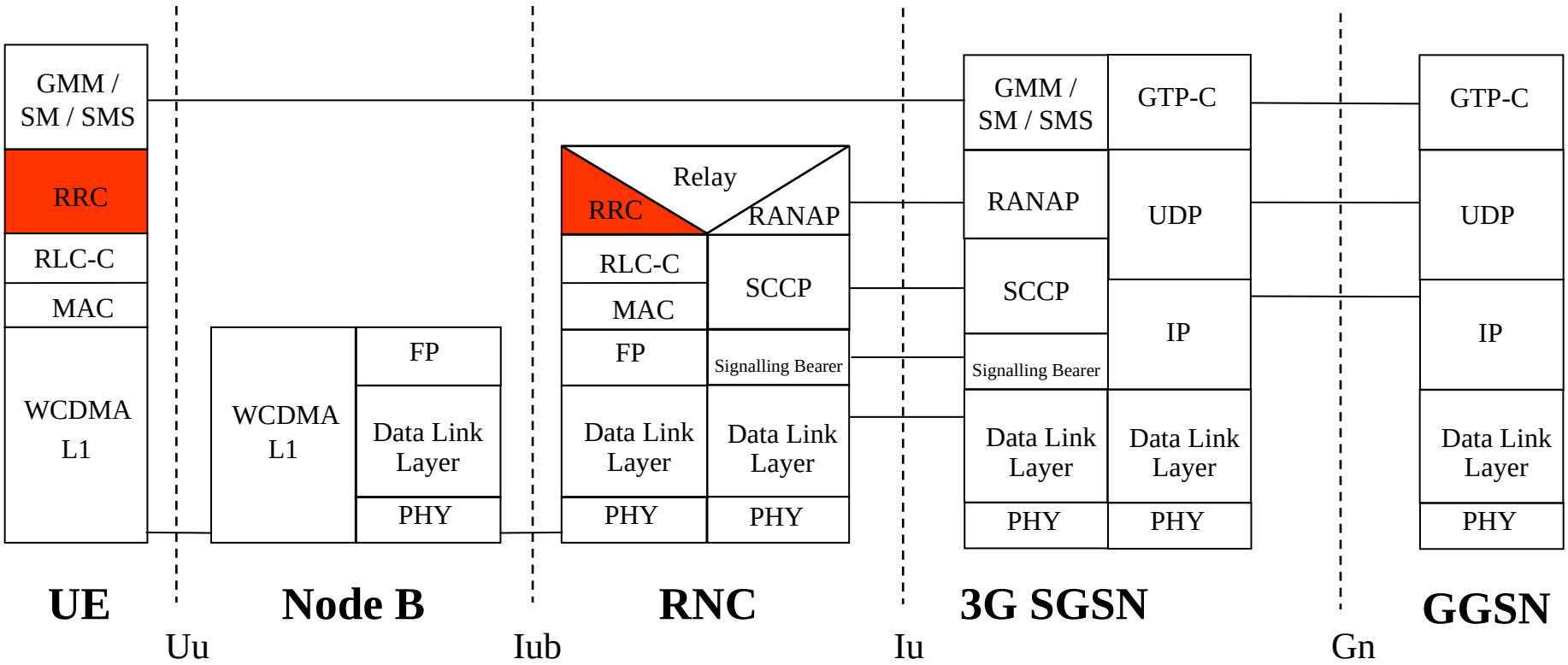
R6: PS-domain UP protocol stacks



Bearer service (BS)	Service Access Point (SAP)	
Service applications	0	1
Network services	2	3
UMTS bearer service	4	5
Radio Access Bearer service	4	7
Core network bearer service	7	5
Radio Bearer service	4	6
RAN Access bearer service	6	7
Backbone network service	10	11
Physical bearer service	12 (14)	13 (15)
UTRA FDD	8	9

There is a one-to-one correspondence between the PDP context, UMTS bearer and RAB, as well as between the RAB and the radio bearer service, which, however, can be carried by more transport channels of the same type at the radio interface

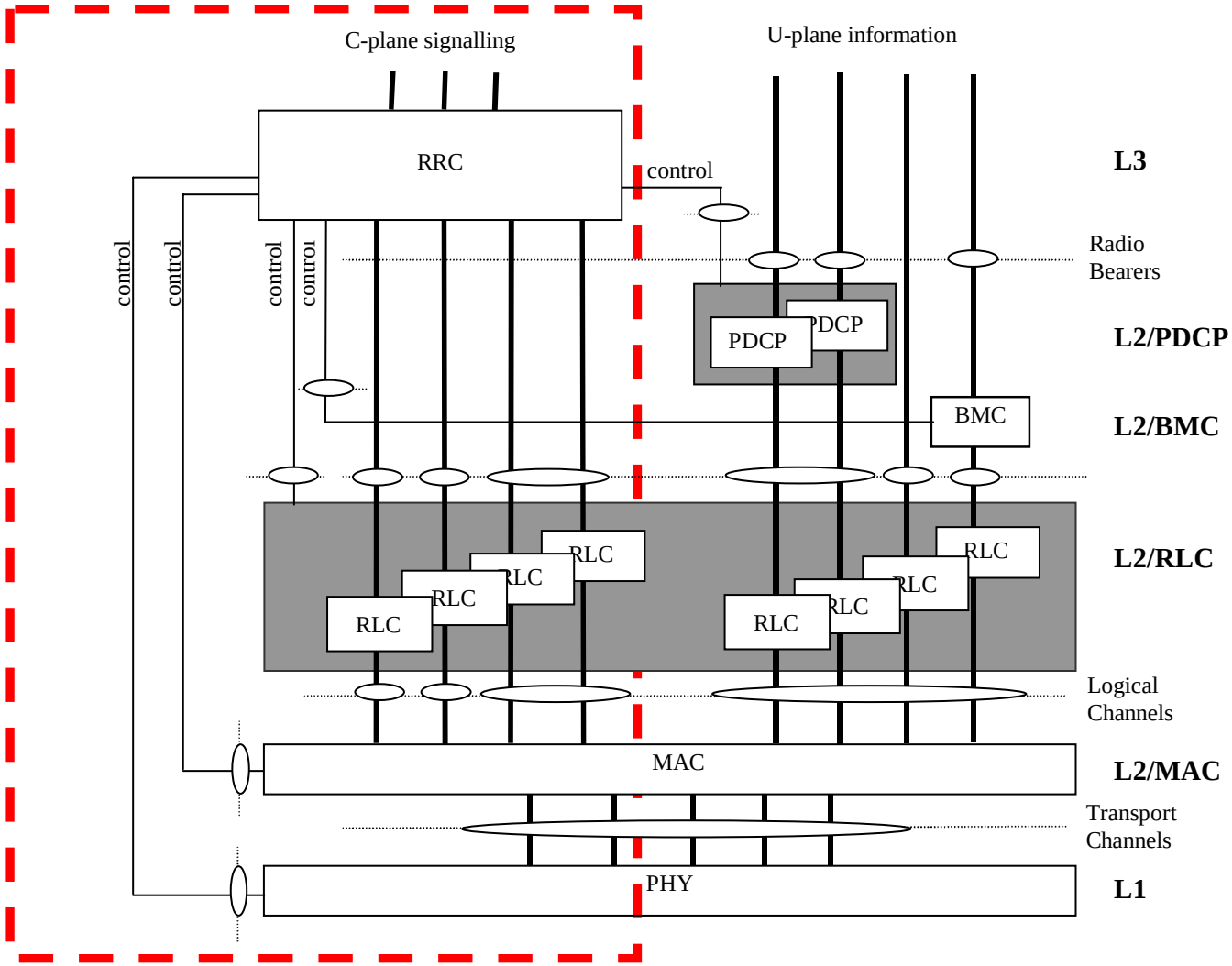
R6: PS-domain CP protocol stacks



The RRC connection is defined as a PTP bidirectional connection between RRC peer entities in the UE and UTRAN

A UE has either zero or one RRC connection

UTRA FDD radio interface protocols



Logical channels (LoCHs)

- Define the transfer of a **specific type of information** over the radio interface
- The logical channels are divided into
  - **Control channels (CCH)** used for transfer of control plane information
  - **Traffic channels (TCH)** used for the transfer of user plane information only

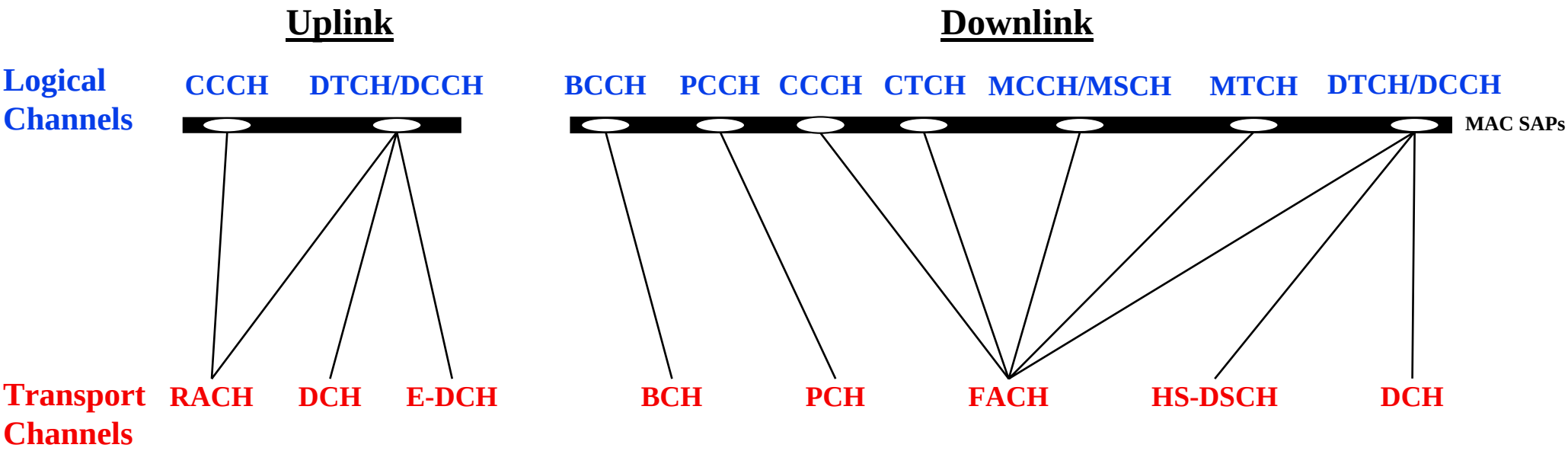
Transport channels (TCHs)

- Specified for **data transport between physical layer and Layer 2** peer entities
- Two types of transport channels exist
  - **Common transport channel (CTCH)** is a resource divided between all or a group of users in a cell (in-band ID for users needed)
  - **Dedicated transport channel (DTCH)** is by definition reserved for a single user

Physical channels (PhCHs)

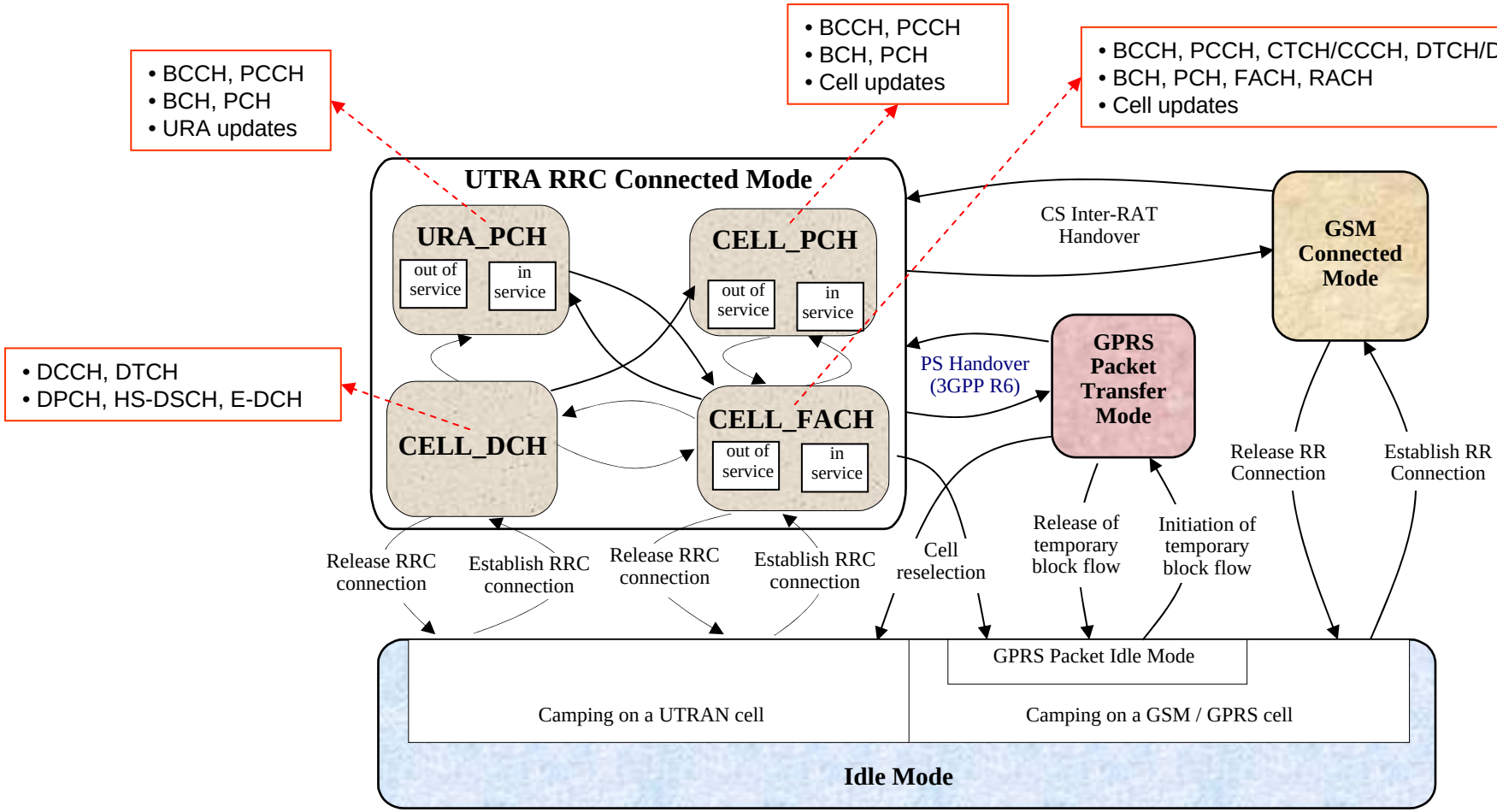
- **Physical channels** are defined by a **carrier frequency**, **scrambling code**, **channelisation code** (optional), time duration (start and stop instants) and, **in the uplink, relative phase (0 or $\pi/2$)**
- A **radio frame** (38 400 chips = **10 ms**) is a processing duration which consists of **15 slots** (15 x **2560 chips**)
- A **sub-frame** (3 slots = **2 ms**) is the basic time interval for **E-DCH** and **HS-DSCH** transmission and related signaling at the physical layer

Mapping of LoCHs onto TCHs



BCCH	Broadcast Control Channel	FACH	Forward Access Channel
BCH	Broadcast Channel	HS-DSCH	High Speed-Downlink Shared Channel
CCCH	Common Control Channel	MCCH	MBMS point-to-multipoint Control Channel
CCH	Control Channel	MSCH	MBMS point-to-multipoint Scheduling
CTCH	Common Traffic Channel	MTCH	MBMS point-to-multipoint Traffic Channel
DCCH	Dedicated Control Channel	PCCH	Paging Control Channel
DCH	Dedicated Channel	PCH	Paging Channel
DTCH	Dedicated Traffic Channel	RACH	Random Access Channel
E-DCH	Enhanced-DCH		

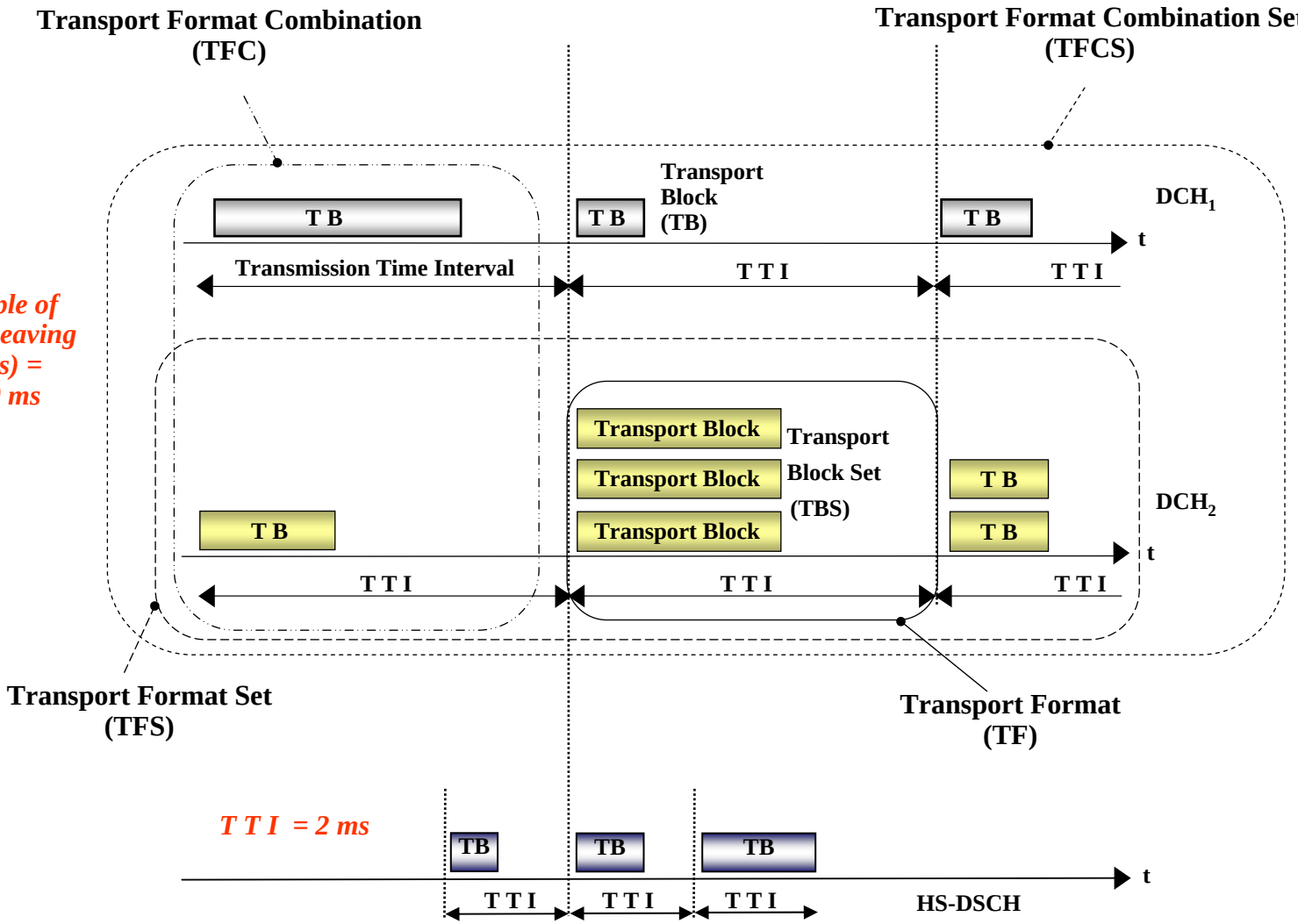
RRC states in connected mode



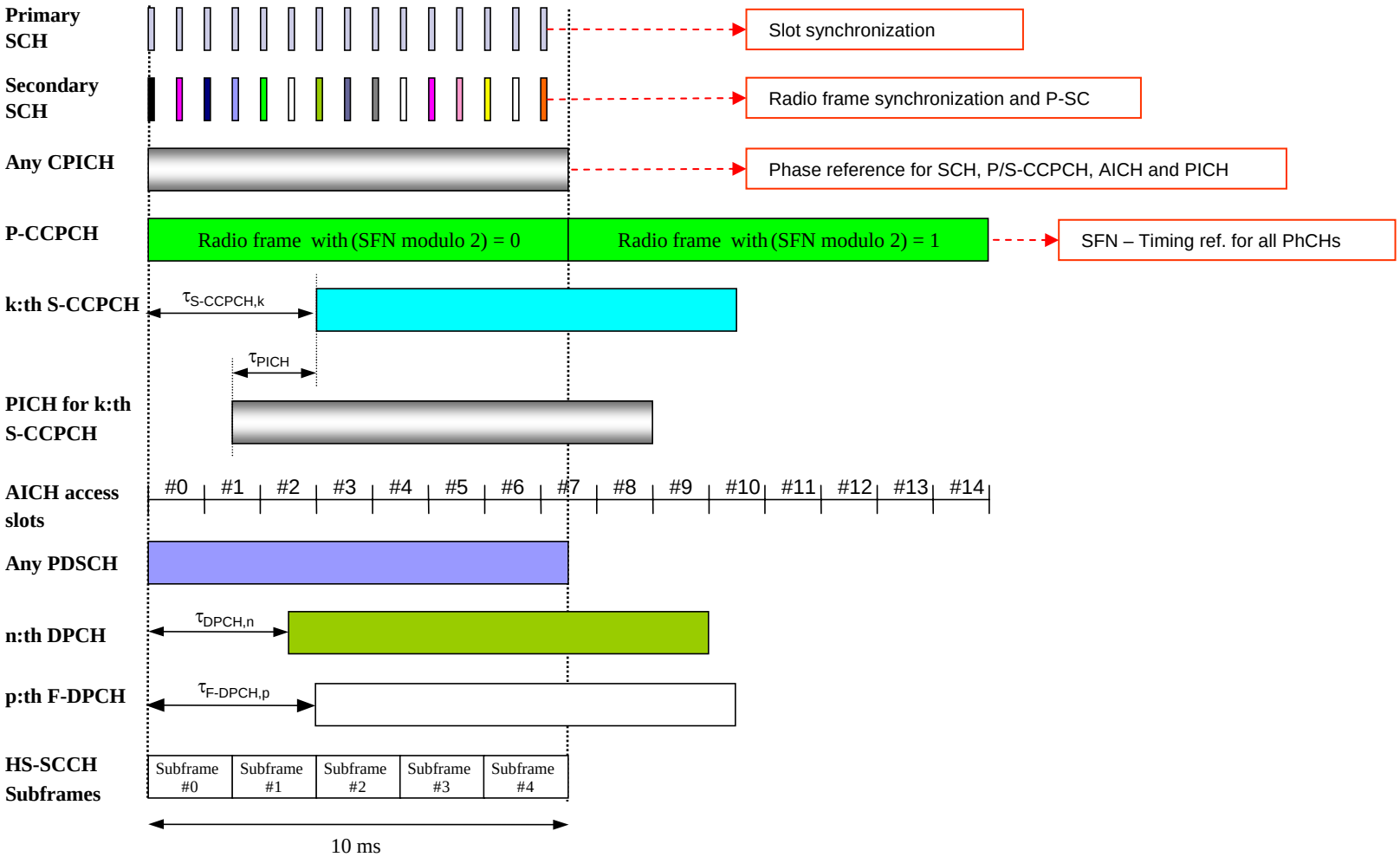
Mapping of TCHs onto PhCHs

TRANSPORT CHANNELS	PHYSICAL CHANNELS
DCH	**Dedicated Physical Data Channel (DPDCH)**
	Dedicated Physical Control Channel (DPCCH)
	Fractional Dedicated Physical Channel (F-DPCH)
E-DCH	**E-DCH Dedicated Physical Data Channel (E-DPDCH)**
	E-DCH Dedicated Physical Control Channel (E-DPCCH)
	E-DCH Absolute Grant Channel (E-AGCH)
	E-DCH Relative Grant Channel (E-RGCH)
	E-DCH Hybrid ARQ Indicator Channel (E-HICH)
RACH	**Physical Random Access Channel (PRACH)**
	Common Pilot Channel (CPICH)
BCH	**Primary Common Control Physical Channel (P-CCPCH)**
FACH	**Secondary Common Control Physical Channel (S-CCPCH)**
PCH	Synchronization Channel (SCH)
	Acquisition Indicator Channel (AICH)
	Paging Indicator Channel (PICH)
	MBMS Notification Indicator Channel (MICH)
HS-DSCH	**High Speed Physical Downlink Shared Channel (HS-PDSCH)**
	HS-DSCH-related Shared Control Channel (HS-SCCH)
	Dedicated Physical Control Channel (uplink) for HS-DSCH (HS-DPCCH)

Example of L2 (MAC)-L1data exchange



Radio frame and slot timing



R6: Physical layers models – UL

- 1 CCTrCH (RACH) or 2 CCTrCH (RACH + E-DCH)
  - 1 RACH CCTrCH = 1 RACH (no multiplexing)
  - 1 E-DCH CCTrCH = 1 E-DCH TrCH, which is carried on the E-DPDCH(s) physical channel(s)
- 1 HS-DPCCH employed for reporting
  - HS-DSCH transport block acknowledgement (ACK/NACK)
  - Channel Quality Indicator (CQI)
- 1 E-DPCCH physical channel carries
  - E-DCH TFCI
  - E-DCH HARQ information

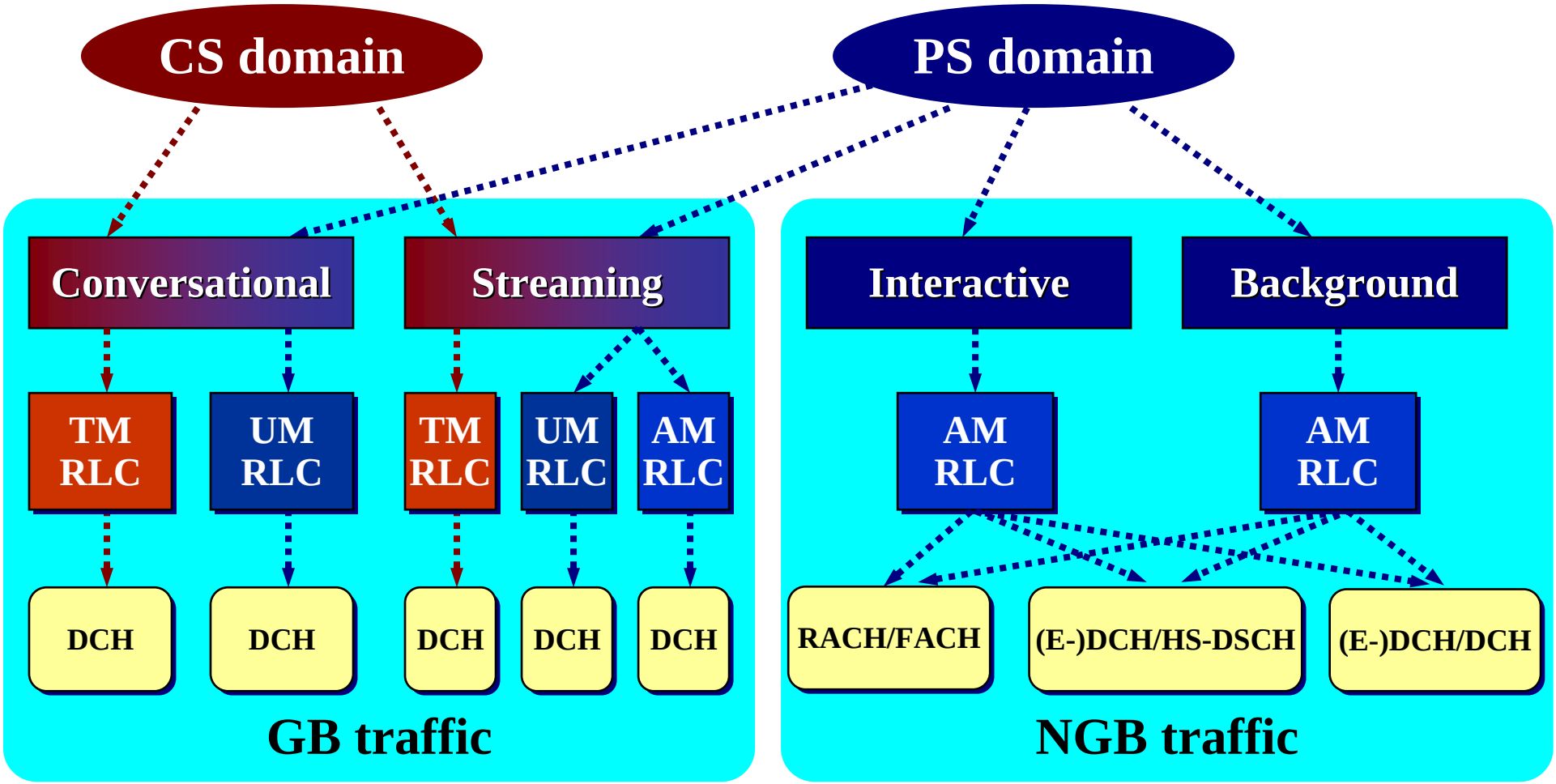
R6: Physical layers models – DL (1/2)

- Multiple CCTrCHs can be transmitted simultaneously to one UE
- Pilot, TPC bits and TFCI are time-multiplexed with complex scrambling onto the same dedicated physical channel
- TPC bits are on F-DPCH(s) for HS-DSCH(s) without a DCH
- A PCH and one or several FACHs can be encoded and multiplexed together, forming a CCTrCH
- A PCH is associated with a separate PICH
- BCH always mapped onto P-CCPCH without any other TCH
- Each HS-SCCH carries HS-DSCH-related L1 signaling for one UE (i.e., TFRI, HARQ info and UE Id via UE-specific CRC) for each HS-DSCH TTI

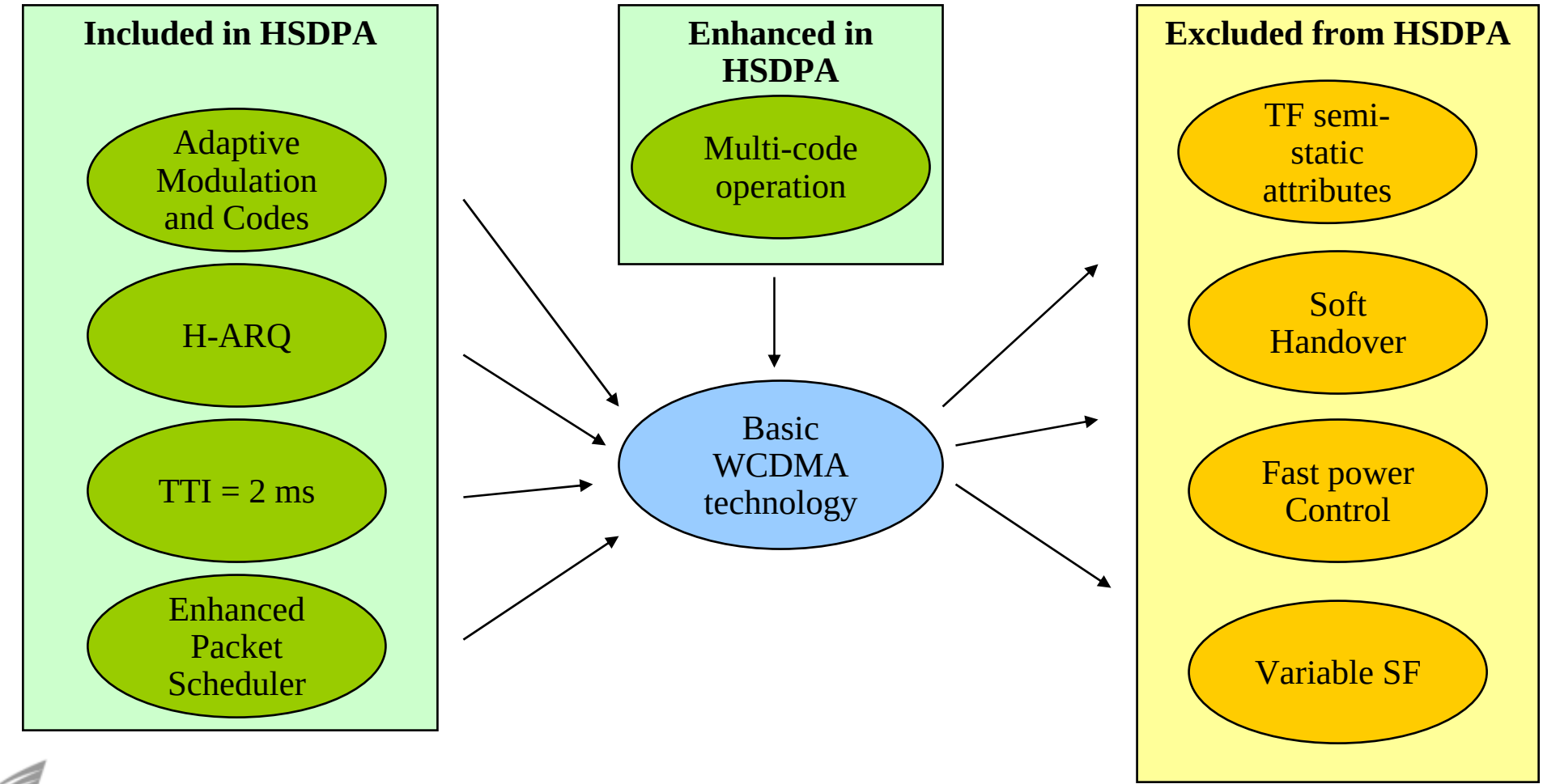
R6: Physical layers models – DL (2/2)

- E-DCH active set can be ≤ DCH active set
- E-DCH ACK/NACK are transmitted on E-HICH
- E-DCH absolute grant is transmitted by the serving E-DCH cell on the E-AGCH
- E-DCH relative grants can be transmitted on E-RGCH by each cell of the E-DCH active set
- There is one serving E-DCH RLS (containing the serving E-DCH cell) and, optionally, one or several non-serving E-DCH radio link(s)
- For all UE categories, the uplink DCH capability is limited to 64 kb/s when the E-DCH is configured for the radio link

Mapping of bearers onto TCHs



HSDPA: Fundamental features



HSDPA: Radio channels – DL (1/2)

- HS-DSCH
  - Defined in R5 and later releases and time/code shared by several terminals
  - No fast PC, but link adaptation by varying effective coding rate (HARQ), number OVSF codes and modulation (QPSK/16QAM)
  - Data channel always associated with a DPCH (or F-DPCH) and one or several HS-SCCHs for related L1 signaling transmission
  - TF: *dynamic part* (TB size; redundancy version/constellation; and modulation scheme), *static part* (TTI = 2ms; turbo-coding 1/3; and CRC = 24 bits)
  - Mapped onto HS-PDSCH
- HS-PDSCH
  - Data channel with SF = 16, multi-code transmission (up to 15 Walsh or OVSF codes), QPSK or 16QAM modulation
  - Transmitted over the entire cell or over only part of the cell using, e.g. using beam-forming antennas

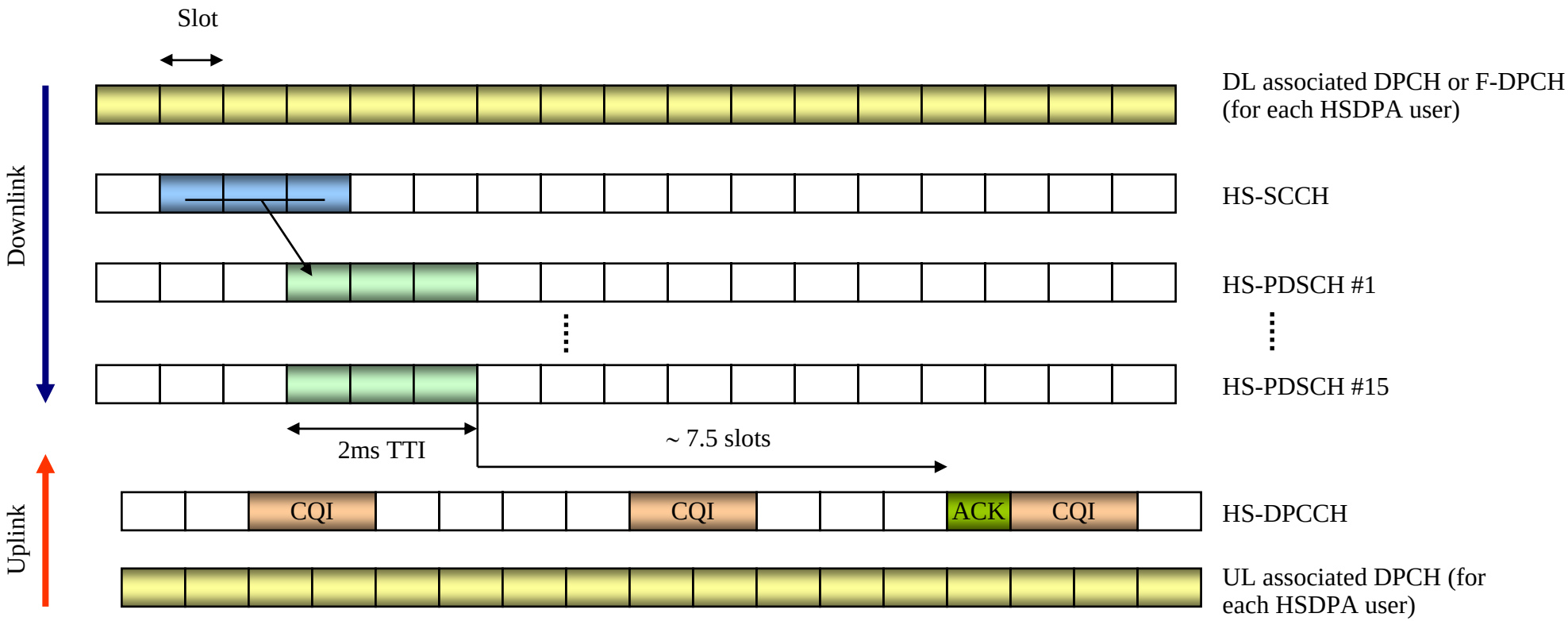
HSDPA: Radio channels – DL (2/2)

- HS-SCCH
  - Fixed-rate physical channel (SF =128) used to carry downlink L1 signaling related to downlink HS-DSCH transmission
    - UE ID mask, which identifies the user to be served in the next TTI
    - TFRI (TB size, modulation scheme and n. of OVSF codes per TTI)
    - HARQ-related information (new data unit or a retransmission that should be combined, associated ARQ process and information about the redundancy version)
  - HS-SCCH power slow power control (offset relative to the pilot bits of the associated DPCH)

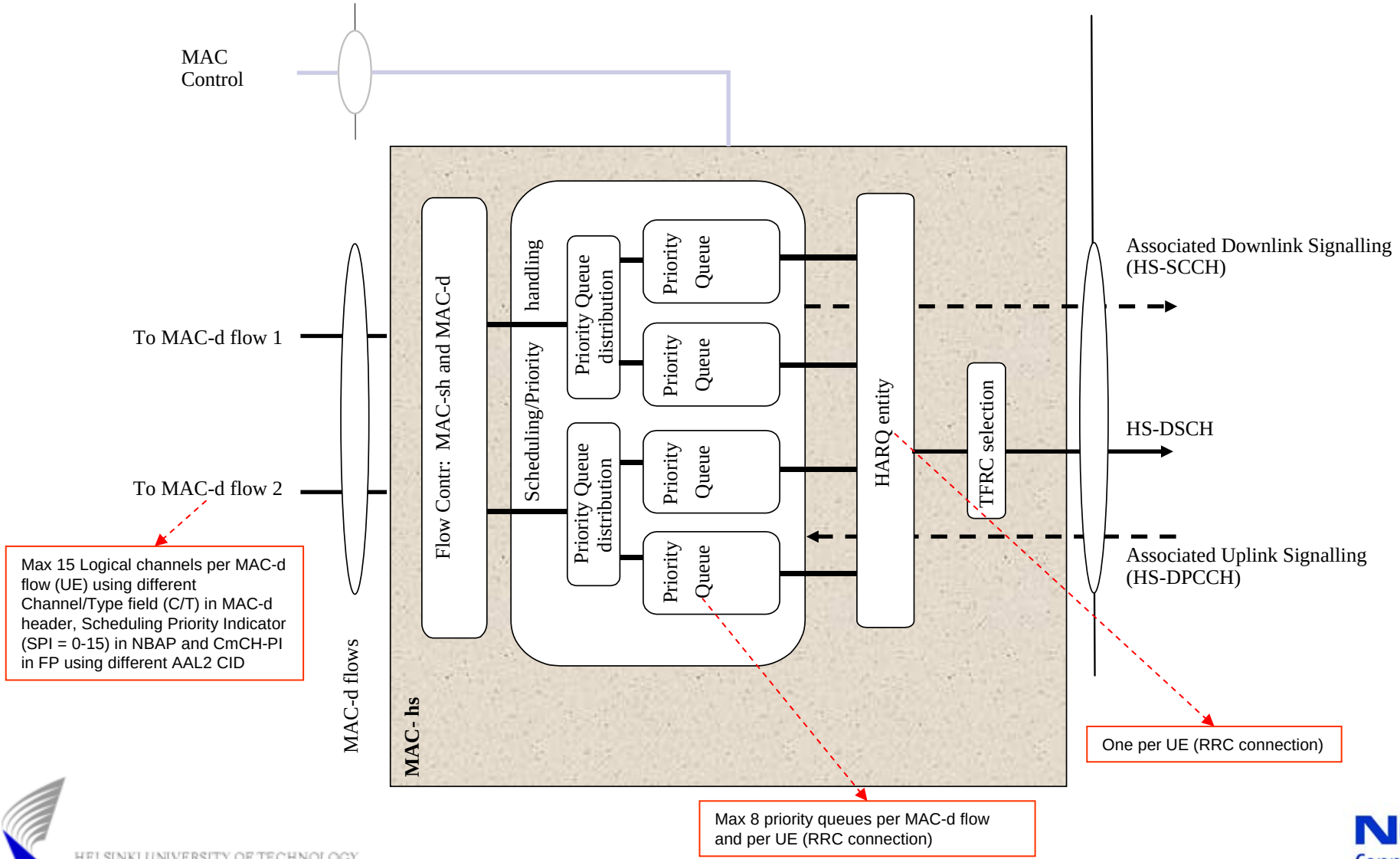
HSDPA: Radio channels – UL (1/1)

- HS-DPCCH
  - Fixed-rate (SF 256) used to carry HARQ acknowledgement (ACK/NACK) and channel quality indication (CQI)
  - One HS-DPCCH on each radio link
  - Can only exist together with an uplink DPCCH for its power control operation, the DPDCH is used as a return channel and user data transmission in UL

HSDPA: physical layer structure



HSDPA: UTRAN end MAC architecture

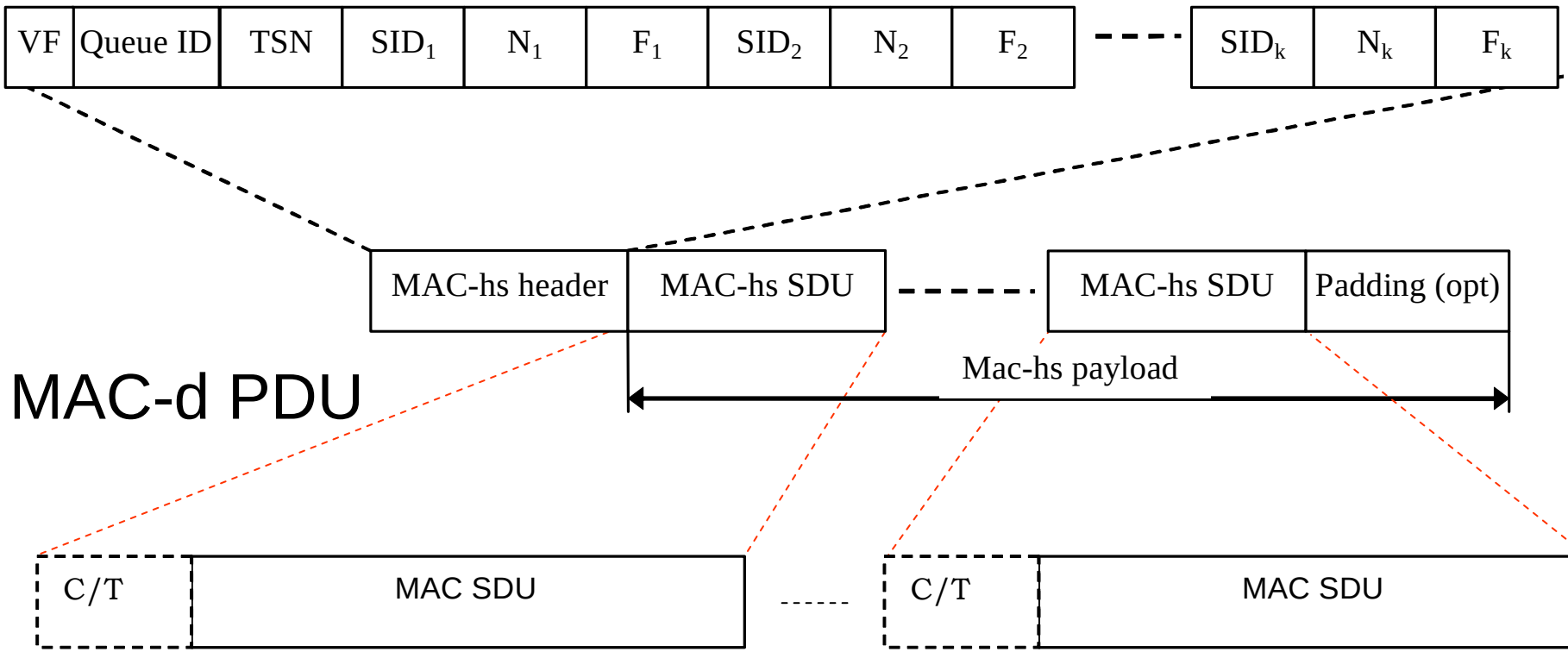


HSDPA: peer-to-peer communication (1/2)

- MAC-d PDU (HS-DSCH)
  - Format equals the format for non HS-DSCH case
- MAC PDU (HS-DSCH)
  - One MAC-hs header
  - One or more MAC-hs SDUs where each MAC-hs SDU equals a MAC-d PDU
  - A maximum of one MAC-hs PDU can be transmitted in a TTI per UE
  - The MAC-hs header is of variable size
  - The MAC-hs SDUs in one TTI belongs to the same reordering queue

HSDPA: peer-to-peer communication (2/2)

- MAC-hs PDU

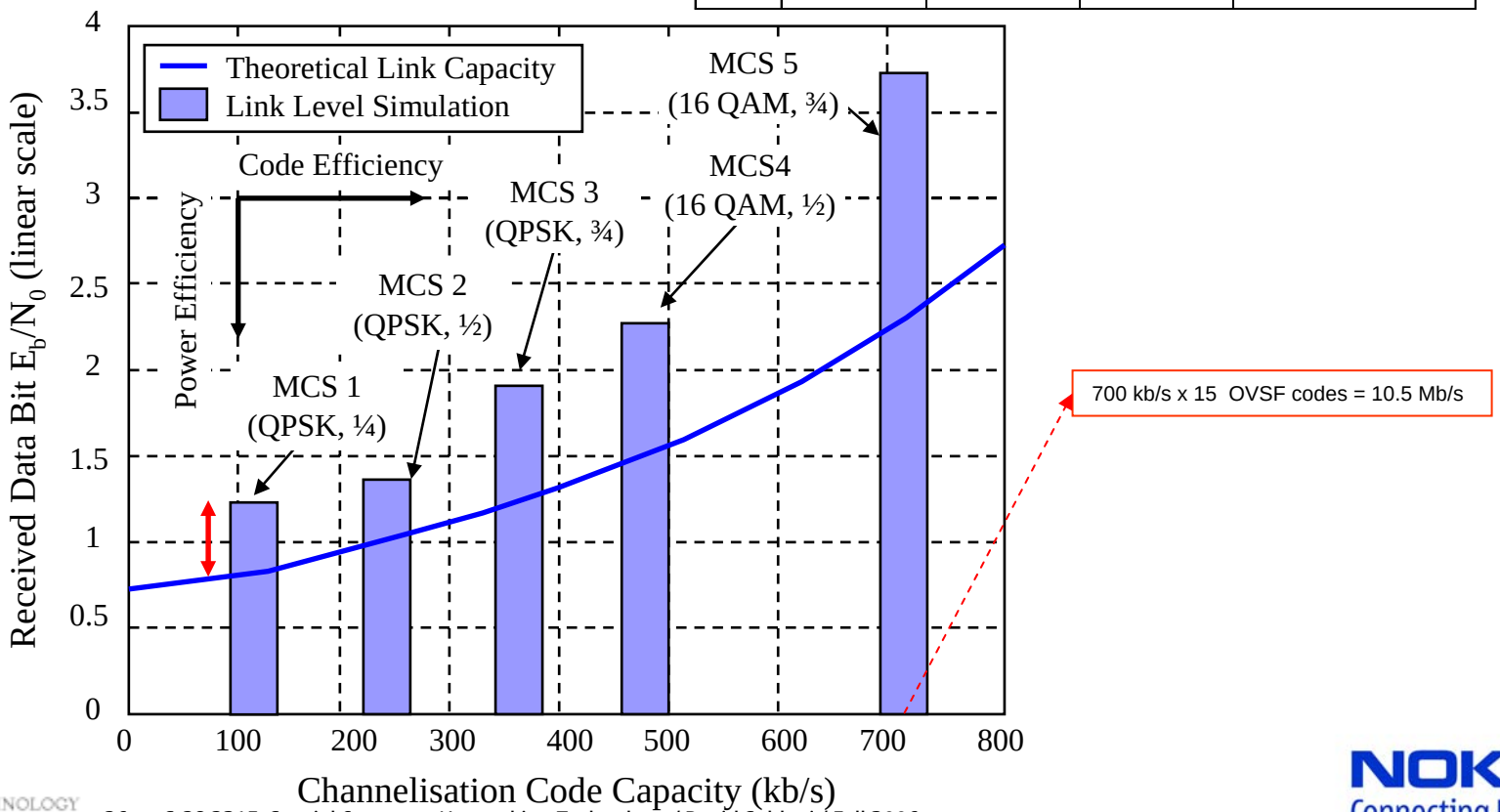


- MAC-d PDU

HSDPA: adaptive modulation and coding

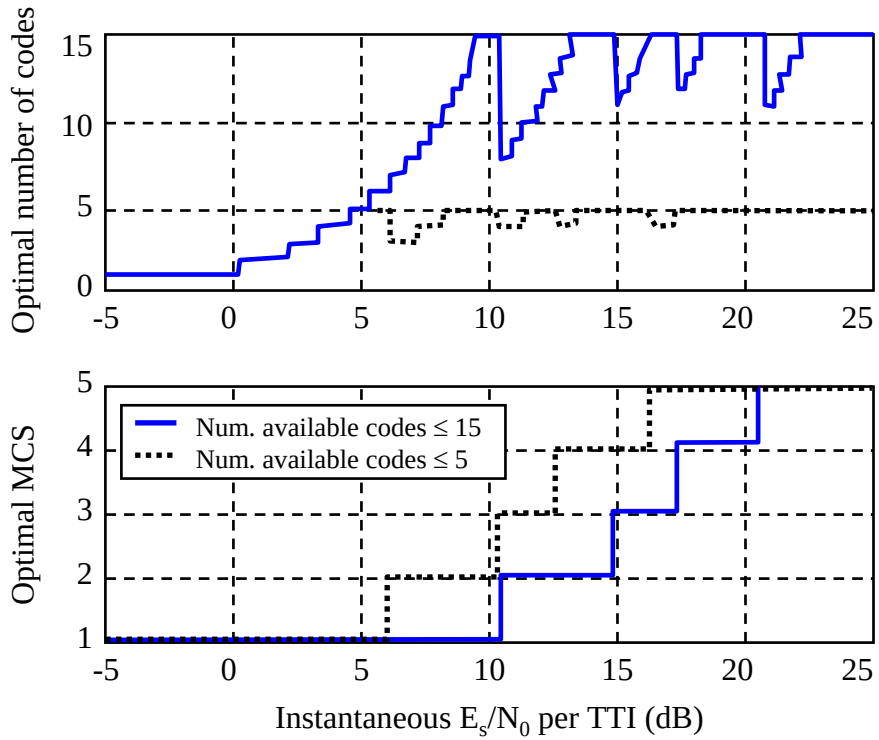
- Highest 1st Tx throughput
- MCS1 is the most spectral efficient allocation

MCS	Modulation	Effective Coding Rate	Bits per TTI	Peak Rate with 1 code (kb/s)
1	QPSK	1/4	240	120
2		1/2	480	240
3		3/4	720	360
4	16 QAM	1/2	960	480
5		3/4	1440	720



HSDPA: AMC and multi-code Tx

- Higher order MCS when all available codes are used is the most spectral efficient allocation



HSDPA: Link Adaptation (LA)

- Channel Quality Indicator (CQI)
  - Reported based on RRC commands
  - Period: 2, 4, 8, 10, 20, 40, 80, 160 ms
- Power measurements on associated DL DPCH
- HARQ Acknowledgement (DL “BLER”)
- MAC/hs buffer size

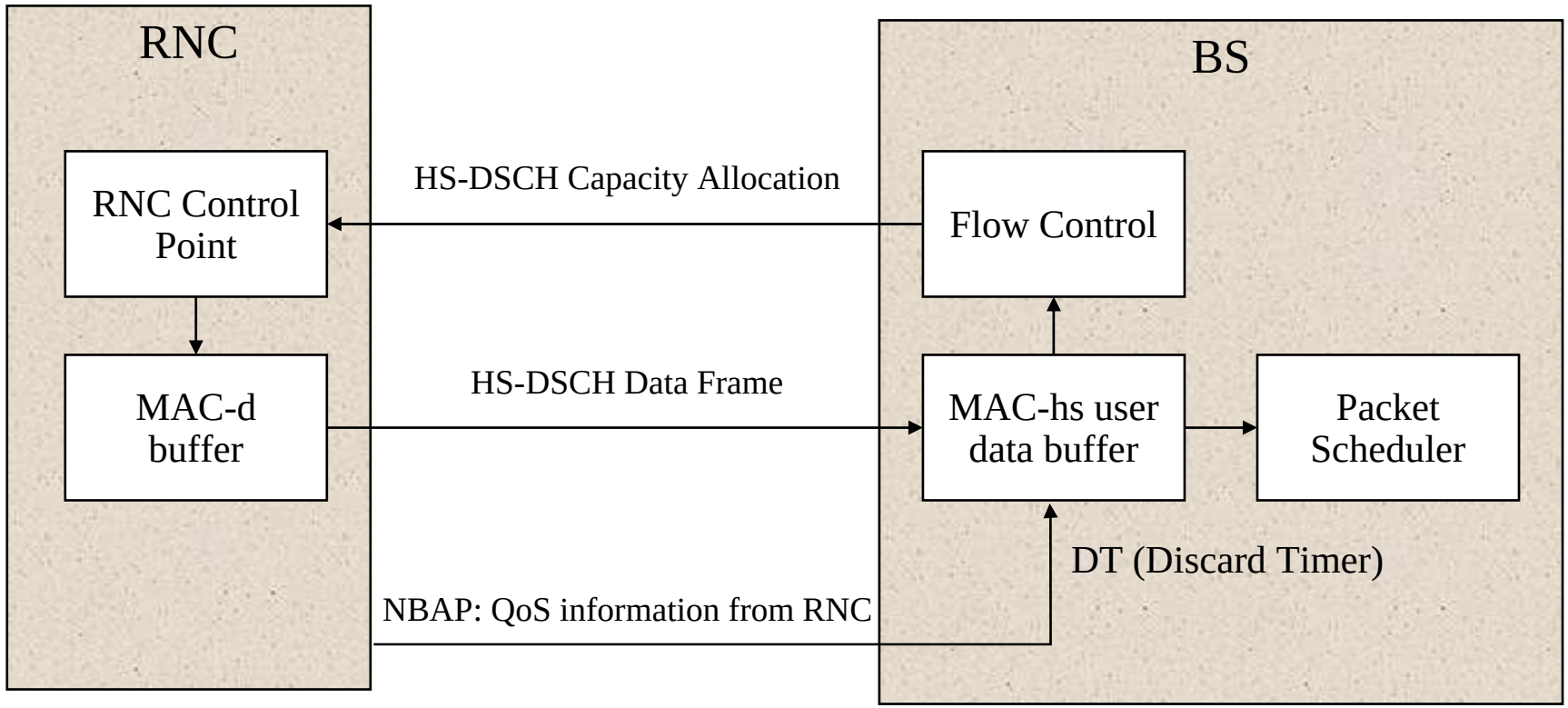
  (Optimal link adaptation functionality makes use of all the above information)

HSDPA: fast Hybrid ARQ

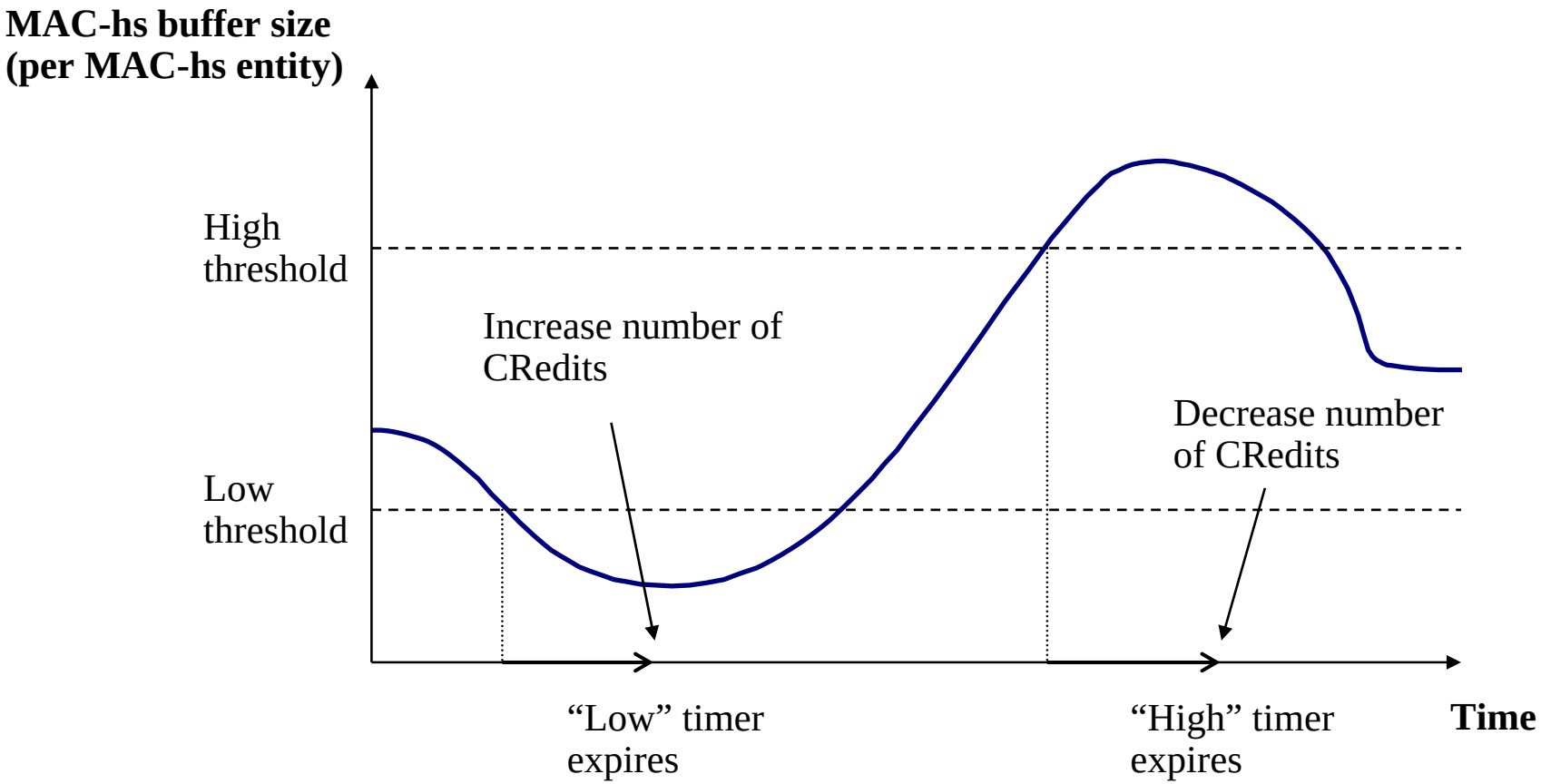
- Stop And Wait (SAW) protocol
  - One HARQ entity handles the hybrid ARQ functionality for one user
  - Tx of current TB until it has been successfully received before initiating Tx of the next one
  - Up to 8 SAW-ARQ processes may transmit in parallel over different TTIs for a UE (RRC-connection)
- Chase combining (CC)
  - Every retransmission is simply a replica of the coded word employed for the first transmission
  - The decoder at the receiver combines these multiple copies of the transmitted packet weighted by the received SNR prior to decoding
- Incremental redundancy (IR)
  - Retransmissions include additional redundant information that is incrementally transmitted if the decoding fails on the first attempt
  - This causes the **effective coding rate to increase** with the number of retransmissions

HSDPA: MAC/hs flow control

- TS 25.321: Flow control is provided independently by MAC-d flow for a given MAC-hs entity



HSDPA: flow control mechanism



HSDPA: MAC/hs packet scheduling

- For each TTI, PS determines which UE (RRC connection and thus which priority queue), or UEs (code-multiplexing), the HS-DSCH should be allocated to and, in collaboration with the link adaptation mechanism, at what data rate
- Scheduling principles
  - Radio resources allocated sequentially (round-robin scheduling among RRC connection)
  - Channel and priority dependent scheduling

HSUPA: Fundamental features

- Faster uplinks with lower latency and improves RL efficiency **without changing uplink modulation**
- The main characteristics of HSUPA are
  - Node B controlled uplink scheduling
  - HARQ protocol between the UE and Node B
  - Possibility of shorter TTI (2 ms) and smaller SF

Effective Coding Rate	User data rate with 1 code (kb/s)	User data rate with 2 codes (Mb/s)	User data rate with 4 codes (Mb/s)	User data rate with 6 codes (Mb/s)
2/3	640	1.28	2.56	3.84
3/4	720	1.44	2.88	4.32
4/4	960	1.92	3.84	5.76

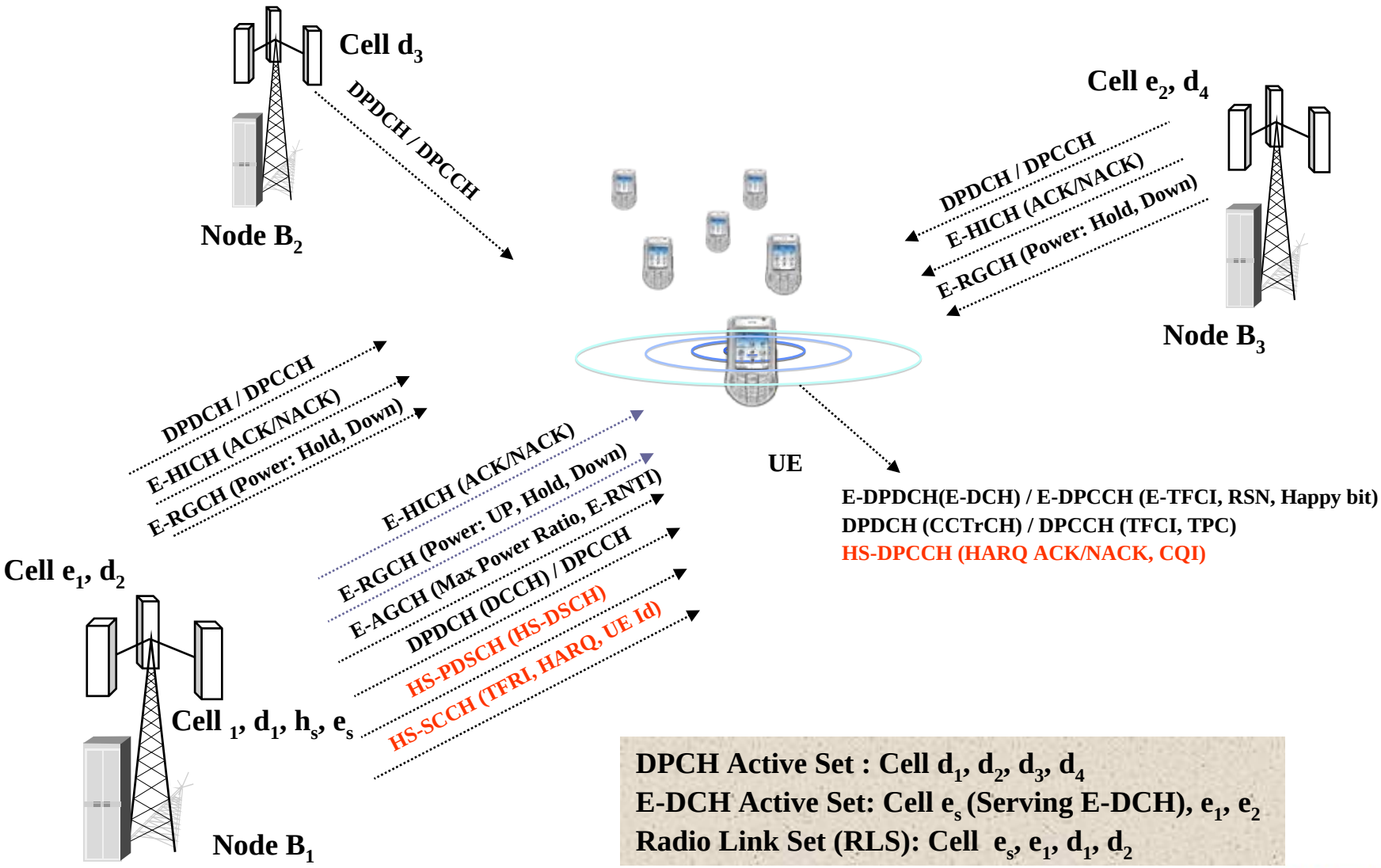
HSUPA: Radio channels – UL

- E-DCH
  - Available in 3GPP R6 and later releases
  - Possibility of changing rate each TTI
  - Supports inner-loop power control and link adaptation by varying the effective coding (HARQ), spreading factor and transmission power
  - TF: *dynamic part* (TB size and redundancy version), *semi-static part* (TTI 2 or 10 ms), *static part* (turbo-coding 1/3, size of CRC = 24 bits)
  - Mapped onto E-DPDCH
- E-DPCH
  - E-DPDCH and E-DPCCH I/Q code-multiplexed with complex scrambling
  - E-DPDCH supports multi-code transmission and SF from 256 down to 2
  - One E-DPCCH with SF 256 transmits L1 control information associated with E-DCH (E-TFCI = TB size, RSN, *happy bit*)
  - E-DPCCH is transmitted with a *power offset* relative to the DPCCH

HSUPA: Radio channels – DL

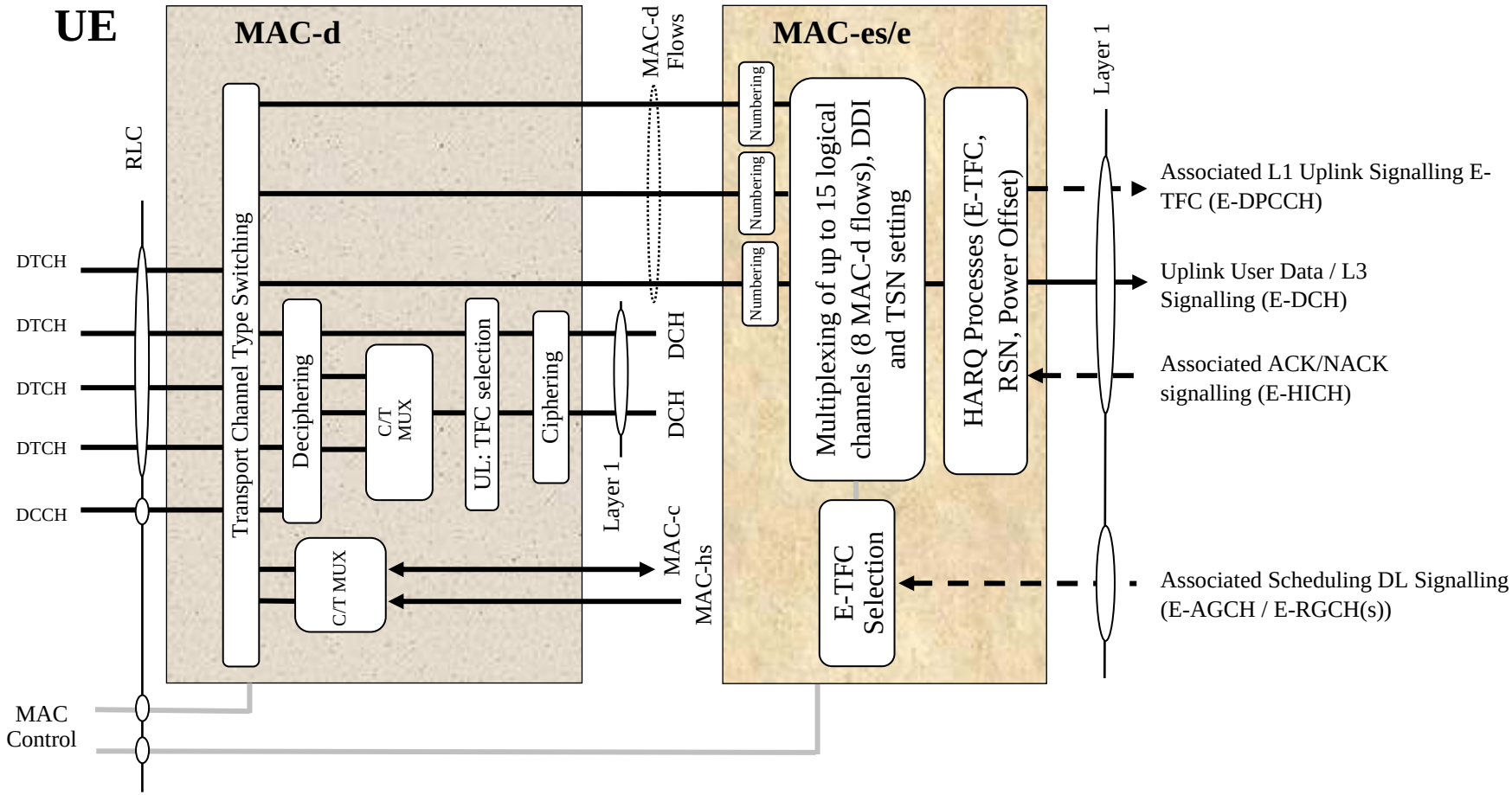
- E-RGCH
  - Fixed-rate physical channel with SF 128 carrying uplink E-DCH relative grants
- E-AGCH
  - Fixed-rate physical channel with SF 256 carrying uplink E-DCH absolute grants
- E-HICH
  - Fixed-rate physical channel with SF 128 carrying the uplink E-DCH HARQ acknowledgement indicator

HSPA: physical layer models

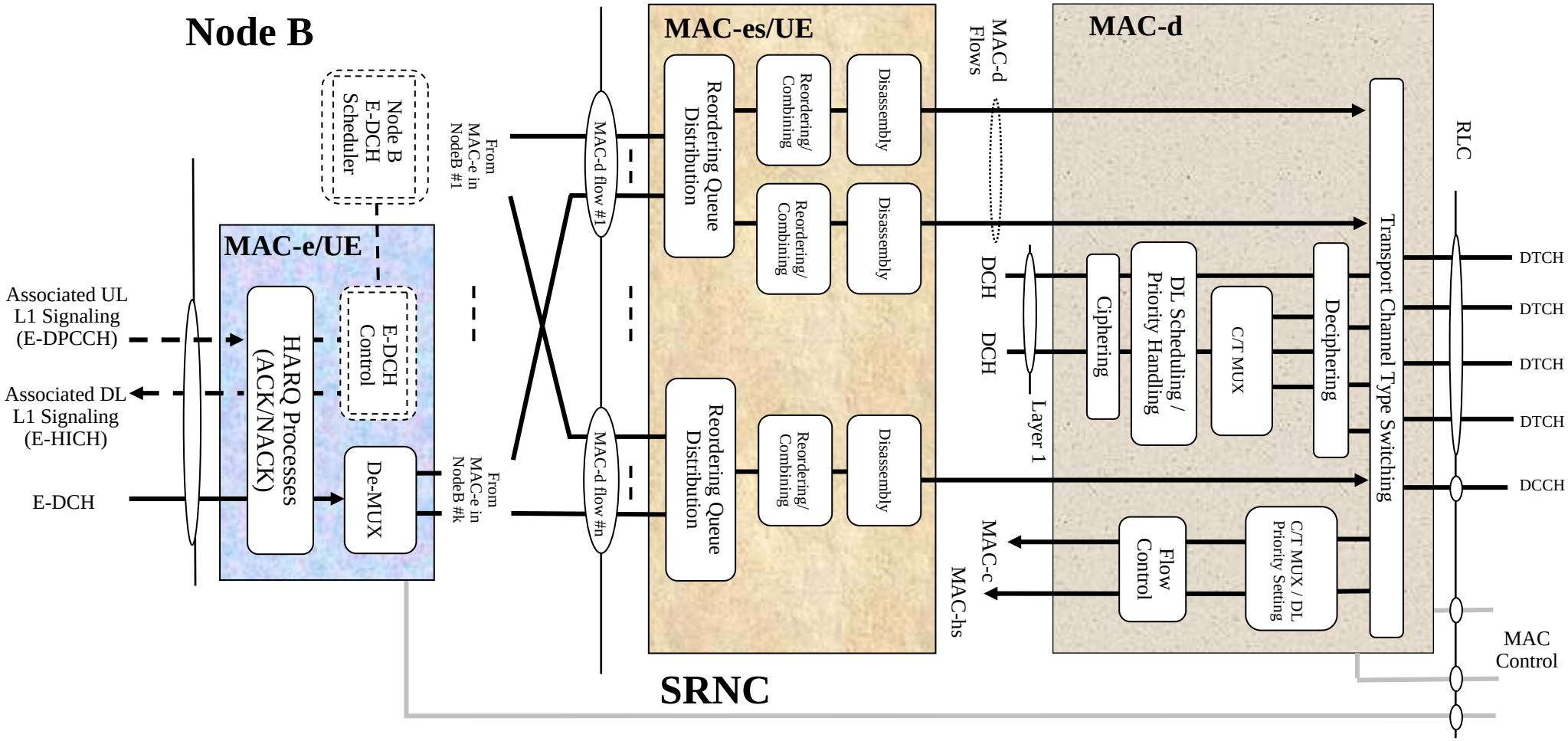


DPCH Active Set : Cell d_1, d_2, d_3, d_4
E-DCH Active Set: Cell e_s (Serving E-DCH), e_1, e_2
Radio Link Set (RLS): Cell e_s, e_1, d_1, d_2

HSUPA: UE-end MAC architecture



HSUPA: UTRAN-end MAC architecture



HSUPA: Node B scheduling (1/2)

- Node B issues **scheduling grants** to indicate to UE the maximum amount of uplink resources it may use
  - Control of max **E-DPDCH/DPCCH power ratio** of active HARQ processes
  - Used only for E-DCH TFC selection algorithm in the UE
  - Sent once per TTI or at a slower rate
- **Absolute grants**
  - E-RNTI of the UE or group of mobiles for which the grant is intended
  - Max E-DPDCH/DPCCH power ratio (*offset*) the UE is allowed to use
  - HARQ process activation flag (in case of a 2-ms TTI)
- **Relative grants**
  - Increase or decrease the resource limitation (power ratio) compared with the previously used value
  - From serving E-DCH RLS: ‘up’, ‘hold’ or ‘down’
  - From non-serving E-DCH RL: ‘hold’ or ‘down’

HSUPA: Node B scheduling (2/2)

- The UE requests resources from BSs in the form of ***scheduling information*** and ***happy bit***
- The UE is not 'happy' when it has power available to send data at higher rates and the total buffer content would require more than *X* ms to be transmitted with the current SG times the ratio of active processes to the total number of processes (1 for TTI 10 ms)
- Scheduling information
  - Sent to the serving E-DCH RLS in a MAC-e PDU
  - **Logical channel ID** of the highest priority channel with data in its buffer
  - **UE buffer occupancy**: status of the highest priority logical channel with data in its buffer
  - **UE power headroom (UPH)**: ratio of the maximum UE transmission power and the corresponding DPCCH code power

HSUPA: Non-scheduled transmissions

- SRNC may configure the UE for non-scheduled transmission
- UE may **send data at any time using the E-DCH**, without receiving any scheduling command from the Node B
- Non-scheduled transmissions are defined **per MAC-d flow**
- The resource for non scheduled transmission (non-scheduled grant) is provided by the SRNC in terms of the **maximum number of bits that can be included in a MAC-e PDU**
- The logical channels are served in the **order of their priorities until the non-scheduled grant and scheduled grants are exhausted**, or the maximum transmit power is reached

References

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  - http://eu.wiley.com/WileyCDA/WileyTitle/productCd-0470016396.html
  - http://www.connecting.nokia.com/NOKIA/nns.nsf/a/78786C61AB5A7C5AC225718F0026BAA3

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See also:

- http://lib.tkk.fi/Diss/2005/isbn9512278340/