WCDMA Physical Layer (Chapter 6)

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Introduction

- This lecture presents a general **WCDMA** or UTRA (Universal Terrestrial Radio Access) FDD (Frequency Division Duplex) physical layer issues.

  - Spreading and Scrambling
  - Transport Channels
  - Physical Channels
  - Signaling
  - Physical Layer Procedures

Mapping to

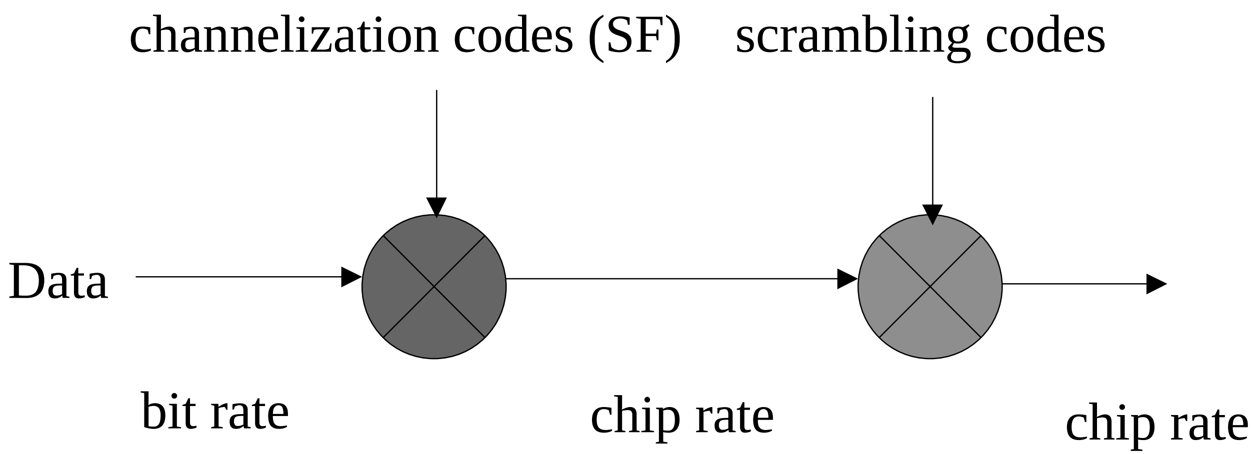
Some Parameters of WCDMA Physical Layer

Carrier Spacing	5 MHz (nominal)
Chip Rate	3.84 Mcps
Frame Length	10 ms (38400 chips)
No. of slots/frame	15
No. of chips/slot	2560 chips (Max. 2560 bits)
Uplink SF	4 to 256
Downlink SF	4 to 512
Channel Rate	7.5 Kbps to 960 Kbps

Spreading and Scrambling

Spreading Operation

- Spreading means increasing the signal bandwidth
- Strickly speaking, spreading includes two operations:
  - Channelisation (increases signal bandwidth) - using orthogonal codes
  - Scrambling (does not affect the signal bandwidth) - using pseudo-noise codes



Channelisation (1/3)

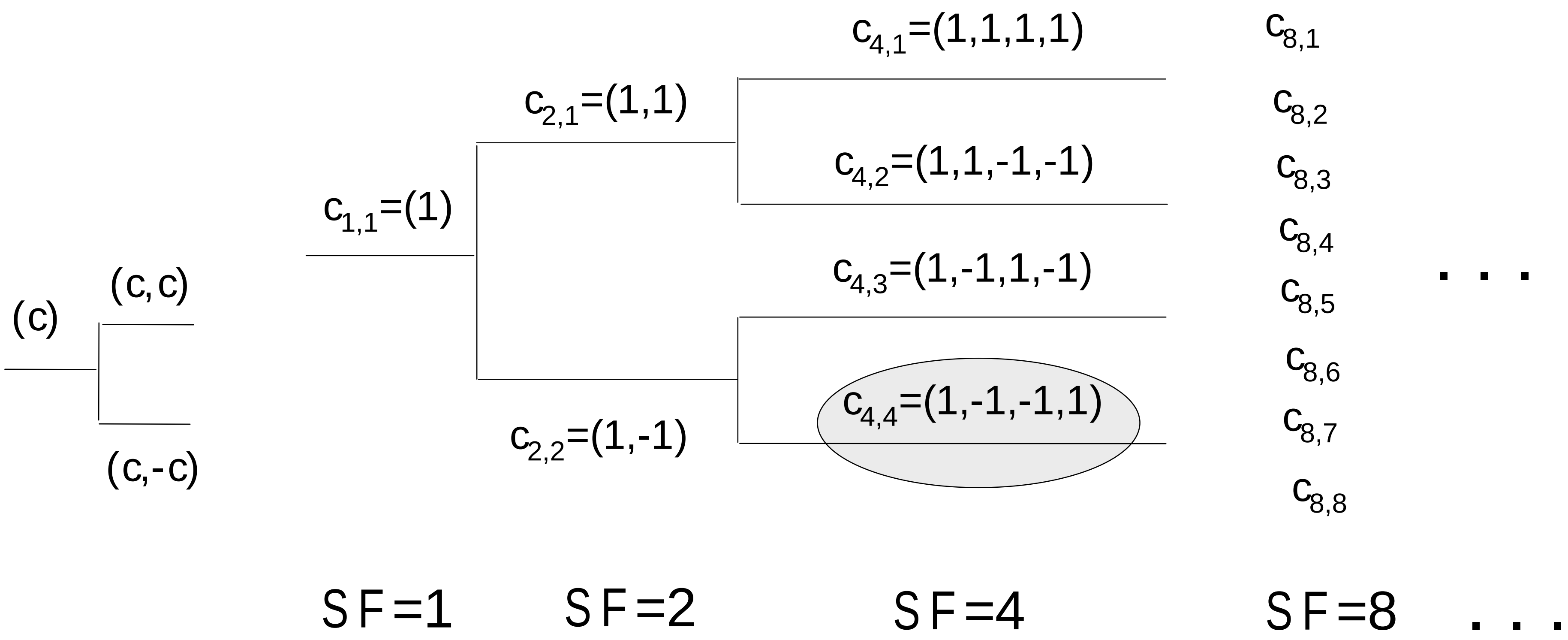
- Channelisation codes are orthogonal codes, based on Orthogonal Variable Spreading Factor (OVSF) technique
- The codes are fully orthogonal, i.e., they do not interfere with each other, only if the codes are time synchronized
- Thus, channelisation codes can separate the transmissions from a single source
- In the downlink, it can separate different users within one cell/sector
- Limited orthogonal codes must be reused in every cell
  - Problem: Interference if two cells use the same code
  - Solution: Scrambling codes to reduce inter-base-station interference

Channelisation (2/3)

- In the uplink, it can only separate the physical channels/services of one user because the mobiles are not synchronised in time.
- It is possible that two mobiles are using the same codes.
- In order to separate different users in the uplink, scrambling codes are used.
- The channelisation codes are picked from the code tree as shown in next slide.
- One code tree is used with one scrambling code on top of the tree.
- If $c_{4,4}$ is used, no codes from its subtree can be used ($c_{8,7}$, $c_{8,8}$, …).

Channelisation (3/3)

Code tree



Scrambling

- In the scrambling process the code sequence is multiplied with a pseudorandom scrambling code.
- The scrambling code can be a long code (a Gold code with 10 ms period) or a short code (S(2) code).
- In the downlink scrambling codes are used to reduce the inter-base-station interference. Typically, each Node B has only one scrambling code for UEs to separate base stations. Since a code tree under one scrambling code is used by all users in its cell, proper code management is needed.
- In the uplink scrambling codes are used to separate the terminals.

Summary

	Channelisation code	Scrambling code
Usage	UL: Separation of physcial data and control channels from same UE DL: Seperation of different users within one cell	UL: Separation of terminals DL: Separation of cells/sectors
Length	UL:4 – 256 chips same as SF DL:4 – 512 chips same as SF	UL: 10ms=38400 chips DL: 10m[illegible]99 chips
No. of codes	No. of codes under one scrambling code = SF	UL: Several millions DL: 512
Code family	Orthogonal Variable Spreading Factor	Long 10ms code: Gold code Short code: Extended S(2) code family
Spreading	Yes, increase transmission bandwidth	No, does not affect transmission bandwidth

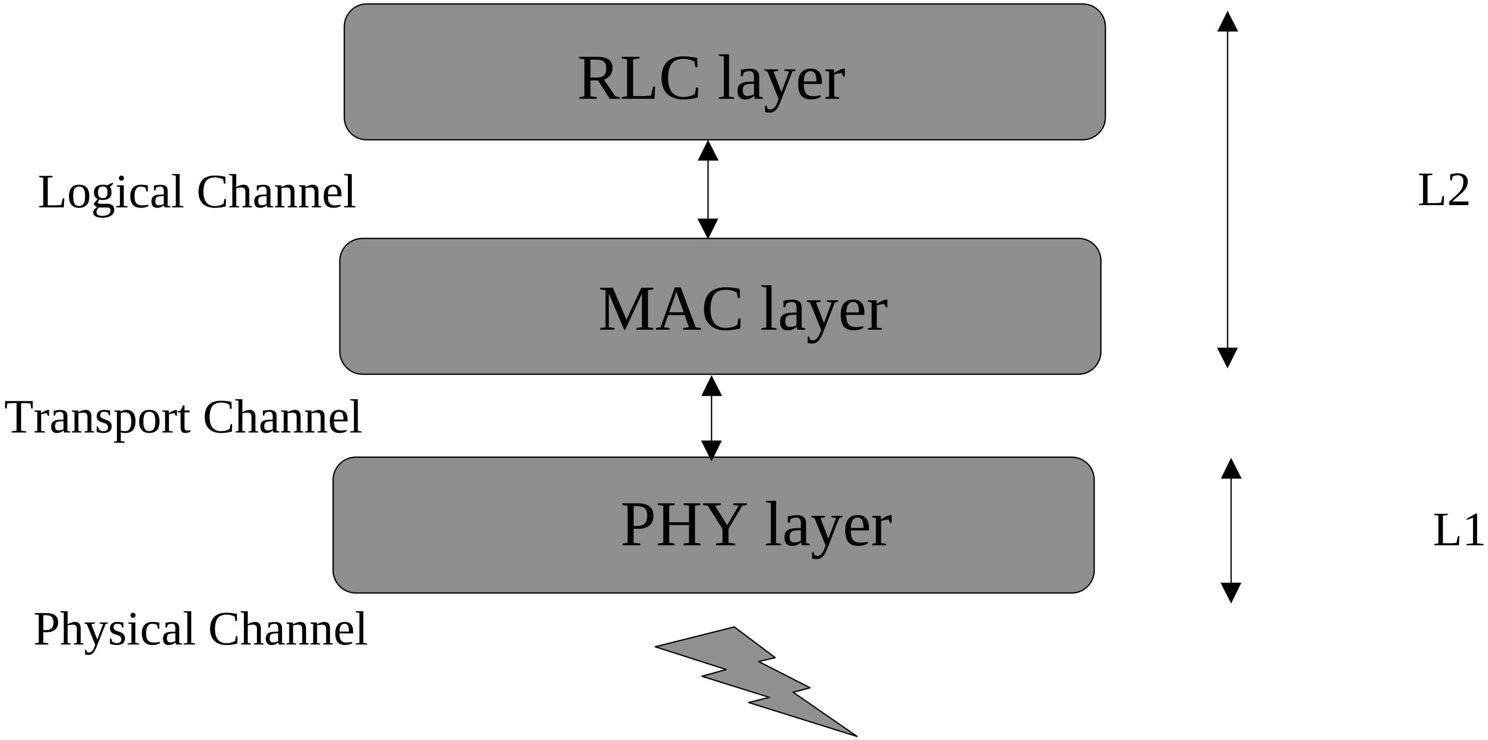
38400

Limited codes in each cell for DL.

Transport Channels

Channel Concepts

- Three separate channels concepts in the UTRA: logical, transport, and physical channels.
- Logical channels define what type of data is transferred.
- Transport channels define how and with which type of characteristics the data is transferred by the physical layer.
- Physical data define the exact physical characteristics of the radio channel.



Transport Channels -> Physical Channels (1/3)

- Transport channels contain the data generated at the higher layers, which is carried over the air and are mapped in the physical layer to different physical channels.
- The data is sent by transport block from MAC layer to physical layer and generated by MAC layer every 10 ms.
- The transport format of each transport channel is identified by the Transport Format Indicator (TFI), which is used in the interlayer communication between the MAC layer and physical layer.
- Several transport channels can be multiplexed together by physical layer to form a single Coded Composite Transport Channel (CCTrCh).

Transport Channels -> Physical Channels (2/3)

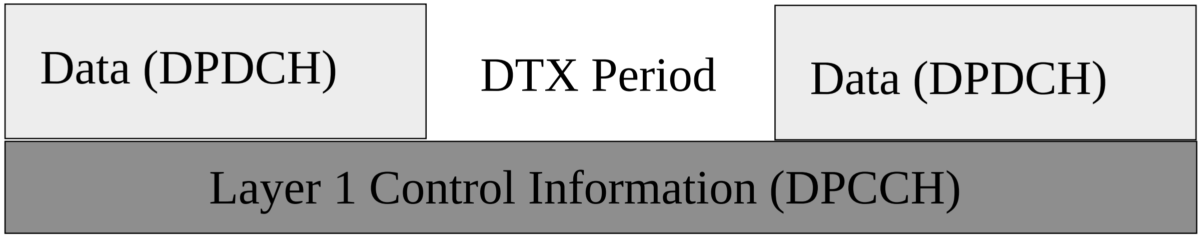
- The physical layer combines several TFI information into the Transport Format Combination Indicator (TFCI), which indicate which transport channels are active for the current frame.
- Two types of transport channels: ***dedicated*** channels and ***common*** channels.
- Dedicated channel –reserved for a single user only.
  - Support fast power control and soft handover.
- Common channel – can be used by any user at any time.
  - Don’t support soft handover but some support fast power control.
- In addition to the physical channels mapped from the transport channels, there exist physical channels for *signaling* purposes to carry only information between network and the terminals.

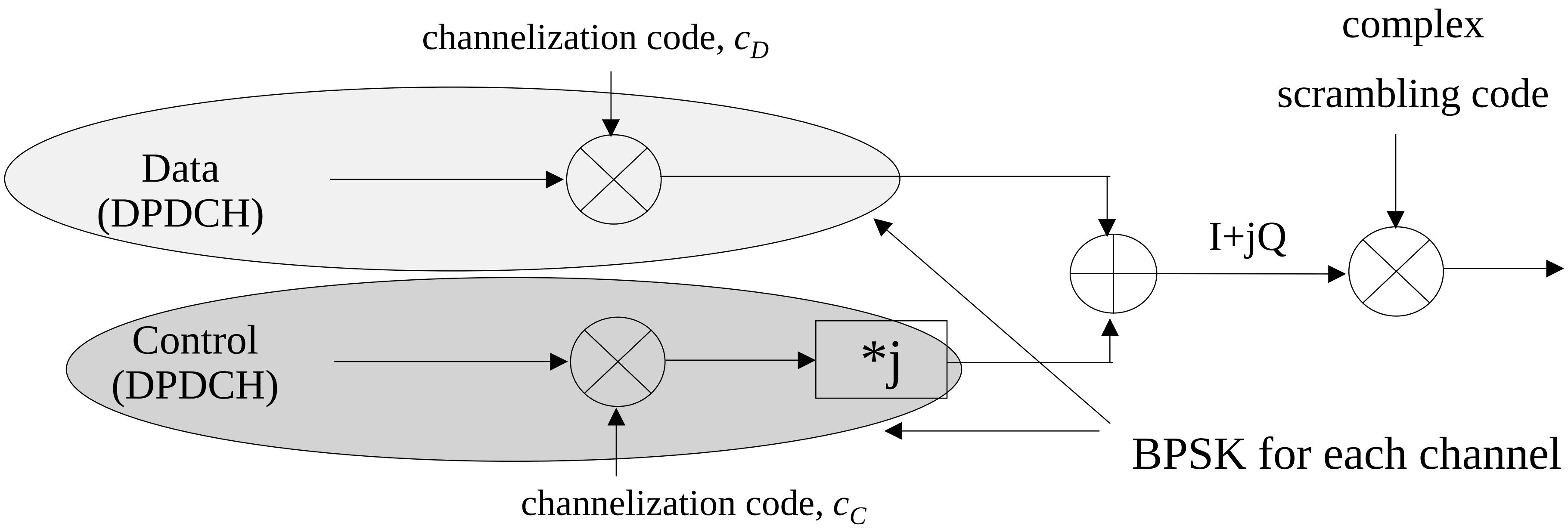
Transport Channels -> Physical Channels (3/3)

Transport Channel	Physical Channel
(UL/DL) Dedicated channel **DCH**	Dedicated physical data channel **DPDCH** Dedicated physical control channel **DPCCH**
(UL) Random access channel **RACH**	Physical random access channel **PRACH**
(UL) Common packet channel **CPCH**	Physical common packet channel **PCPCH**
(DL) Broadcast channel **BCH**	Primary common control physical channel **P-CCPCH**
(DL) Forward access channel **FACH** (DL) Paging channel **PCH**	Secondary common control physical channel **S-CCPCH**
(DL) Downlink shared channel **DSCH**	Physical downlink shared channel **PDSCH**
Signaling physical channels	Synchronisation channel **SCH**
	Common pilot channel **CPICH**
	Acquisition indication channel **AICH**
	Paging indication channel **PICH**
	CPCH Status indication channel **CSICH**
	Collision detection/Channel assignment indicator channel **CD/CA-ICH**

UL Dedicated Channel DCH (1/3)

- Due to audible interference to the audio equipment caused from the discontinuous UL transmission, two dedicated physical channels are I-Q/code multiplexing (called dual-channel QPSK modulation) instead of time multiplexing.





UL Dedicated Channel DCH (2/3)

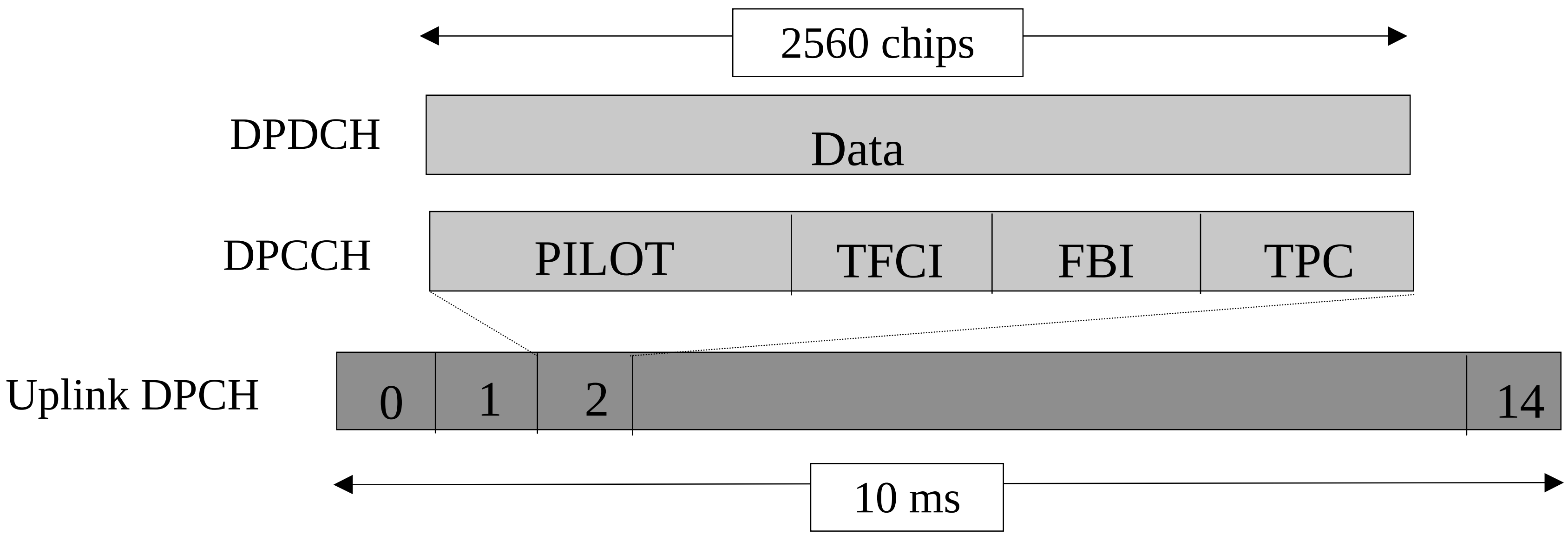
- Dedicated Physical Control Channel (DPCCH) has a fixed spreading factor of 256 and carries physical layer control information.
- DPCCH has four fields: Pilot, TFCI, FBI, TPC.

  Pilot – channel estimation + SIR estimate for PC

  TFCI – bit rate, channel decoding, interleaving parameters for every DPDCH frame

  FBI (Feedback Information) – transmission diversity in the DL

  TPC (Transmission Power Control) – power control command



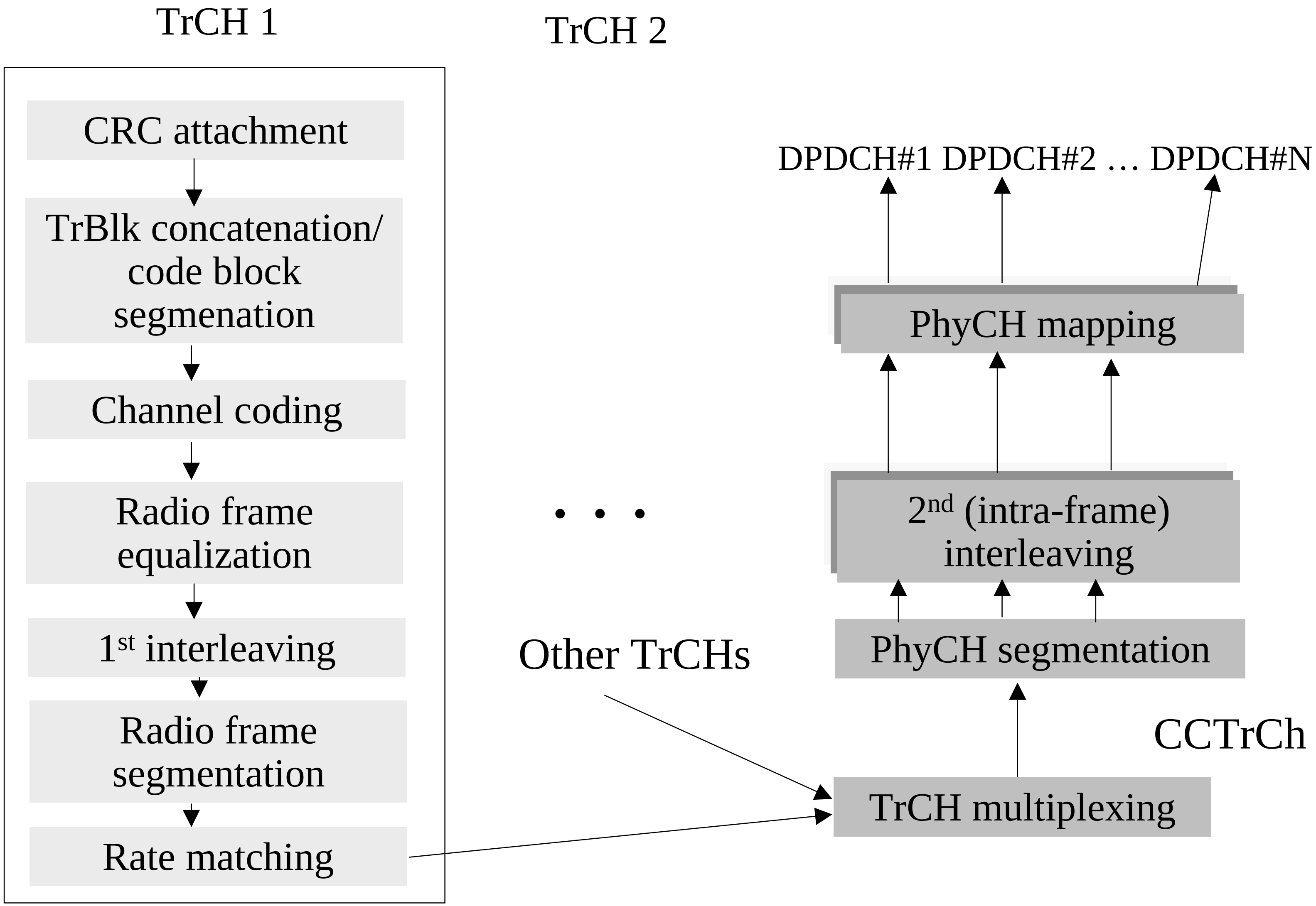
UL Dedicated Channel DCH (3/3)

- Dedicated Physical Data Channel (DPDCH) has a spreading factor from 4 to 256 and its data rate may vary on a frame-by-frame basis.
- Parallel channel codes can be used in order to provide 2 Mbps user data

3.84 Mcps/256=15 kbps

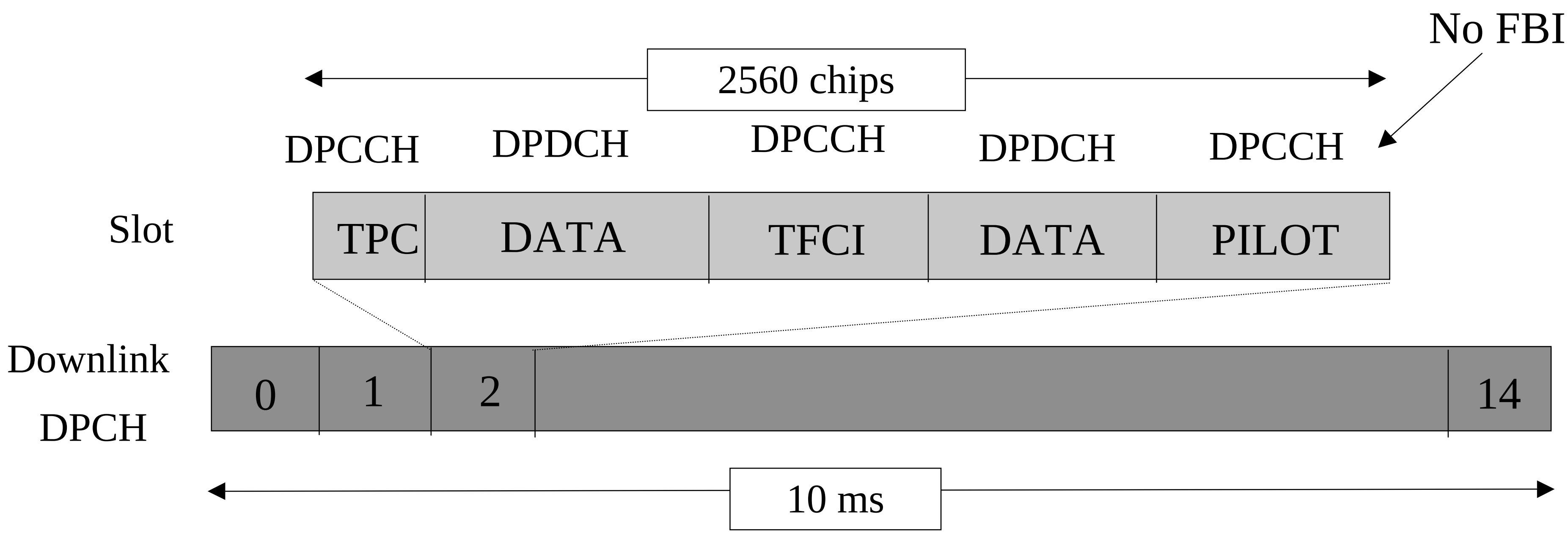
DPDCH SF	DPDCH channel bit rate (kbps)	Max. user data rate with ½ rate coding (approx.)
256	15	7.5 kbps
128	30	15 kbps
64	60	30 kbps
32	120	60 kbps
16	240	120 kbps
8	480	240 kbps
4	960	480 kbps
4, with 6 parallel codes	5740	2.3 Mbps

UL Multiplexing and Channel Coding Chain



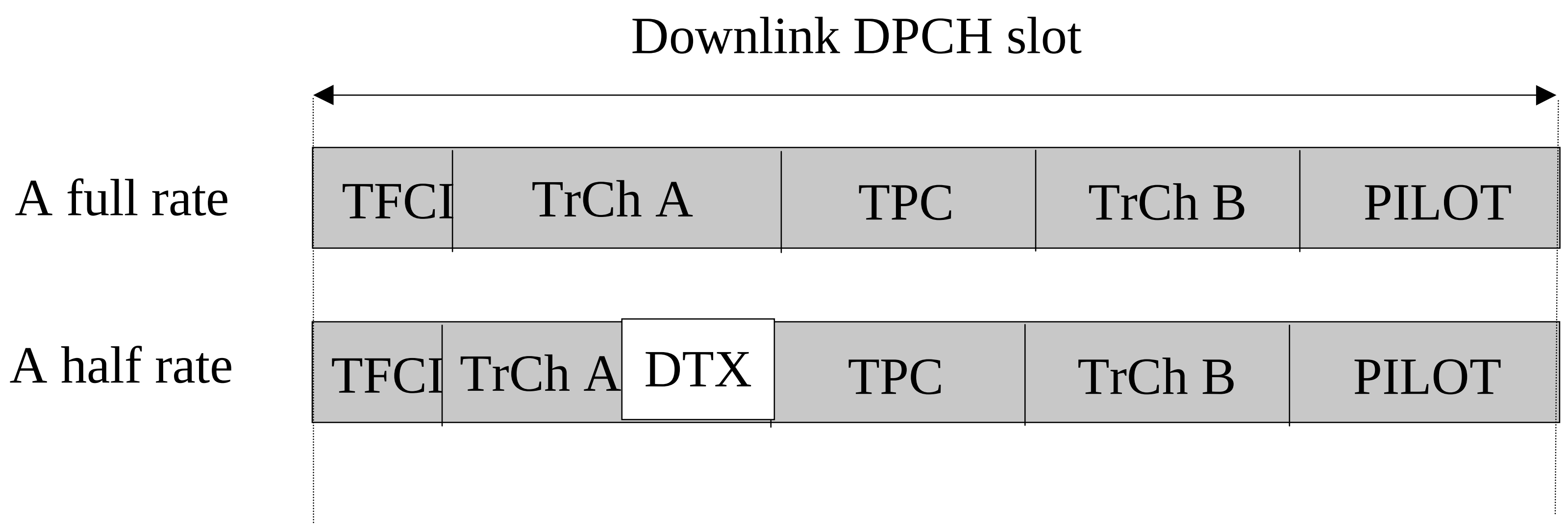
DL Dedicated Channel DCH (1/3)

- In the DL no audible interference is generated with DTX because the common channels are continuously transmitting.
- Downlink DCH is transmitted on the Downlink Dedicated Physical Channel (Downlink DPCH); thus, DPCCH and DPDCH are time-multiplexed and using normal QPSK modulation.



DL Dedicated Channel DCH (2/3)

- A code tree under one scrambling code is shared by several users. Normally, one scrambling code and thus only one code tree is used per sector in the BS.
- DCH SF does not vary on a frame-by-frame basis; thus, data rate is varied by rate matching operation, puncturing or repeating bits, or with DTX, where the transmission is off during part of the slot.
- The SF is the same for all the codes with multicode transmission.

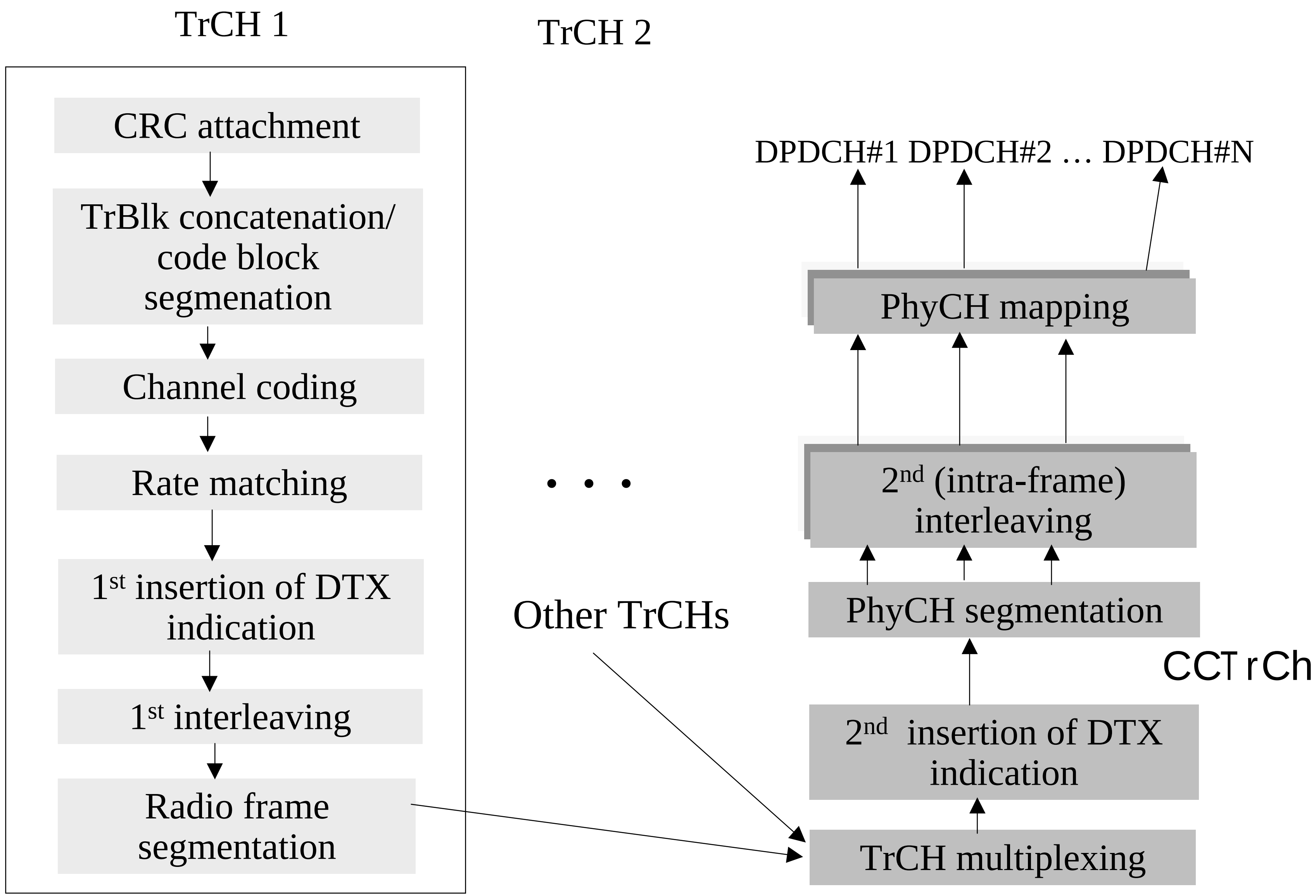


DL Dedicated Channel DCH (3/3)

- UL DPDCH consists of BPSK symbols whereas DL DPDCH consists of QPSK symbols. The bit rate in the DL DPDCH can be almost double that in the UL DPDCH.

Spreading factor	Channel symbol rate (kbps)	Channel bit rate (kbps)	DPDCH channel bit rate range (kbps)	Max. user data rate with ½ rate coding (approx.)
512	7.5	15	3-6	1-3 kbps
256	15	30	12-24	6-12 kbps
128	30	60	42-51	20-24 kbps
64	60	120	90	45 kbps
32	120	240	210	105 kbps
16	240	480	432	215 kbps
8	480	960	912	456 kbps
4	960	1920	1872	936 kbps
4, with 3 parallel codes	2880	5760	5616	2.3 Mbps

DL Multiplexing and Channel Coding Chain



Downlink Shared Channel (DSCH)

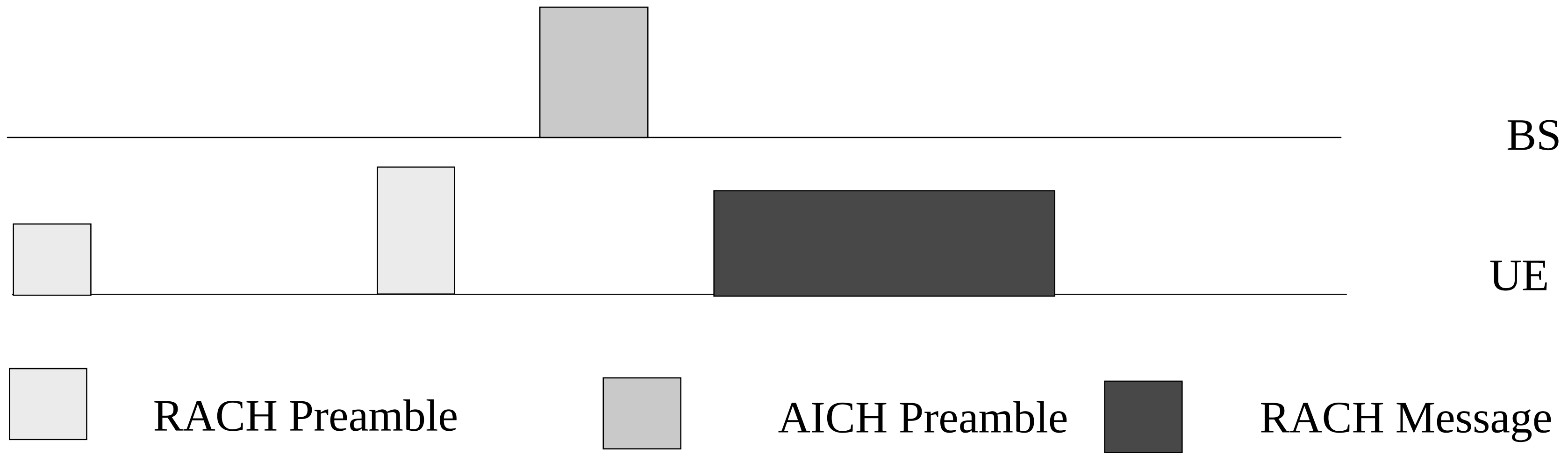
- Used for dedicated control or traffic data (bursty traffic).
- Shared by several users. Each user may allocate a DSCH for a short period of time based on a particular packet scheduling algorithm.
- Support the use of fast power control, but not soft-handover.
- Use a variable spreading factor on a frame-by-frame basis so that bit rate can be varied on a frame-by-frame basis.
- Associated with a DL DPCH with the use of DPCCH. Such a DL DPCCH from TFCI provides the power control information, an indication to which terminal to decode the DSCH and spreading code of the DSCH.
- Since the information of DSCH is provided from an associated DL DPCH, the PDSCH frame may not be started before 3 slots after the end of that associated DL DPCH.

Random Access Channel (RACH)

- A contention-based uplink transport channel; thus, no scheduling is performed.
- Use of RACH
  - Carry control information from the UE to set up an initial connection. For example, to register the UE after power-on to the network or to perform location update or to initiate a call.
  - Send small amount of packet data to network for 1 to 2 frames.
- Since it is needed to be heard from the whole cell for signaling purposes, the data rate is quite low.
- No power control is supported.

RACH Operation

- First, UE sends a preamble.
  - The SF of the preamble is 256 and contain a signature sequence of 16 symbols – a total length of 4096 chips.
- Wait for the acknowledged with the Acquisition (AICH) from the BS.
- In case no AICH received after a period of time, the UE sends another preamble with higher power.
- When AICH is received, UE sends 10 or 20 ms message part.
  - The SF for the message is from 32 to 256.

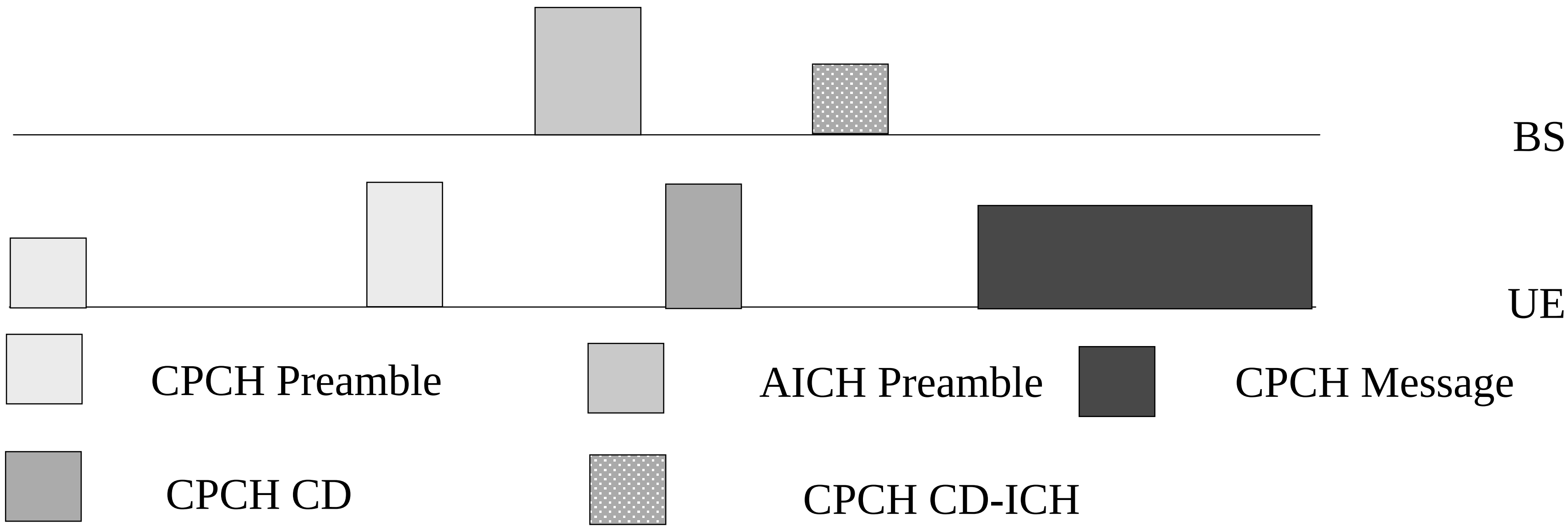


Common Packet Channel (CPCH)

- A contention-based uplink transport channel for transmission of bursty data traffic.
- Different from RACH, channel can be reserved for several frames and it uses fast power control.
- Information of CPCH is provided by
  - DL DPCCH for fast power control information.
  - Forward Access Channel (FACH) for higher layer DL signaling.
- CPCH operation is similar to RACH operation except that it has Layer 1 Collision Detection (CD).
- In RACH, one RACH message is lost, whereas in CPCH an undetected collision may lose several frames and cause extra interference.

CPCH Operation

- After receiving CPCH AICH,
  - UE sends a CPCH CD preamble with the same power from another signature.
  - If no collision after a certain time, the BS echo this signature back to the UE on the CD Indication Channel (CD-ICH).
  - Then, the UE sends data over several frames with fast power control.
- The CPCH status indicator channel (CSICH) carries the status of different CPCH information.



Broadcast Channel (BCH)

- Downlink common transport channel.
- The physical channel of BCH is Primary Common Control Physical Channel (Primary CCPCH).
- BCH:
  - broadcast the system and cell-specific information, e.g., random access codes or slots.
  - terminals must decode the broadcast channel to register to the cell.
  - uses high power in order to reach all users within a cell.

Forward Access Channel (FACH)

- Downlink common transport channel.
- It can be multiplexed with PCH to the same physical channel, Secondary CCPCH, or standalone.
- FACH:
  - carry control information to UEs within a cell.
  - carry small amount of packet data.
  - no power control.
  - can have several FACHs. But the primary one must have low data rate in order to be received by all terminals.
  - In-band signaling is needed to inform for which user the data was intended.

Paging Channel (PCH)

- Downlink common transport channel for transmission of paging and notification messages, i.e., when the network wants to initiate communication with the terminal.
- It can be multiplexed with FACH to the same physical channel, Secondary CCPCH, or standalone.
- The identical paging message can be sent in a single cell or hundreds of cells. The paging message has to be reached by all the terminals within the whole cell.
- Its transmission is associated with transmission of paging indicator in paging indicator channel (PICH).

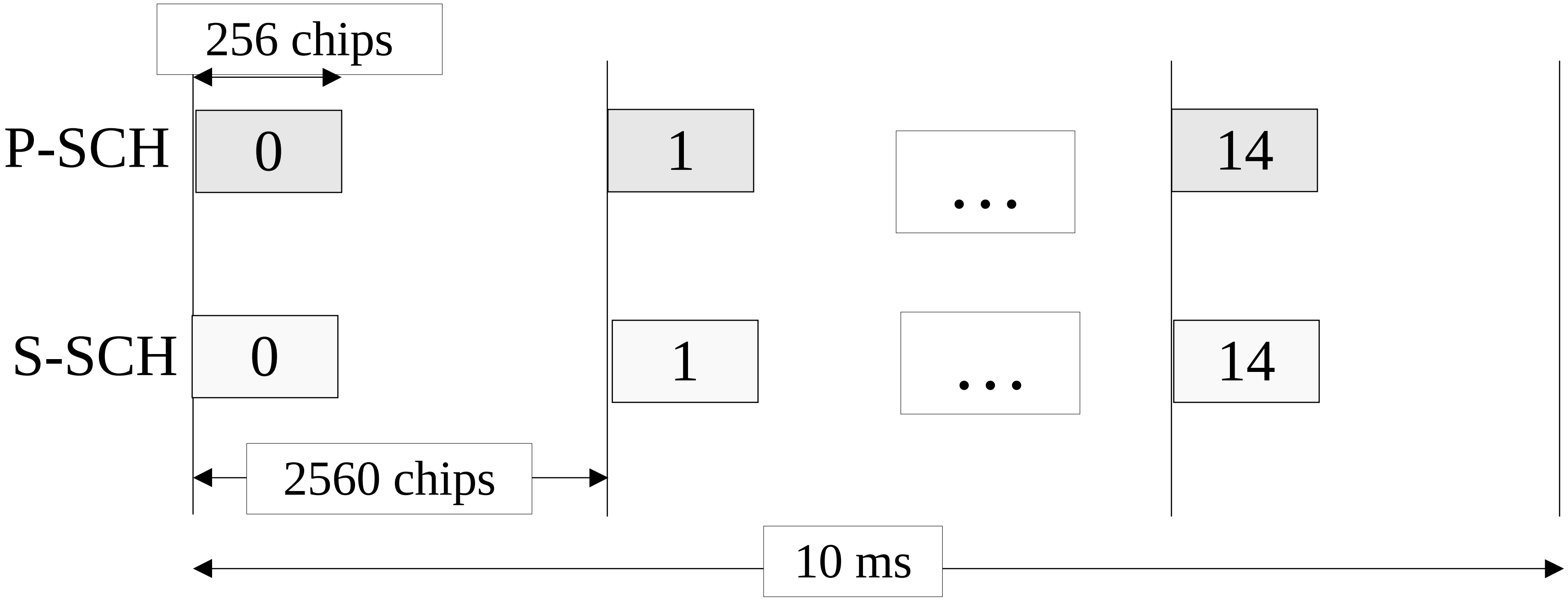
Signaling Physical Channels

Common Pilot Channel (CPICH)

- Downlink channel with a fixed rate of 30 Kbps or SF of 256.
- Scrambled with the cell-specific primary scrambling code.
- Use for channel estimation reference at the terminal.
- Two types: primary and secondary CPICH
- Primary CPICH
  - the measurements for the handover and cell selection / reselection.
  - phase reference for SCH, primary CCPCH, AICH and etc.
- Secondary CPICH may be phase reference for the secondary CCPCH.

Synchronisation Channel (SCH) – Cell Searching

- SCH is used for cell search.
- Two subchannels: primary and secondary SCH.
- P-SCH and S-SCH are only sent during the first 256 chips of each slot in parallel and time-multiplexed with the Primary CCPCH.

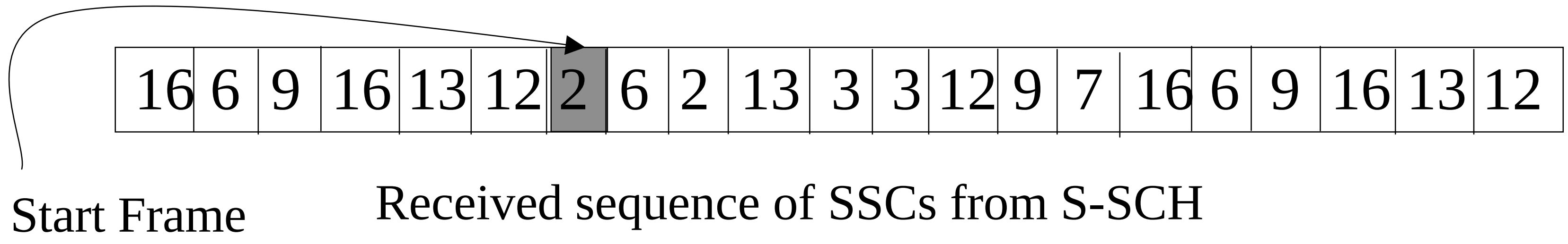


Synchronisation Channel (SCH) – Cell Searching

- Cell search using SCH has three basic steps:
  - The UE searches the 256-chip primary synchronisation code, which is common to all cells and is the same in every slot. Detect peaks in the output of the filter corresponds to the slot boundary (slot synchronisation).
  - The UE seeks the largest peak secondary synchronisation code (SSC). There are 64 unique SSC sequences. Each SSC sequence has 15 SSCs. The UE needs to know 15 successive SSCs from the S-SCH, then it can determine the code group in order to know the frame boundary (frame synchronisation).
  - Each code group has 8 primary scrambling. The correct one is found by each possible scrambling code in turn over the CPICH of that cell.

SSC Sequences

Secondary Synchronisation Code (SSC) and Code Group															
Code group	#0	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14
: :															
30	2	5	11	7	2	11	9	4	16	7	16	9	14	14	4
31	2	6	2	13	3	3	12	9	7	16	6	9	16	13	12
32	2	6	9	7	7	16	13	3	12	2	13	12	9	16	6
: :															



Primary Common Control Physical Channel (Primary CCPCH)

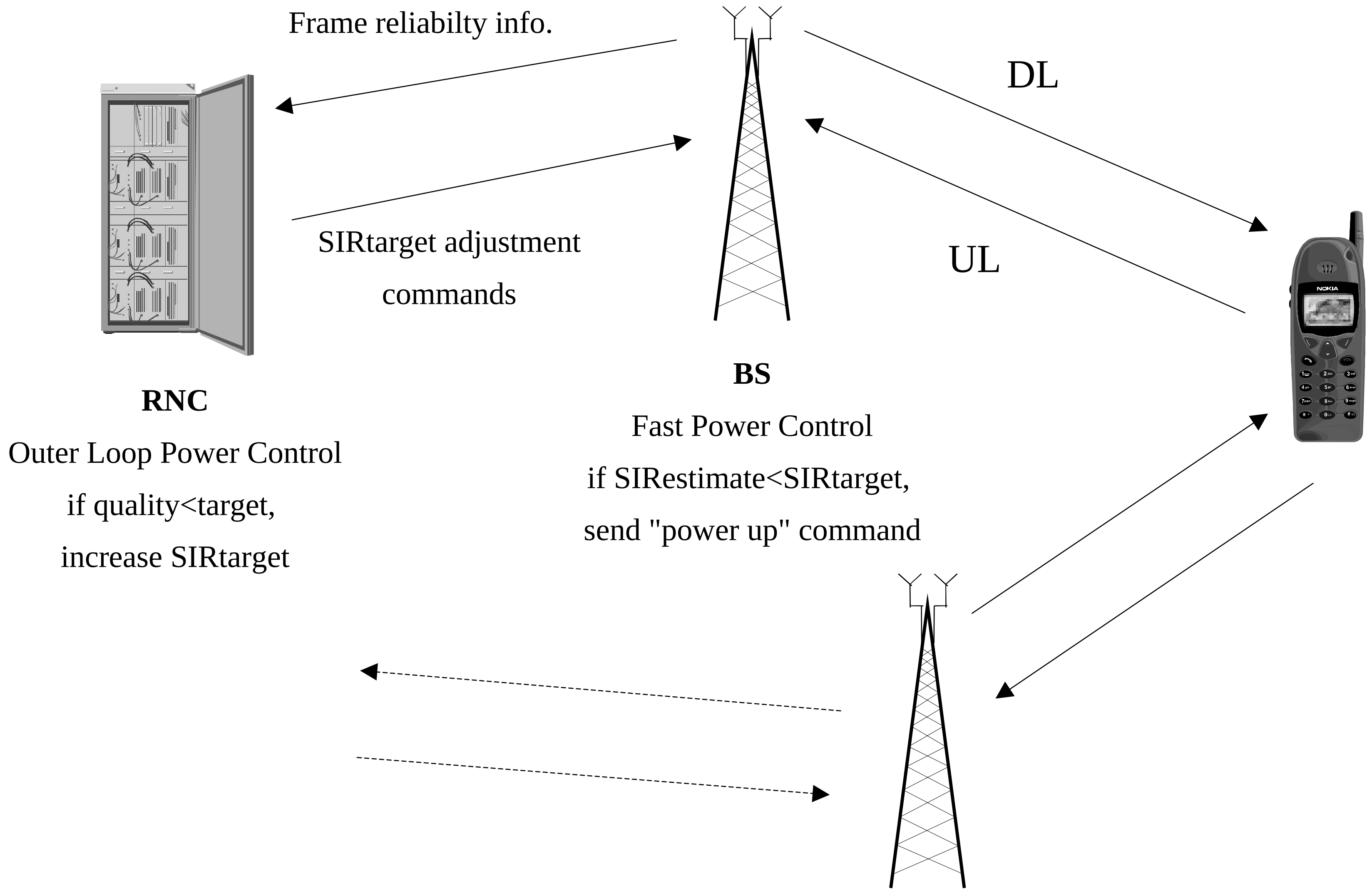
- Carries broadcast channel (BCH).
- Needs to be demodulated by all terminals within the cell.
- Fixed rate of 30 kbps with a spreading factor of 256.
- Contains no power control information.
- Primary CCPCH is time-multiplexed with SCH; thus, it does not use the first 256 chips. Channel bit rate is reduced to 27 kbps.

Secondary Common Control Physical Channel (Secondary CCPCH)

- Carries two transport channels: FACH and PCH, which can be mapped to the same or separate channels.
- Variable bit rate.
- Fixed spreading factor is used. Data rate may vary with DTX or rate matching parameters.
- Contains no power control information.

Physical Layer Procedures

Power Control Procedure



Power Control (PC) – (1/2)

- *Fast* Closed Loop PC – Inner Loop PC
  - Feedback information.
  - Uplink PC is used for near-far problem. Downlink PC is to ensure that there is enough power for mobiles at the cell edge.
  - One PC command per slot – 1500 Hz
  - Step 1 dB or 0.5 dB (1 PC command in every two slots).
  - The SIR target for fast closed loop PC is set by the outer loop PC.
  - Two special cases for fast closed loop PC:
    - Soft handover: how to react to multiple power control commands from several sources. At the mobile, a “power down” command has higher priority over “power up” command.
    - Compressed mode: Large step size is used after a compressed frame to allow the power level to converge more quickly to the correct value after the break.

Power Control (PC) – (2/2)

- Closed Loop PC - Outer Loop PC
  - Set the SIR target in order to maintain a certain frame error rate (FER). Operated at radio network controller (RNC).
- Open loop PC
  - No feedback information.
  - Make a rough estimate of the path loss by means of a downlink beacon signal.
  - Provide a coarse initial power setting of the mobile at the beginning of a connection.
  - Apply only prior to initiating the transmission on RACH or CPCH.

Transmit Diversity (BS) – (1/2)

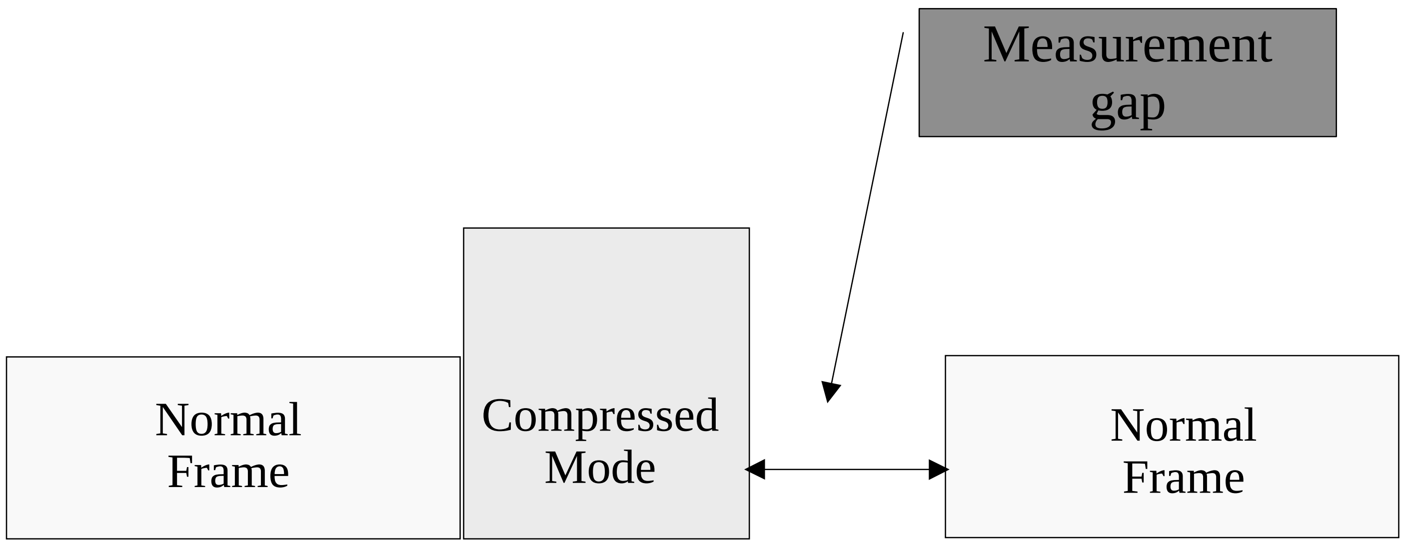
- Antenna diversity means that the same signal is transmitted or received via more than one antenna.
- It can create multipath diversity against fading and shadowing.
- Transmit diversity at the BS - open-loop and closed-loop.
- Open Loop Mode
  - No feedback information from the UE to the BS.
  - BS decides the appropriate parameters for the TX diversity.
  - Normally use for common channels because feedback information from a particular UE may not be good for others using the same common channel.
  - Uses space-time-block-coding-based transmit diversity (STTD).

Transmit Diversity (BS) – (2/2)

- Closed Loop Mode
  - Feedback information from the UE to the BS to optimize the transmission from the diversity antenna.
  - Normally use for dedicated channels because they have the feedback information bits (FBI).
  - Based on FBI, the BS can adjust the phase and/or amplitude of the antennas.

Compressed Mode (1/2)

- The compressed mode is needed when making measurement from another frequency.
- The transmission and reception are halted for a short time to perform measurements on the other frequencies.



Compressed Mode (2/2)

- Three methods for compressed mode:
  - Lowering the data rate from higher layers.
  - Increasing the data rate by changing the spreading factor.
  - Reducing the symbol rate by puncturing at the physical layer multiplexing chain.
- More power is needed during compressed mode.
- No power control during compressed mode. Large step size is used after a compressed frame to allow the power level to converge more quickly to the correct value after the break.

Handover

- Intra-mode handover
  - Include soft handover, softer handover and hard handover.
  - Rely on the Ec/No measurement performed from the CPICH.
- Inter-mode handover
  - Handover to the UTRA TDD mode.
- Inter-system handover
  - Handover to other system, such as GSM.
  - Make measurement on the frequency during compressed mode.