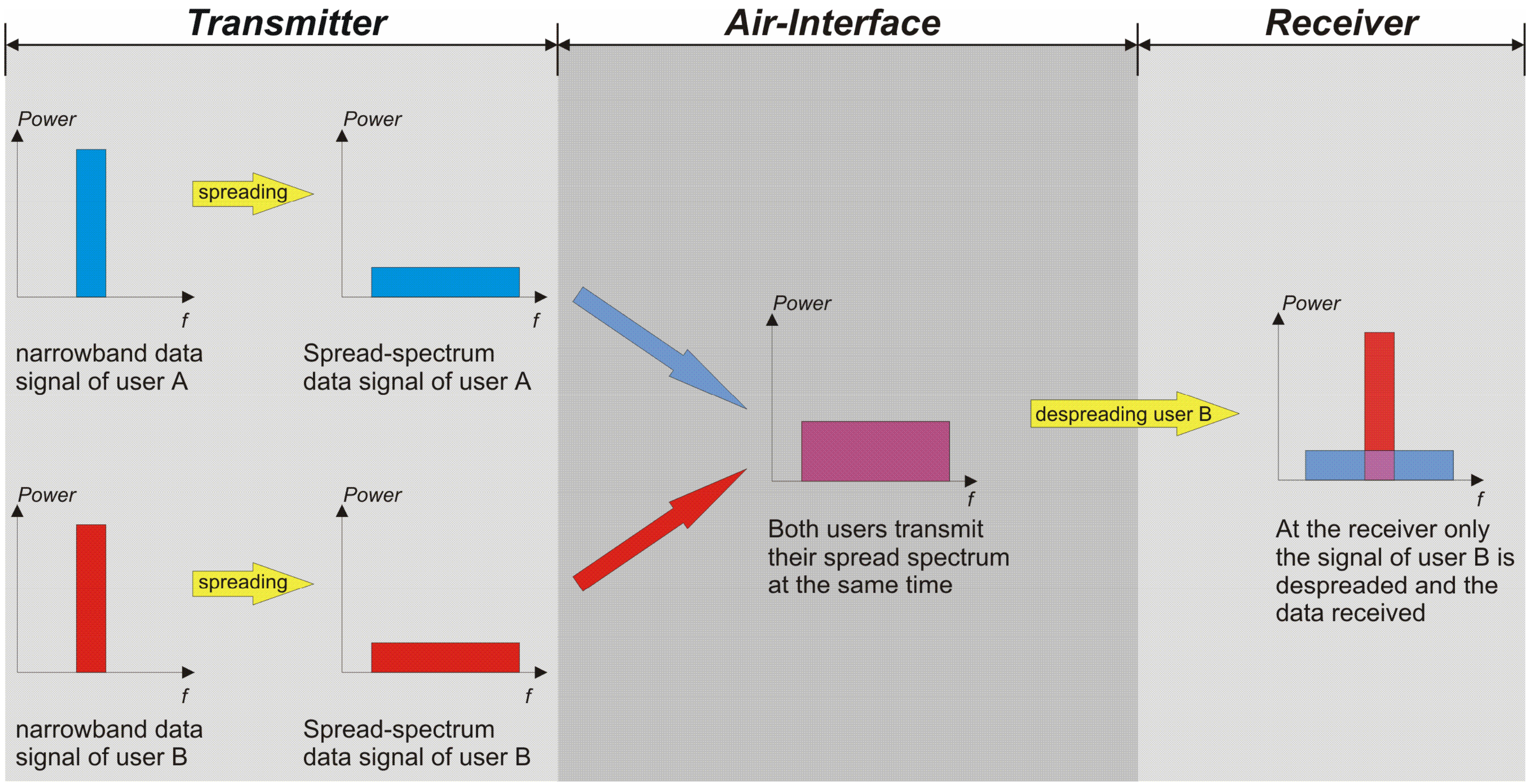
(1) Characteristics of Spread Spectrum Systems

- **Multiple access capability**

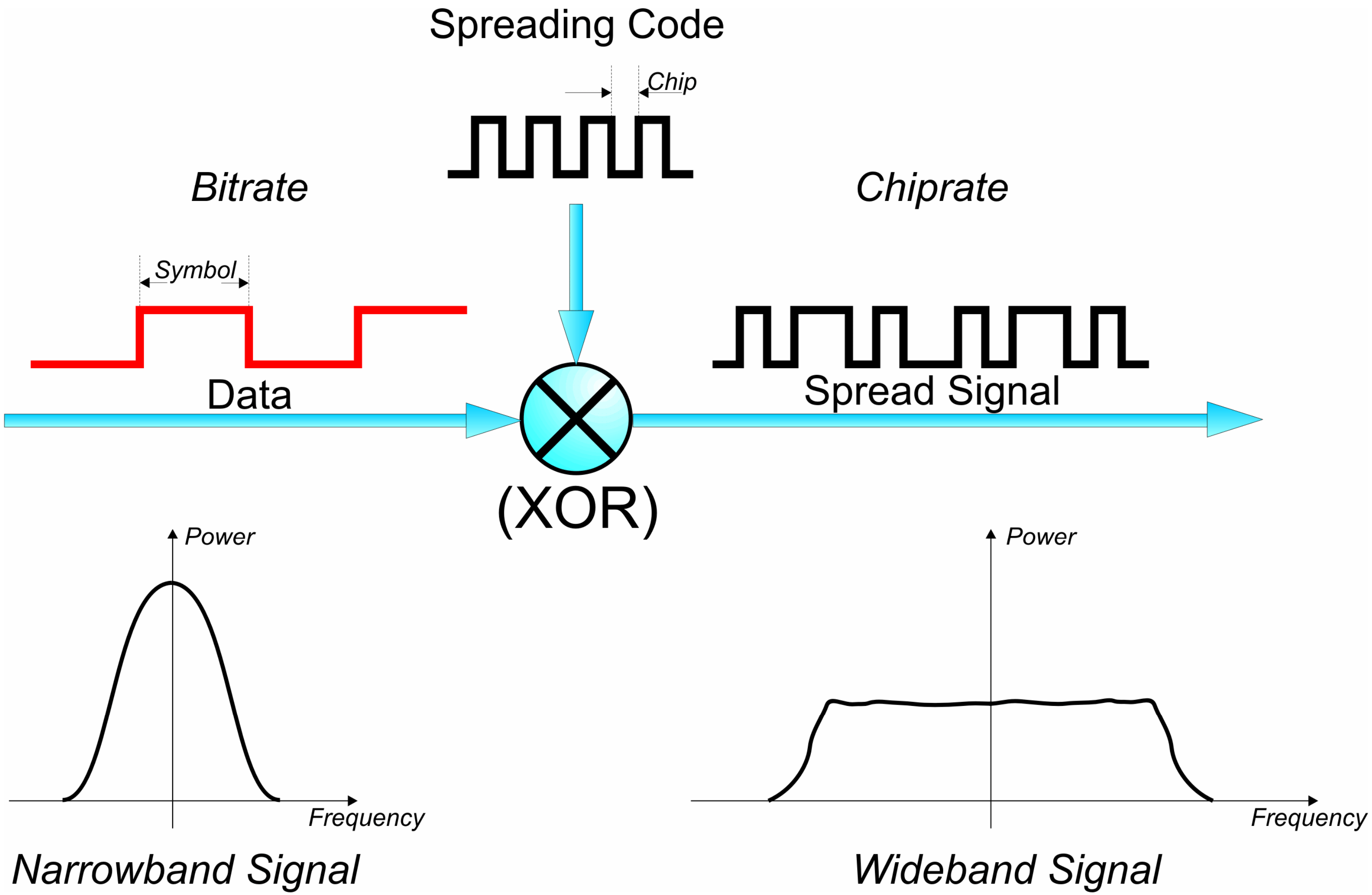


(1) Characteristics of Spread Spectrum Systems

Multiple access capability

- **Transmitter**
  The transmitter encodes the information with the assigned spreading code. Since the bandwidth of the spreading code is much larger than the bandwidth of the information signal, the bandwidth of the information signal is increased. This process also distributes the signal power over the entire bandwidth. Hence, the power per hertz (power spectral density) of the spread signal is much lower than the power spectral density of the narrow band signal.
- **Air Interface**
  The signals of multiple users are transmitted simultaneously over the air interface. At the input resistance of the receiving antenna all signals will be superimposed.
- **Receiver**
  At the receiver side, the sum of all transmitted signals is received. Each receiver knows the spreading code of the desired user (transmitter) and decodes the received sum signal with this code. The decoding process despreads only the signal of the desired user, the signals of the other users will be unchanged. Thus the power of this signal will be increased in relation to the other users signal.
  Hence, the common medium shared in a CDMA scheme is power. It is the spreading process that gives the CDMA scheme multiple access capability.

Direct Sequence Spread Spectrum (DS-SS)



Direct Sequence Spread Spectrum (DS-SS)

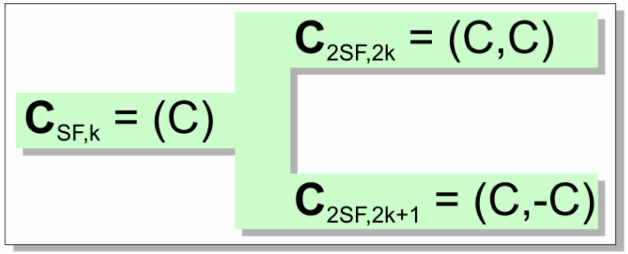
In a DS-SS, the narrowband data signal is multiplied (XOR) with a special code. These codes are orthogonal to each other and thus in an ideal environment they don't interfere with each other. In this way the orthogonality between codes (users) can be used to separate different users within one cell.
The code properties which are necessary for maintaining orthogonality between the users will be explained later.

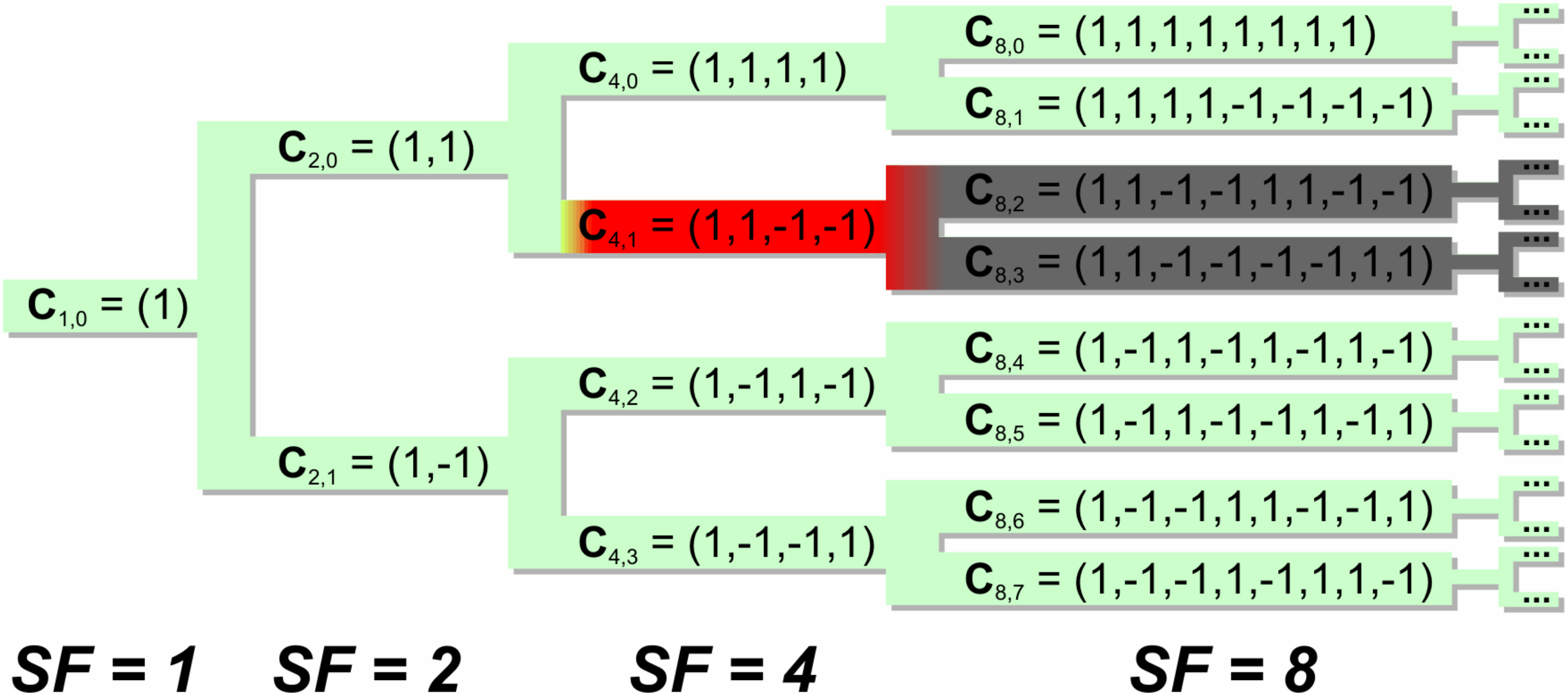
By multiplying the narrowband user signal with the (much) more frequent spreading code, the bandwidth transmitted on the air interface is "spread". For CDMA systems such spreading factors are in the range between less than 10 and up to 1000.

To differentiate the bits in the data signal from the bits in the spread signal, the bits in the data signal are called (Data-) **Symbols** and the bits in the spread signal are called **Chips**. (Be aware, the word symbol here has a different meaning than a modulation symbol).

As opposed to assigning a defined frequency channel as in FDMA systems or a defined timeslot as in TDMA systems, a defined code is assigned to each user in a CDMA system.

(1) Spreading Codes





(1) Spreading Codes

The spreading codes used for UTRA are taken from the *Walsh tree*. Codes taken from different branches of this tree are absolutely orthogonal, which means that in a ideal environment, they do not interfere with each other.
This can be checked by using the crosscorrelation function. If the correlation between two codes is zero (zero interference), these codes are called orthogonal.

Each code is uniquely described as $C_{SF,k}$, where SF is the spreading factor of the code and k is the code number (ranging from 0 to SF-1).
These codes are generated by using the *Hadamard matrix.* The generation of the codes is defined as:

$$C_{1,0} = 1$$

$$\begin{bmatrix} C_{2,0} \\ C_{2,1} \end{bmatrix} = \begin{bmatrix} C_{1,0} & C_{1,0} \\ C_{1,0} & -C_{1,0} \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

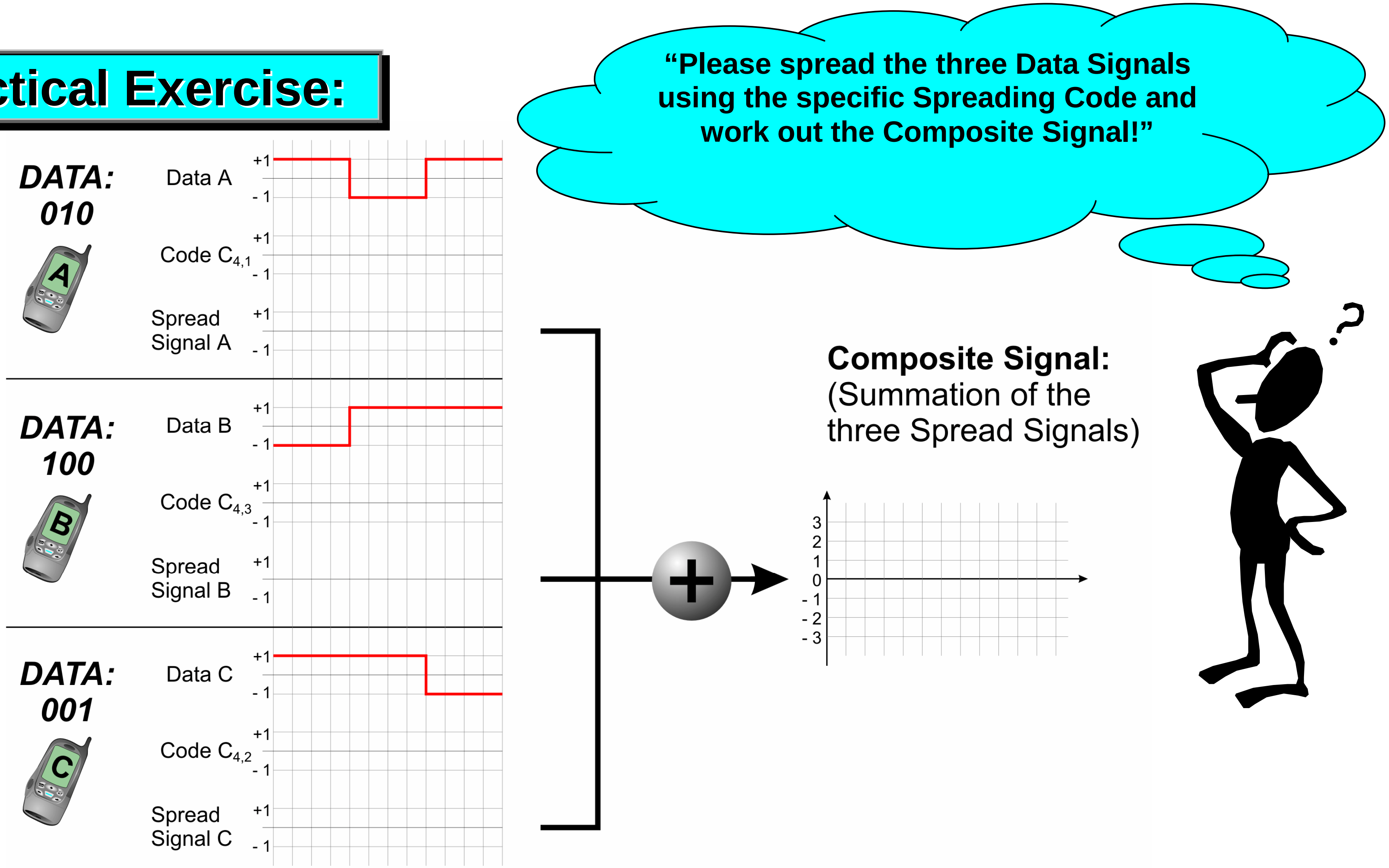
User data which are spread with e.g. code $C_{8,2}$ may also be de-spread using code $C_{4,1}$ since code $C_{8,2}$ is nothing more than two times code $C_{4,1}$. (N.B. code $C_{16,4}$ is also nothing else than four times $C_{4,1}$, and hence, data spread using code $C_{16,4}$ can also be despread using code $C_{4,1}$). Therefore, these codes are also called Orthogonal Variable Spreading Factor (OVSF) codes.

However, if one user is assigned code $C_{8,2}$, no other codes from its branch may be used (i.e. $C_{16,4}$, $C_{16,5}$, $C_{32,8}$, …). These subtree codes would not be orthogonal with the parent code $C_{8,2}$. Since code $C_{16,4}$ is nothing more than two times code $C_{8,2}$, these two codes correlate perfectly and the user signal could not be recovered at all. In addition, the code $C_{4,1}$ may not be used since it would (at least partially) interfere with all code of this branch with higher spreading factors ($C_{8,2}$ and $C_{8,3}$; $C_{16,4}$ until $C_{16,7}$; etc.)

For UTRAN FDD the minimum permitted spreading factor is SF 4. This means that each data symbol is represented by 4 chips. As illustrated, only 4 codes with SF=4 may be assigned. Then, no other orthogonal codes are available, although with 4 chips in total 16 codewords could be constructed!
This means that only four users can be assigned with spreading factor 4, which allows the highest data rate. In this case, no codes are left for all other users.

[TS 25.213 (FDD) / TS 25.223 (TDD)]

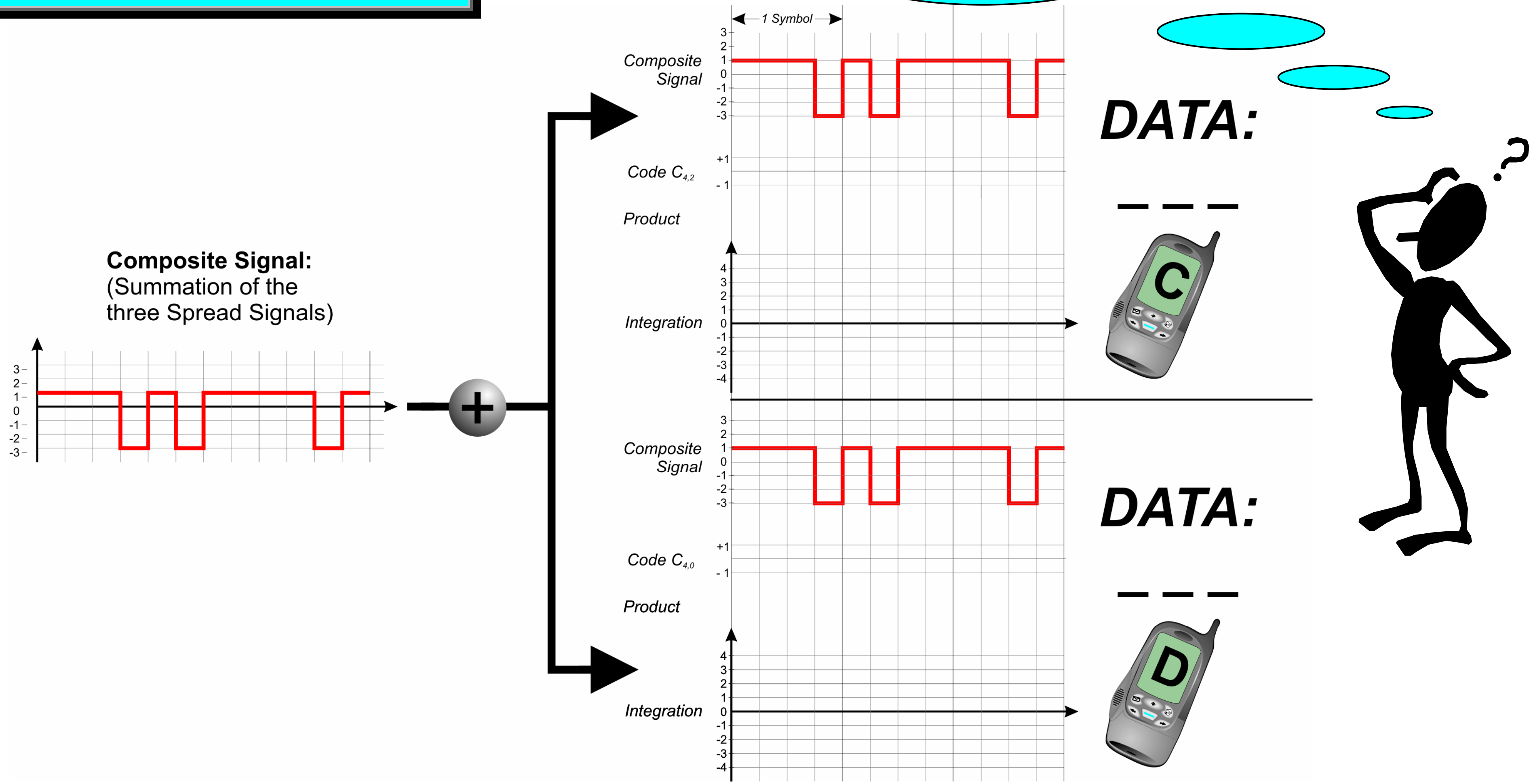
Practical Exercise:



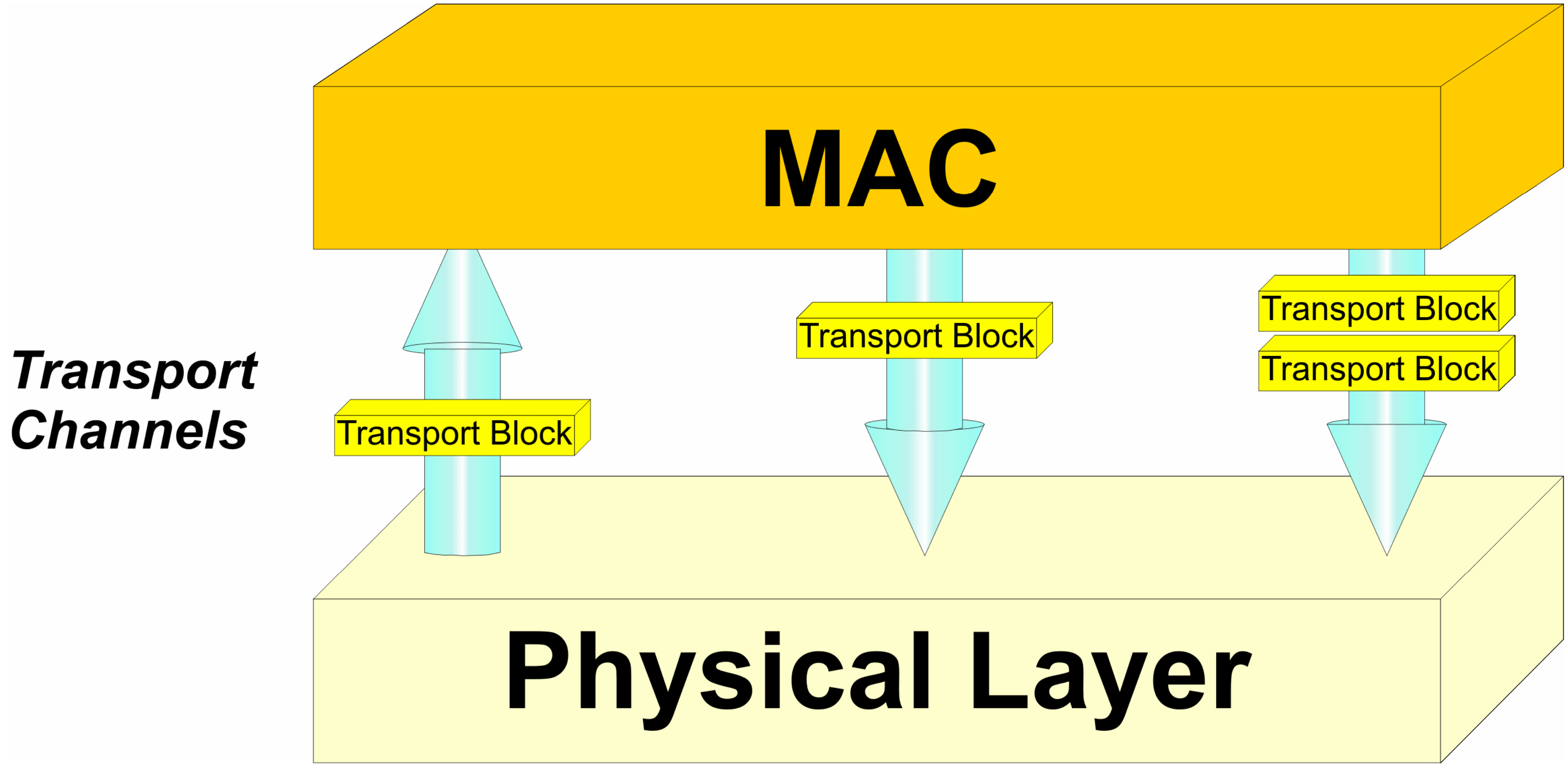
Practical Exercise:

"Please recover the original Data transmitted for User C back from the Composite Signal and check what an intruder, using code $C_{4,0}$, would receive!"

Composite Signal: (Summation of the three Spread Signals)



(1) Data Transfer on Transport Channels



(1) Data Transfer on Transport Channels

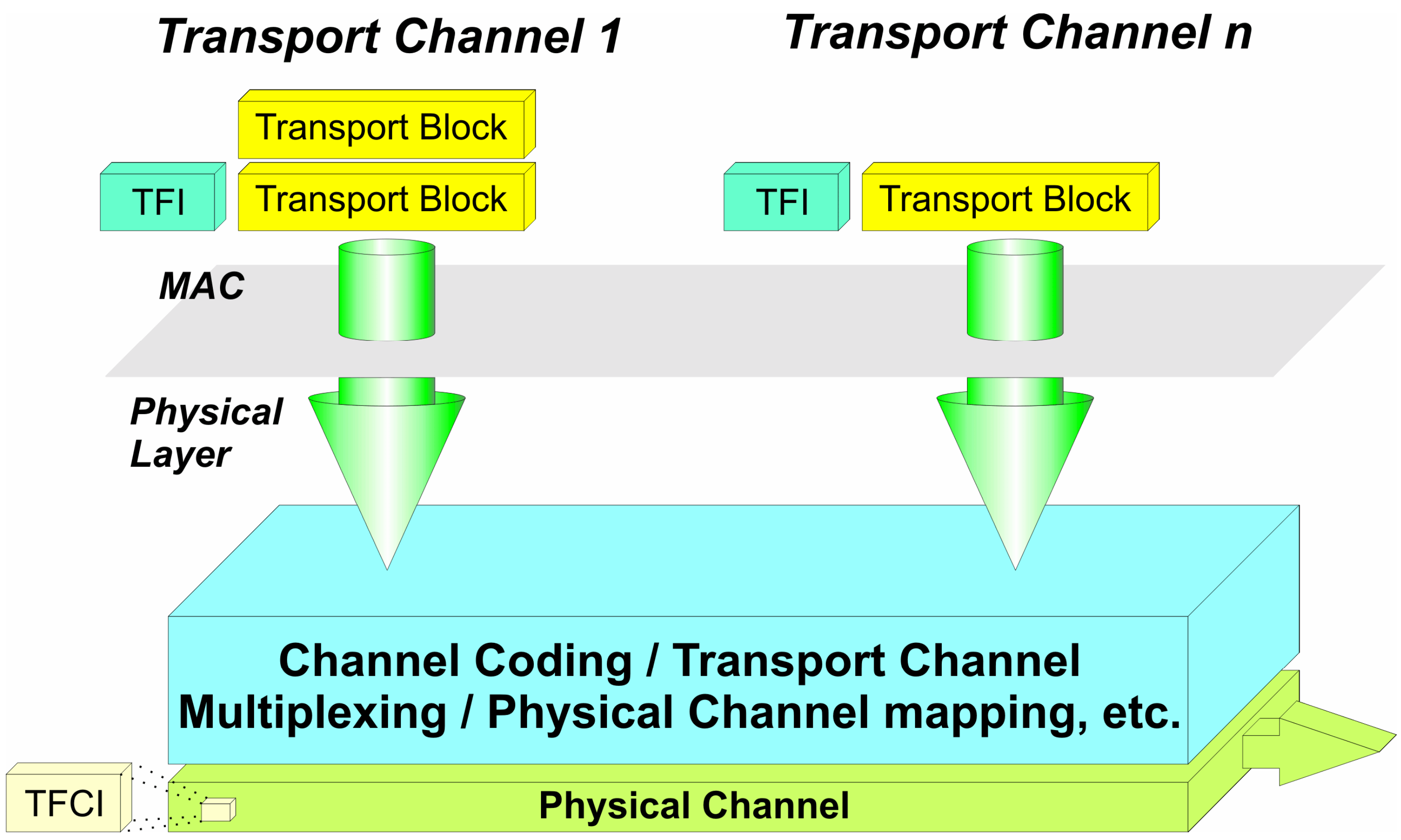
Transport Channels are unidirectional resources.

MAC is responsible for the mapping of data to the physical layer via Transport Channels.

The data transfer on Transport Channels is performed via Transport Blocks.
The Physical Layer operates in 10 ms time slices (radio frames), which are filled up with the data received by MAC for processing and transmitting. Therefore MAC generates (a) new transport block(s) every 10 ms (or a multiple of that) and sends it to the Physical Layer.

In order to support variable bit rate connections it is also possible to transmit several transport blocks via the same Transport Channel within the same frame (10ms or a multiple of 10 ms).

Transport Channel Processing Chain



TFCI: Transport Format Combination Indicator

Transport Channel Processing Chain

If several Transport Channels are active simultaneously in a given connection (e.g. one or several dedicated traffic channels and one dedicated control channel), these channels are multiplexed together by layer 1. After multiplexing, the various Transport Channels are mapped to Physical Channels.

Since each of the Transport Channels may carry a different service (e.g. speech and web browsing), multiplexing of Transport Channels is also denoted as Service Multiplexing.

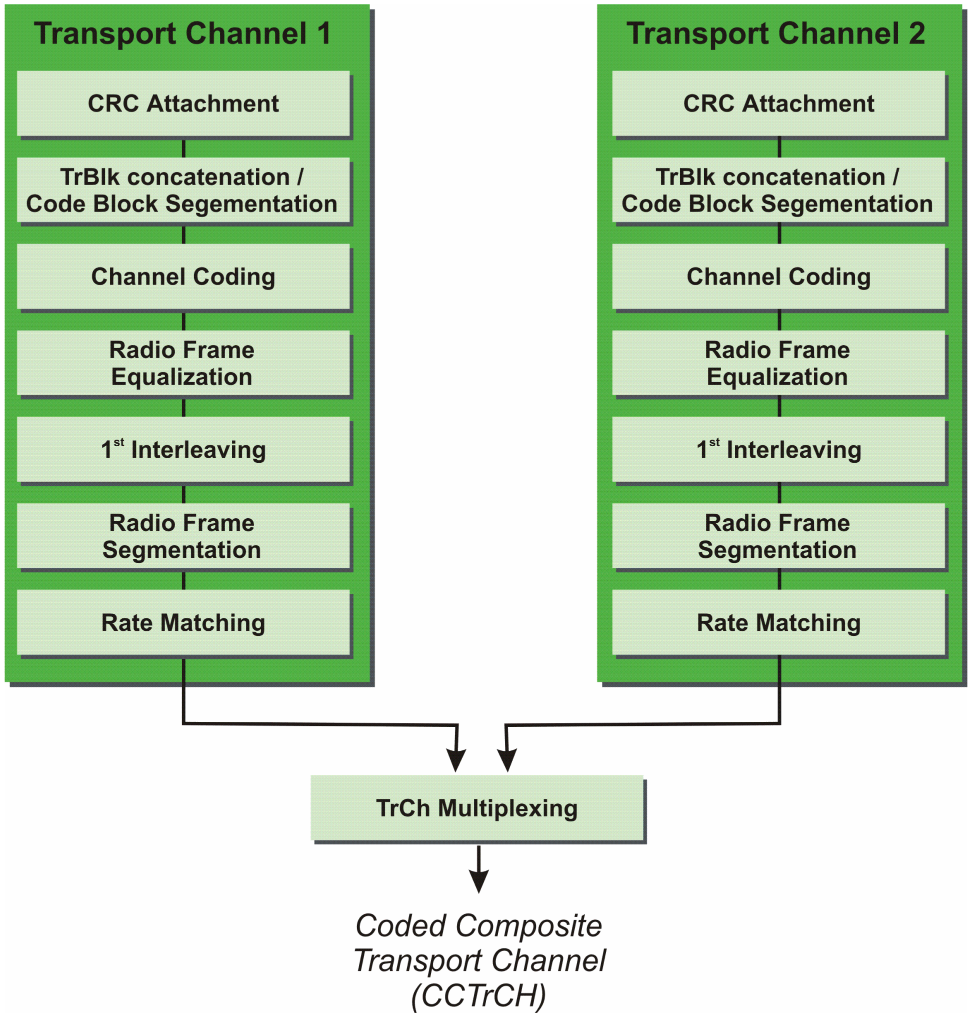
For each transport channel one or more Transport Format Indicators (TFI) are defined. All combinations of the TFIs of all transport channels to be multiplexed form the Transport Format Combination Set (TFCS). The actually selected combination within a Transmission Time Interval (TTI) is referred to as the Transport Format Combination Indicator (TFCI).

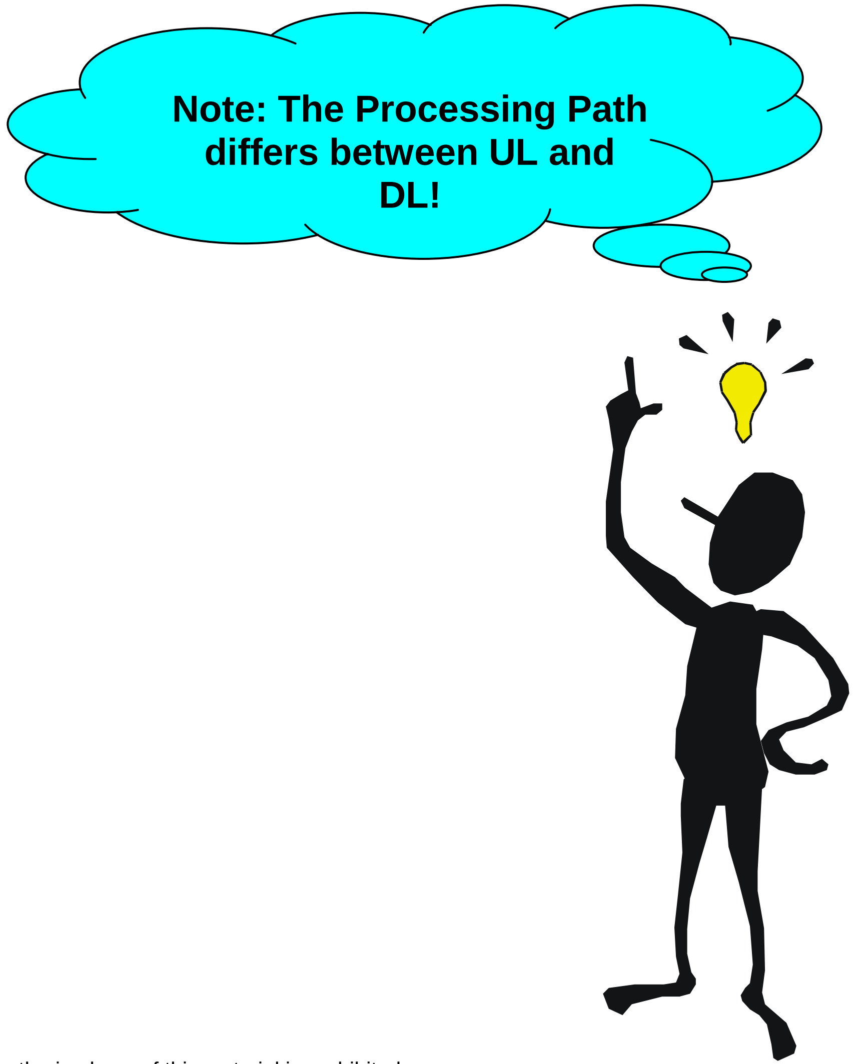
To indicate which Transport Formats are transmitted within the Physical Channel, each Physical Channel includes the TFCI. The TFCI describes the actual used combination of transport formats per radio frame.

The TFCS includes all possible combinations of Transport Formats from Transport Channels to be multiplexed.

The TFCI indicates which Transport Formats are active within this Physical Channel.

Uplink Data Processing Path





Uplink Data Processing Path

CRC Attachment

For each arriving Transport Block a CRC is calculated and added. The use of CRC bits enables error detection at the receiving entity.

Transport Block Concatenation / Code Block Segmentation

After the CRC attachment all Transport Blocks in a TTI are concatenated serially. If the number of bits after concatenation is larger the maximum number of bits of a code block allowed for the channel coding scheme, code block segmentation is carried out. Therefore, the concatenated transport blocks are segmented into equally sized code blocks.

Channel Coding

After CRC Attachment and Transport Block Concatenation / Code Block Segmentation, the Channel Coding is performed.

Radio Frame Equalization

Radio Frame Equalization ensures that the channel coded data string can be segmented into N data segments which all have the same size (N = TTI / 10ms). Therefore the input bit sequence is padded with the necessary number of bits (in UL only).

1st Interleaving

1st Interleaving is executed over the length of the TTI if the TTI is longer than 10ms. Interleaving is used in order to randomize transmission errors on the air interface.

Radio Frame Segmentation

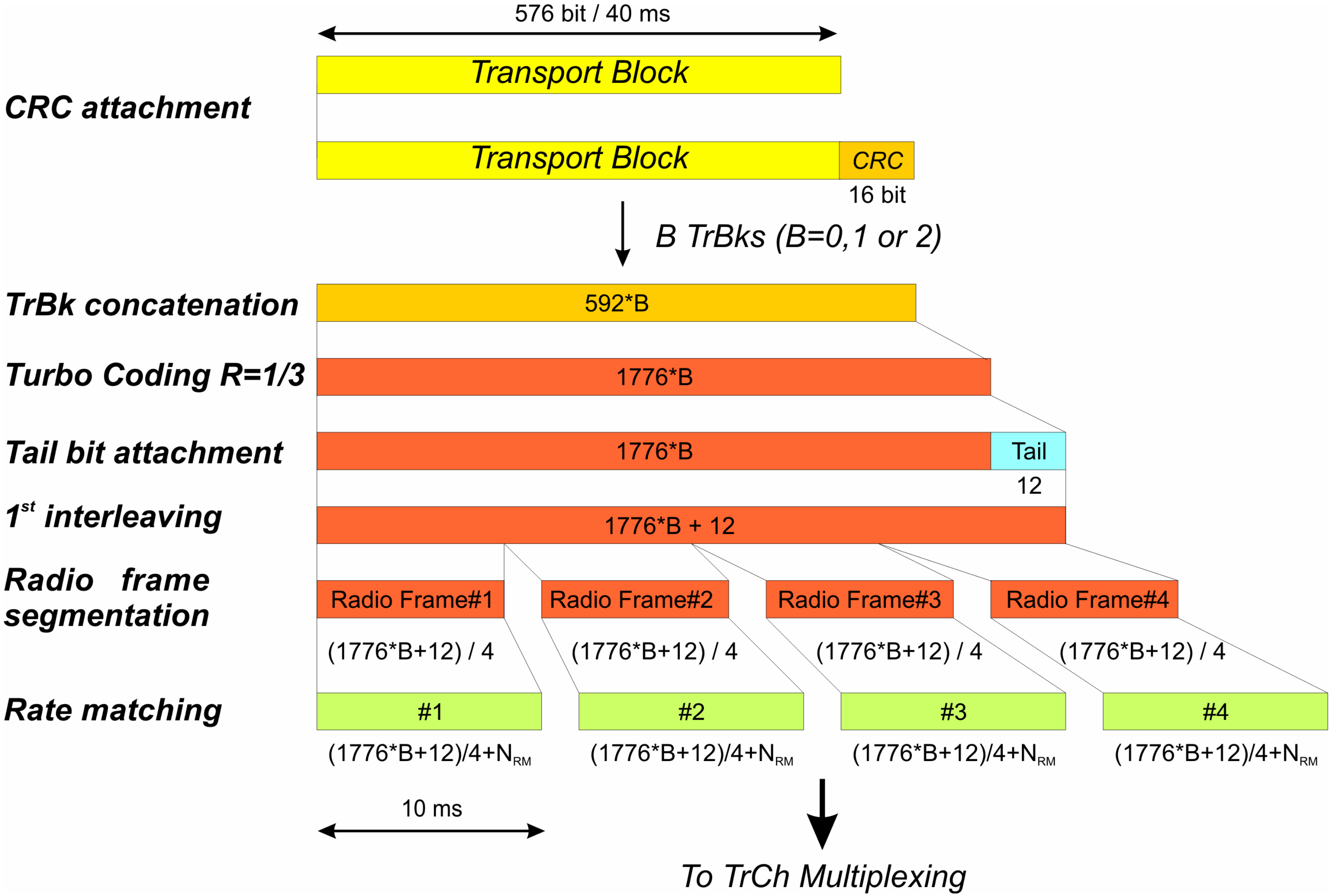
After 1st Interleaving, the data is segmented into N 10 ms segments (N = TTI / 10ms). Since Radio Frame Equalization has been performed, the sequence length of the input bit is guaranteed to be an integer multiple of N.

Rate Matching

Rate Matching means that bits on a Transport Channel are repeated or punctured. The Rate Matching Process ensures that the total amount of data after Transport Channel Multiplexing is identical to the required amount of data per radio frame (before spreading).

[3GTS 25.212]

Data Processing Path for 28.8 kbps bearer



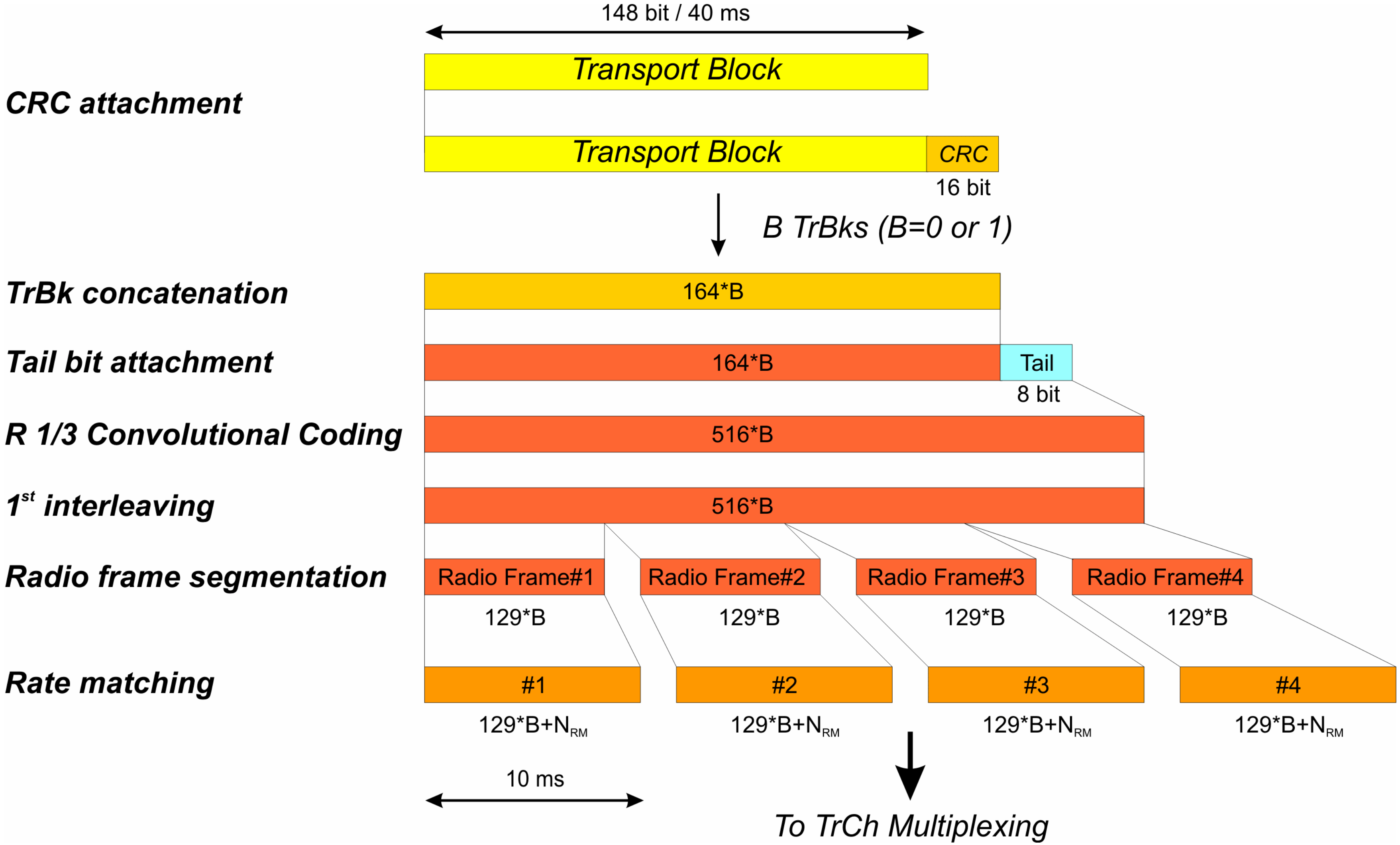
Data Processing Path for 28.8 kbps bearer

Example of the processing steps for a 28.8 kbps Radio Bearer.

[3GTS 25.944]

Transport Channel Parameters:		***Transport Channel 28.8 kbps***
TrCH type		DCH
TB sizes, bit		576
TFS	TF0, bits	0x576
	TF1, bits	1x576
	TF2, bits	2x576
TTI, ms		40
Coding type		TC
CRC, bit		16
Max number of bits/TTI after channel coding		3564
Uplink: Max number of bits/radio frame before rate matching		891
RM attribute		160-200

Data Processing Path for 3.4 kbps signaling bearer



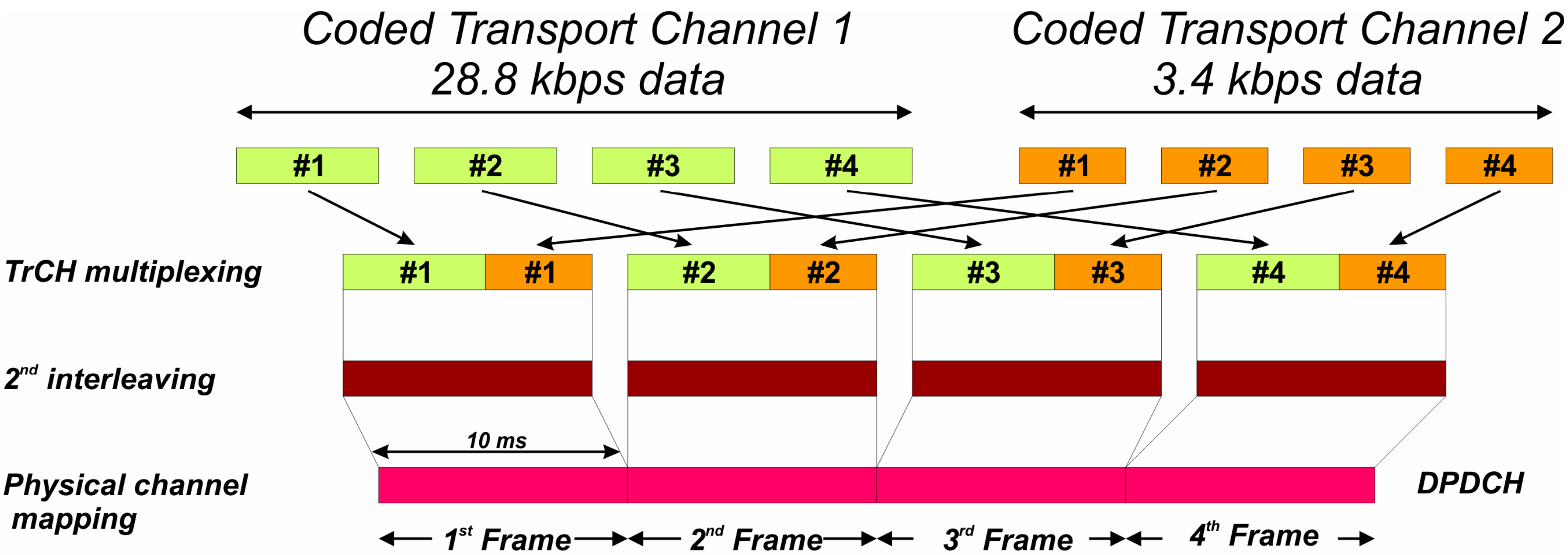
Data Processing Path for 3.4 kbps signaling bearer

Example of the processing steps for a 3.4 kbps Signaling Radio Bearer.

[3GTS 25.944]

Transport Channel Parameters:		***Transport Channel 3.4 kbps***
TrCH type		DCH
TB sizes, bit		148
TFS	TF0, bits	0x148
	TF1, bits	1x148
	TF2, bits	N/A
TTI, ms		40
Coding type		CC 1/3
CRC, bit		16
Max number of bits/TTI after channel coding		516
Uplink: Max number of bits/radio frame before rate matching		129
RM attribute		155-185

Transport Channel Multiplexing

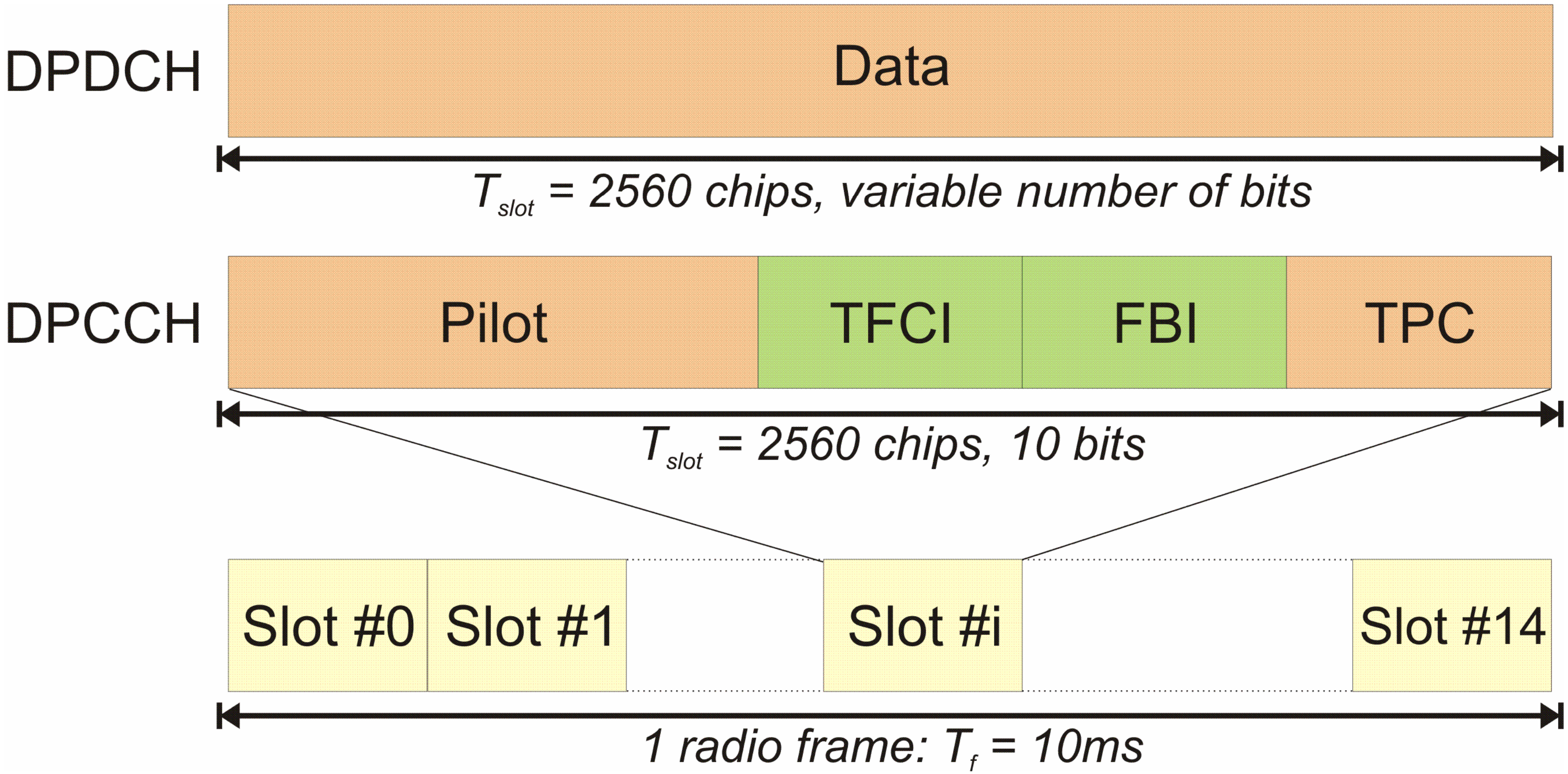


Transport Channel Multiplexing

After both the Channel Coding and the Rate Matching process, the coded Transport Channels are multiplexed together to a single Coded Composite Transport Channel (CCTrCh).

Since the Rate Matching process ensures that the bit rate of the CCTrCh is identical to the total bit rate of the Physical Channel, the bit sequence can be mapped exactly onto the Physical Channel.

Frame Structure of UL DPDCH / DPCCH



Frame Structure of UL DPDCH / DPCCH

DPDCH

The DPDCH carries the DCH. The number of bits that can be mapped on the DPDCH is variable and depends on the SF. The rate matching process matches the number of bits in one frame to fit one DPDCH exactly.

The bit rate of the DPDCH is variable and may change every 10 ms (1 radio frame). The SF ranges from 256 down to 4.

DPCCH

The DPCCH is required for system operation and for indicating the bit rate of the DPDCH. It carries all the information, which is relevant to the physical layer.

⇒ Pilot

The pilot bits are a defined bit pattern. They are used by the NodeB to estimate the channel conditions and to calculate the Signal to Interference Ratio (SIR) for the power commands.

⇒ TFCI

The Transport Format Combination Identifier informs the NodeB about the Transport Formats, which are active within the simultaneously transmitted DPDCH

⇒ FBI

The Feedback Information bits are used to support transmission techniques requiring feedback from the UE to the UTRAN (e.g. SSDT).

⇒ TPC

The Transmit Power Control field carries the power commands for the downlink fast closed-loop power control (1500 Hz).

The SF for the DPCCH is always 256, i.e. there are always 10 bits per uplink DPCCH slot ⇨ data rate of 15 kbps.

The DPDCH and the DPCCH are transmitted simultaneously in a code division manner.

[3GTS 25.211]

Data rates on Uplink DPDCH

Mind: The number of bits on the DPDCH depends on the Spreading Factor!

$$Bitrate = \frac{Chiprate}{SF} = \frac{3.84Mcps}{SF}$$

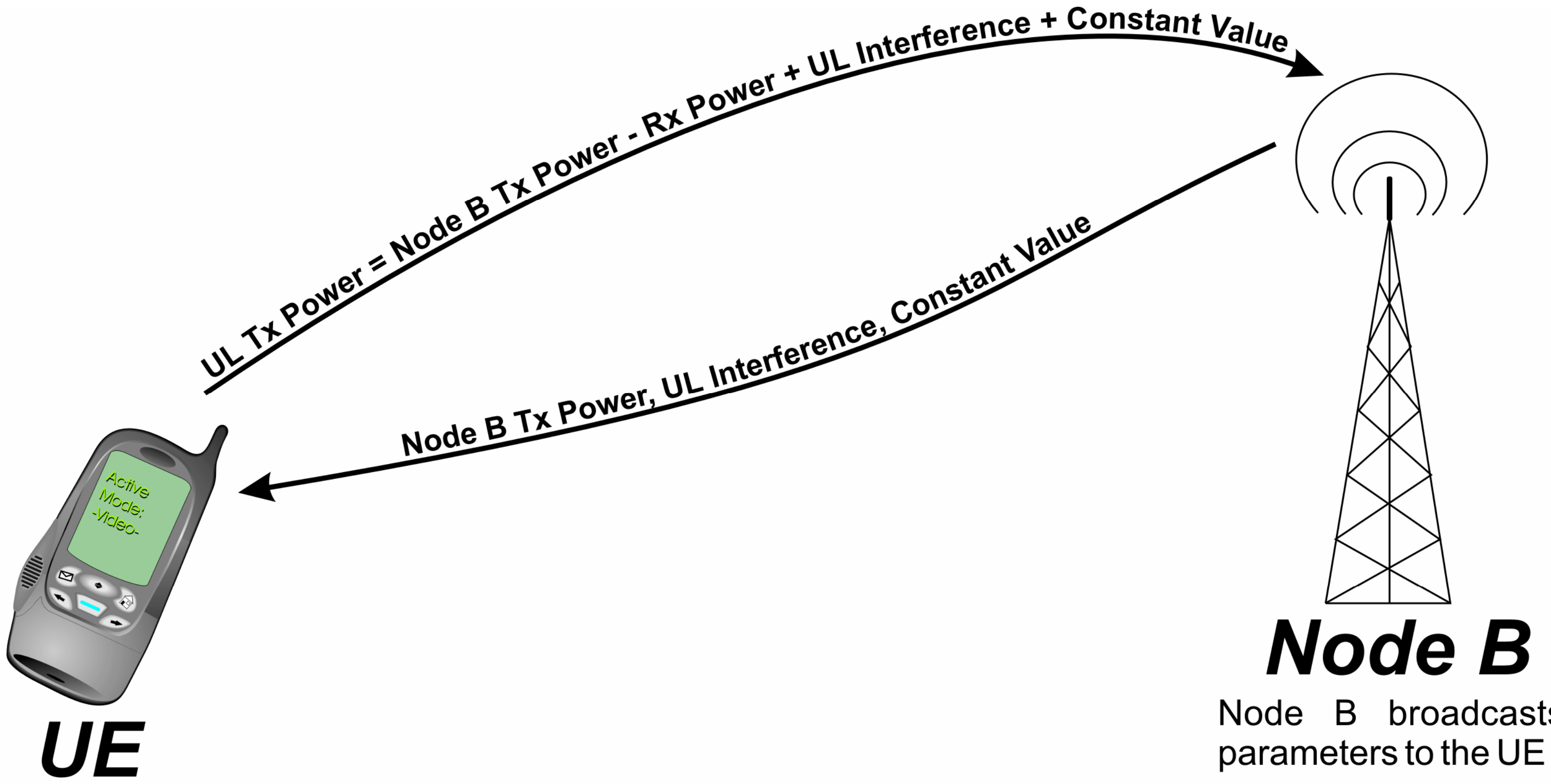
Channel Bit Rate (kbps)	Spreading Factor	Bits per Frame (10ms)	Bits per Slot (0.6667ms)
15	256	150	10
30	128	300	20
60	64	600	40
120	32	1200	80
240	16	2400	160
480	8	4800	320
960	4	9600	640

Data rates on Uplink DPDCH

The data rate on the DPDCH is variable. The SF ranges from 256 down to 4.

[3GTS 25.211]

Open Loop Power Control



UE calculates adequate Tx power using received parameters and measured Rx power

Node B broadcasts parameters to the UE

Open Loop Power Control

For Open Loop Power Control, the output power (TX power) of the UE is dependent on the received (RX) power.
The NodeB transmits the parameters which are needed by the UE to calculate the adequate output power via the system information. The lower the RX power, the higher the TX power of the UE.

⇒ For open loop power control, the output power of the UE is solely based on the received power from the NodeB.

The problem is that the interference level is frequency selective. If, for example, only the downlink frequency has interference, the output power of the UE would be higher than needed resulting in unnecessarily high interference on the air interface.

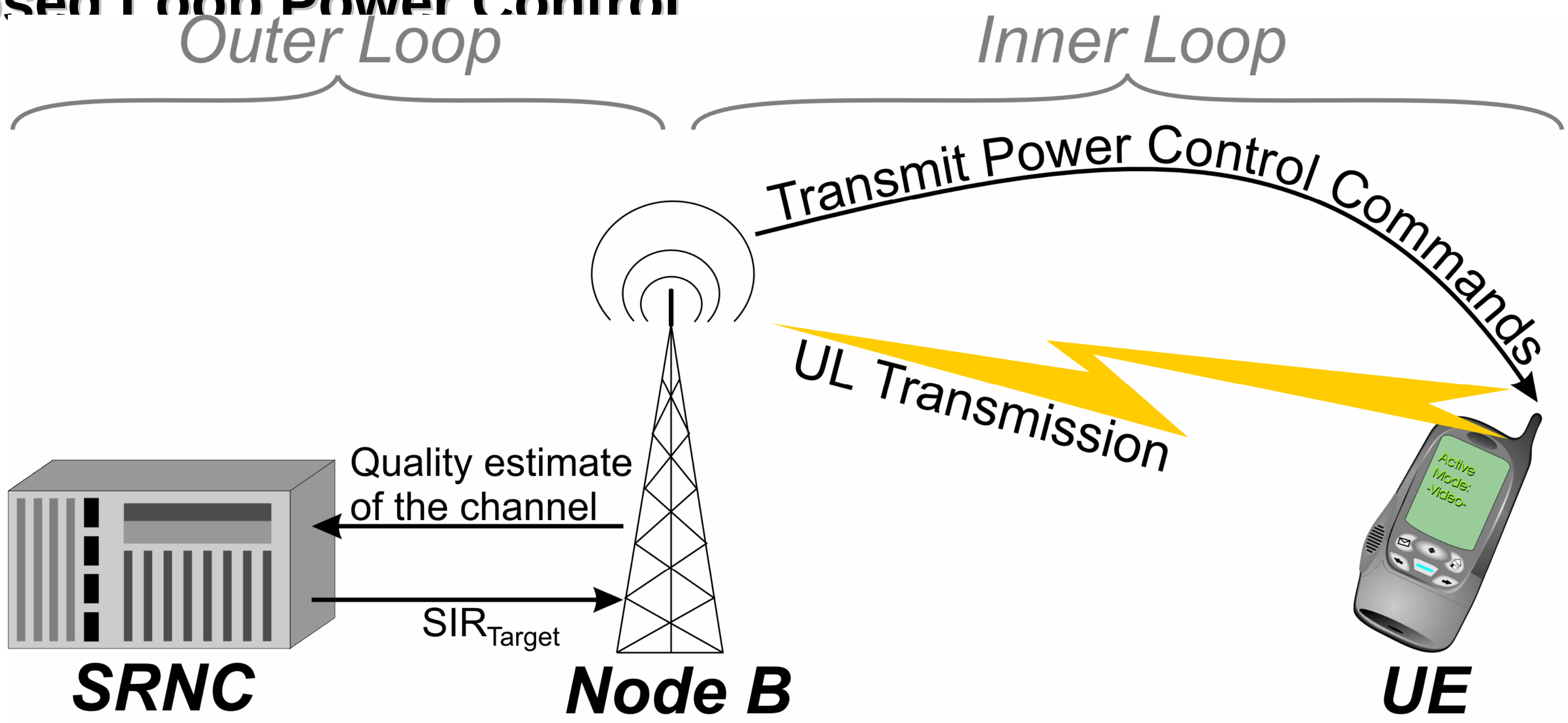
⇒ Since the TX and RX signals in FDD use different frequencies (190 MHz shift), this method gives the right output power only on average.

The advantage of the Open Loop Power Control is that no feedback channel is required.

⇒ This method is used if no feedback channel is available, i.e. initial network access.

[3GPP TS 25.214 (5), 25.101 (6.4)]

Closed Loop Power Control



SRNC compares the estimated level with the repaired quality level and sets SIR_{Target} for Inner Loop Power Control accordingly.

Node B estimates SIR and transmits TPC commands to achieve $SIR_{EST} = SIR_{Target}$

UE increases / decreases transmit power according to the TPC commands

Closed Loop Power Control

In contrast to open loop power control, closed loop power control is based on measurements performed by the receiving entity. Closed loop power control is used both in the uplink and in the downlink.
Closed loop power control is based on two measurements:

Outer Loop Power Control

The outer loop power control is located in the SRNC (UL) and in the UE (DL).
In the UL, the SRNC sets the SIR target for the UL inner loop power control which is located in the NodeB according to the target channel quality value.
The DL outer loop power control works in a similar way except that the UE estimates the DL channel quality. However, the DL channel quality target is also set by the SRNC.
The Outer Loop Power Control sets the SIR target for the Inner Loop Power Control according to the desired channel quality. The outer loop power control is more quality control of the radio channel than power control.

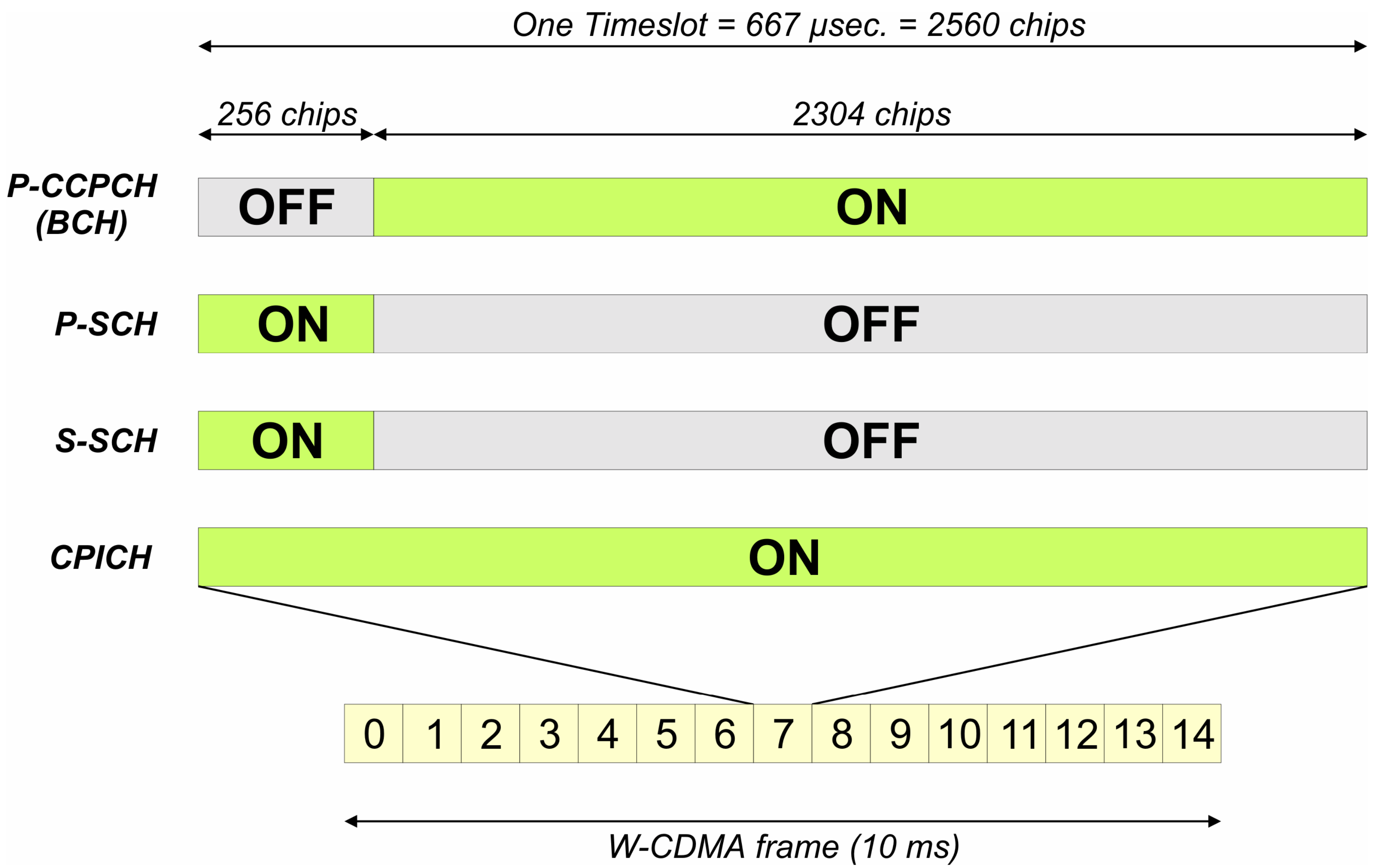
Typically, the outer loop power control is updated 10 – 100 times per second (10 – 100 Hz).

Inner Loop Power Control

The inner loop measures the SIR (Signal to Interference Ratio) on the air interface. The SIR target is determined by the Outer Loop Power Control.
The receiving entity sends a Transmit Power Control (TPC) command to the transmitting entity to either increase or decrease the transmission power.
The Inner Loop Power Control is based on the SIR received. Since the receiving entity controls the output power of the transmitting entity, one speaks about closed loop power control.

The Inner Loop Power Control is also referred to as fast-closed loop power control since the transmission power is updated each 0,667 ms (1500 Hz).

(1) Cell Search Procedure



(1) Cell Search Procedure

CPICH

The CPICH is a continuous loop broadcast of the NodeB scrambling code. Since no additional spreading is applied to this signal, it is quite easy for the UE to acquire a lock to this reference. The total number of different scrambling codes in downlink direction is limited to 512 organized in 64 code groups with 8 codes each.

P-SCH

The P-SCH is an important channel used by the UE for cell search. It is time multiplexed with the P-CCPCH. The P-SCH transmits the primary synchronization code (PSC), which is common to all cells and is known by the UE.

S-SCH

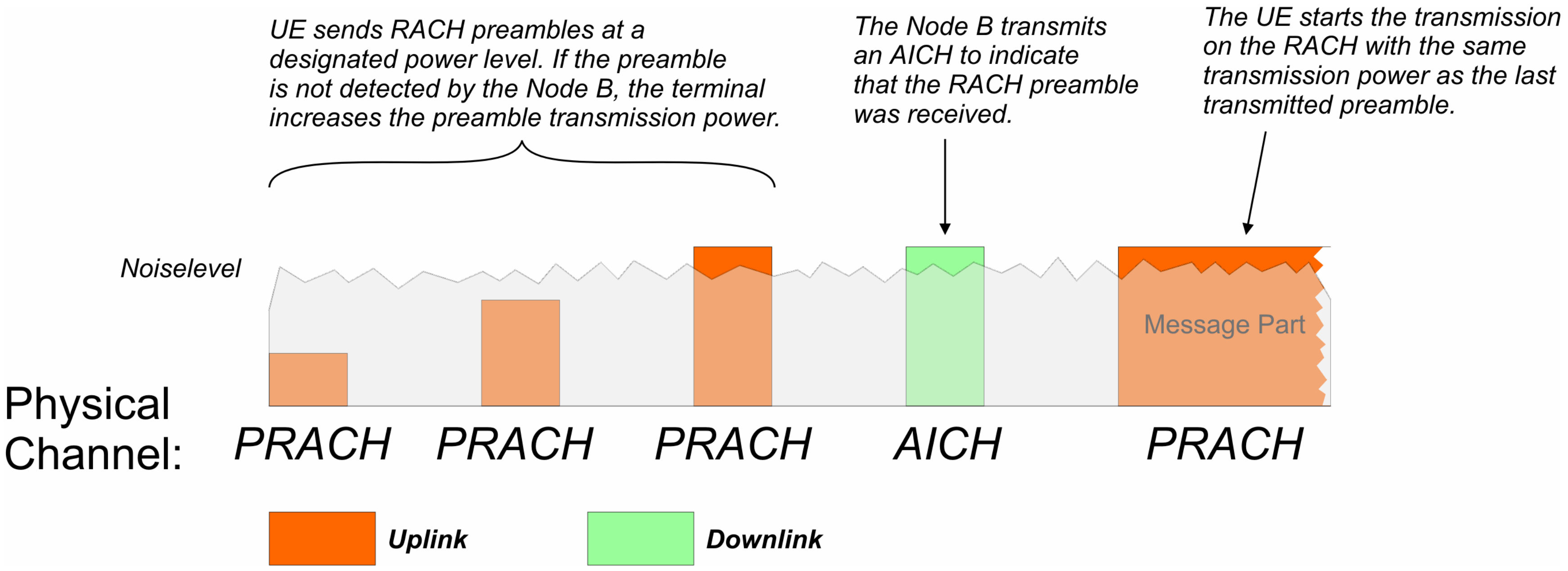
The S-SCH transmits the SSC (Secondary Synchronization Code). It is transmitted simultaneously with the P-SCH and is also time multiplexed with the P-CCPCH.

P-CCPCH

The P-CCPCH carries the BCH and is off while the P-SCH and S-SCH are transmitted.

(1) Physical Layer Procedures

- **RACH Access Procedure**



(1) Physical Layer Procedures

RACH Procedure Access

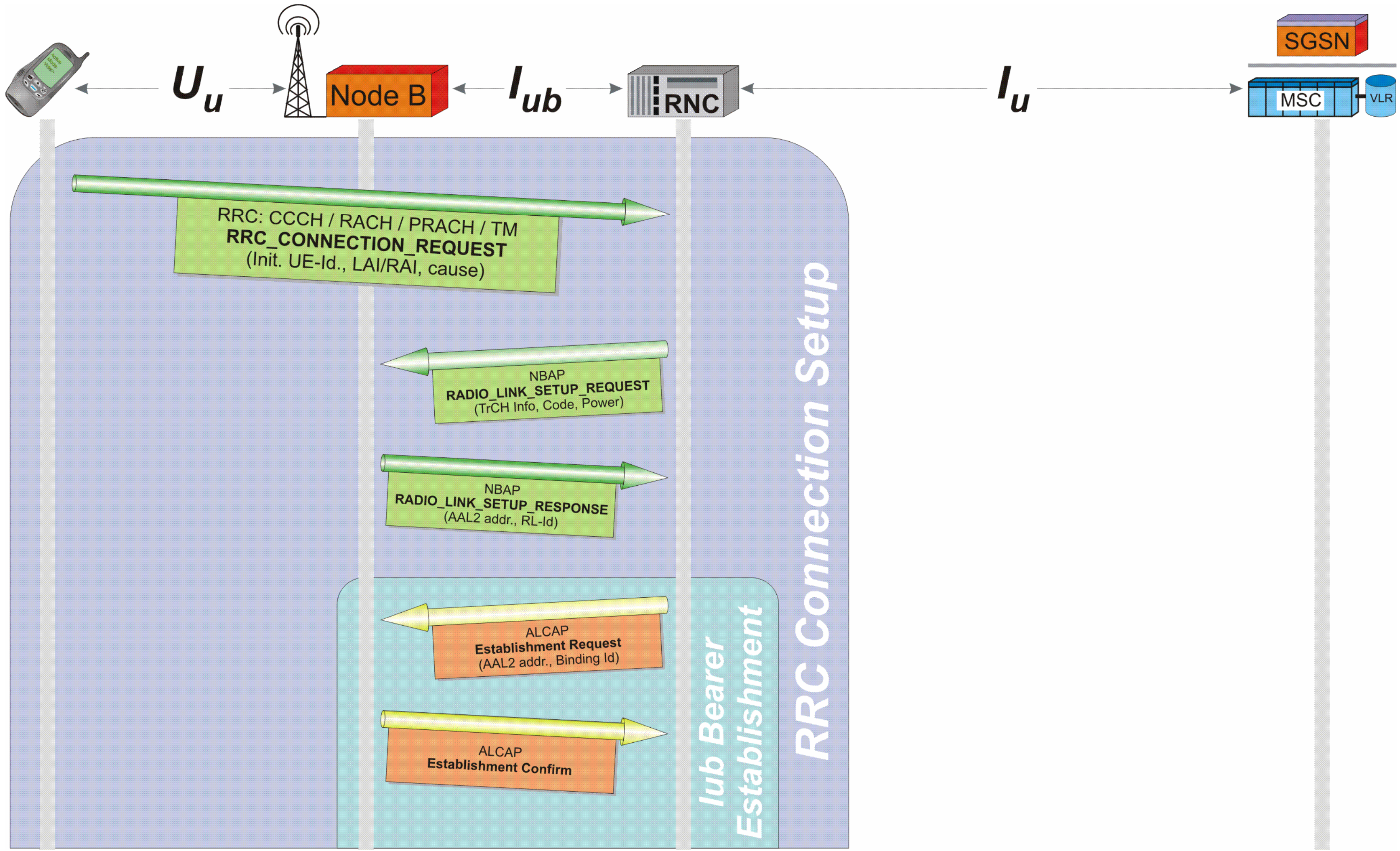
The random access procedure in a CDMA system has to cope with the near-far problem since there is no exact knowledge of the required transmission power. The initial power is estimated by the open loop power control.
The UE sends the RACH preamble at the initial power level. If the terminal receives no AICH, the UE sends the next access preamble with increased output power.

When the AICH is detected, RACH transmission starts.

The RACH transmission can last either 10 ms or 20 ms.

[3GPP TS 25.211, 25.133 (6.3), 25.303 (6.7.2)]

(1) Mobile Originated Call Establishment



(1) Mobile Originated Call Establishment

RRC Connection Setup

It is assumed the UE is in idle state, it is attached to the network but no radio connection exists.

Initiated by an UE internal primitive for service request which could be a request for a call setup or a location update the UE will start with a *RRC connection request* message. This message will be transferred using the RACH transport channel and relayed in the node B on the Iub RACH port.
Based on the cause for this request the RNC decides to allocate a dedicated or a common transport channel for this transaction over the air interface and allocates the resources. The cause already includes first information about the request itself (registration, MOC or MTC, QoS class (conversational, streaming, interactive or background), emergency call, signaling transfer, etc.).

[3GPP TR 25.931 (7.3)]

Iub Bearer Establishment

An Iub bearer will be set up to provide the connection between the node B and the RNC. Therefore the node B is informed about the transport channel and physical parameters (*radio link setup request*) and will reserve and configure the requested resources. It is assumed the RNC will setup a dedicated channel on the air interface and the received transport blocks will then be relayed over the Iub bearer to the RNC.
After configuration, the node B will start reception to obtain uplink synchronization. The resource reservation is confirmed together with returning the node B transport layer address in the *radio link setup response* message. Next, the RNC will establish the Iub bearer using the ALCAP protocol in the transport network control plane.

[3GPP TR 25.931 (4.6), 25.303]

Note: For each message the first line shows the initiating layer and – if applicable - the different channel types used including the RLC transmission mode. The message name is in the second line and major information elements of this message are given in the last line.

This scenario shall provide an understanding of the message sequence flow during MOC. For an better view less important messages and simple acknowledgement messages are suppressed.

Radio network messages are shown in green color, transport network messages in red color.

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