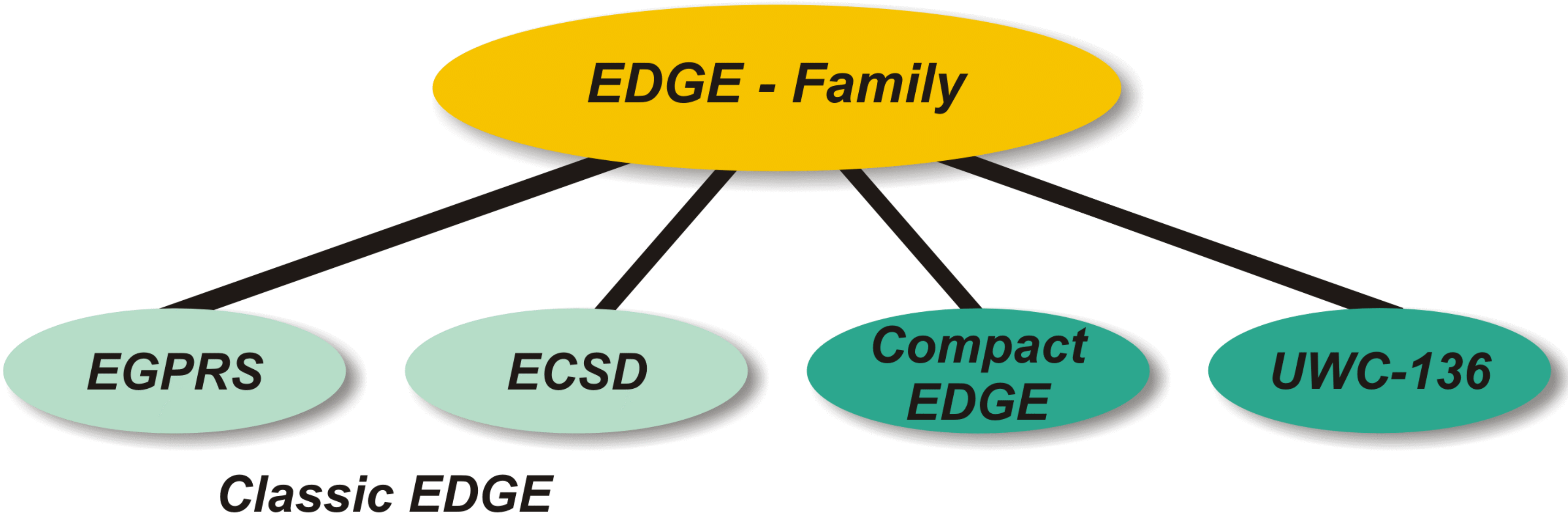
The EDGE Family



The EDGE Family

As early as 1997, people at ETSI started with the concept of an enhancement for the two high speed mobile data upgrades for GSM-networks that were not yet fully defined: HSCSD and GPRS. The name for this enhancement was EDGE or Enhanced Data rates for Gsm Evolution. Nowadays, this flavor of EDGE is also referred to as classic EDGE.

One year later, in 1998, the US-ANSI community also discovered EDGE as a cheap, feasible and fast solution to bring high speed mobile data services to their IS-136 PCS-networks. Finally, the same ANSI-community put in EDGE as their proposal for 3G-services (IMT-2000) to the ITU-T. Let us take a closer look at these different EDGE-family members:

EGPRS

EGPRS or Enhanced General Packet Radio Service represents an optional update for conventional GPRS. The related improvements compared to plain GPRS are remarkable. When considering only the achievable throughput rates, the related effort to install EGPRS is small compared to launching 3G networks. In theory, the maximum throughput of EGPRS on the SAP between RLC/MAC and LLC is 473.6 kbit/s (⇔ DL / 8 TS's / MCS-9). More realistic are throughput rates of approximately 100 kbit/s in downlink direction (DL / 4 TS's / MCS-5 and MCS-6).

ECSD

ECSD or Enhanced Circuit Switched Data is basically an upgrade for HSCSD. For ECSD, the so called E-TCH's with a throughput rate of up to 43.2 kbit/s have been defined. Still, the lacking interest in HSCSD also has up to now avoided any effort to develop ECSD capable equipment.

Compact EDGE

Compact EDGE really represents an EGPRS overlay network for existing IS-136 networks. Compact EDGE is clearly defined in the GSM-recommendations and provides EGPRS-services while still camping on an IS-136 network.

UWC-136

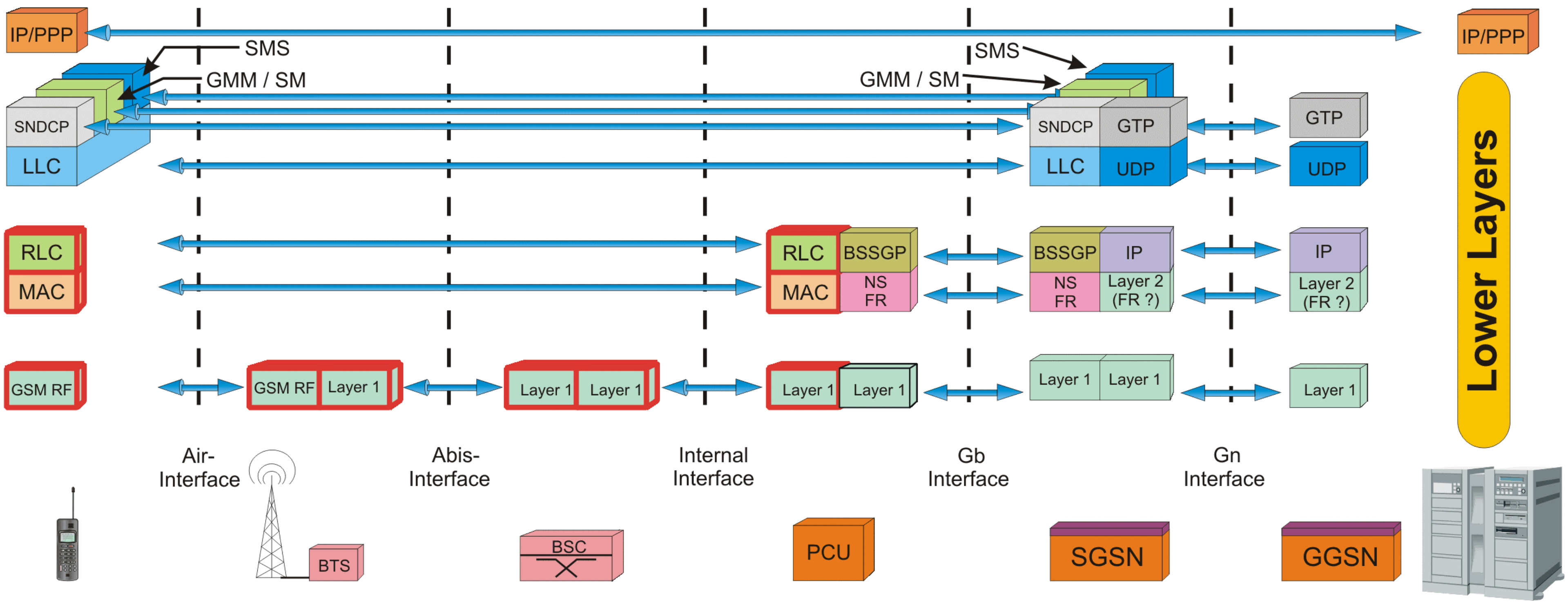
UWC-136 represents the input of the ANSI-community to the ITU-T for a 3rd generation mobile standard. With the diminishing support for IS-136, interest in developing the related infrastructure is low.

Finally, what do all these different technologies have in common? Why are all of them linked to EDGE? The simple answer is that all these technologies support 8-PSK modulation as alternative modulation scheme. Still, the only EDGE-flavor which is seriously under development is EGPRS.

US-operators with IS-136 networks have revised their general track for mobile network services in the year 2000 and have decided to migrate their existing networks to GSM. This process is still ongoing and these US-operators are definitely the most important supporters of EGPRS today.

EGPRS Specific Changes

- **Changes of the Protocol Stack**



EGPRS Specific Changes

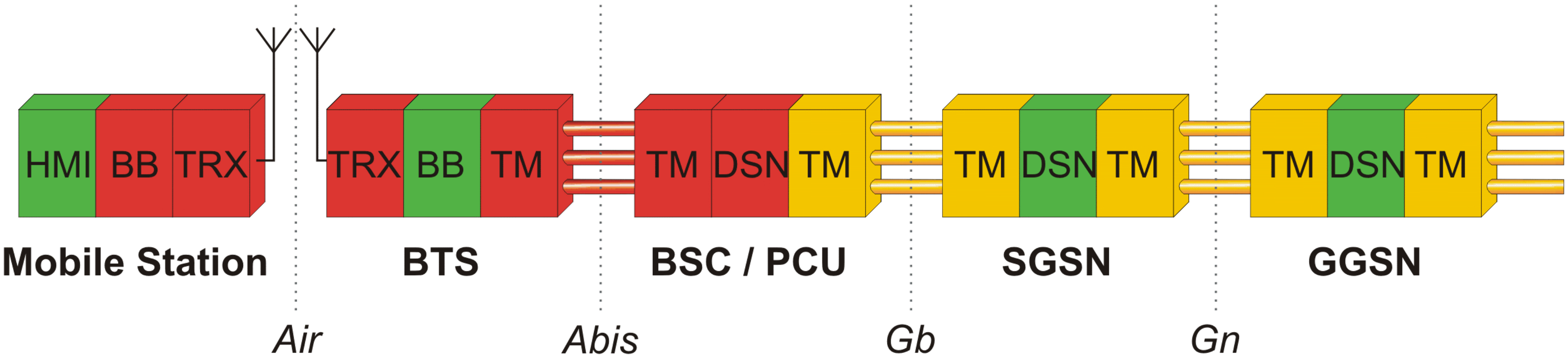
Changes of the Protocol Stack

The figure represents the GPRS/EGPRS protocol stack. The protocols with red outer lines are the very protocols which are different between GPRS and EGPRS.

These protocols to be changed are all physical layer protocols from the mobile station up to the PCU and the RLC/MAC-protocol.

Most importantly, all protocols beyond the PCU and all protocols above RLC/MAC do not require adjustments.

EGPRS Specific Hardware Upgrades



- (green) = Modest or no Changes are required
- (yellow) = Hardware **Expansions** are required
- (red) = Extensive **Hard- and Software Changes** are required

EGPRS Specific Hardware Upgrades

Mobile Station

An EGPRS capable mobile station cannot be provided through a "simple" software upgrade. Most importantly, EGPRS capable mobile stations have to support 8-PSK reception (not transmission). Therefore, the TRX needs to be modified. Secondly, EGPRS capable mobile stations require more processing power and more memory in the Base Band (BB) to support the faster throughput rates and more sophisticated procedures of EGPRS. In return, these updates ask for more battery power and for improved engineering e.g. when it comes to heat deviation.

Base Transceiver Station

Obviously, the BTS needs new transceiver modules to support 8-PSK modulation in both directions. Since the base station is usually quite powerful, hardware upgrades of the base band should be modest and only required in exceptional cases. However, the transmission modules (TM) to the BSC require extensive upgrades and reconfigurations to support the faster EGPRS-channels.

Abis-Interface

Surprisingly, one of the most serious constraints for EGPRS implementation is the Abis-interface. One needs to consider that the Abis-interface has been tailored to support 16 kbit/s-channels. We will get back to this issue on the following page.

Base Station Controller / Packet Control Unit

The BSC is actually a small *circuit-switched* switch, comparable to the MSC. Unlike the MSC, the BSC has originally been developed or altered to switch 16 kbit/s- or 8 kbit/s-channels for GSM-fullrate and halfrate. For GPRS, the PCU has been appended to relieve the BSC from packet-switched switching tasks. Besides, the DSN in the BSC is not designed to switch 64 kbit/s-channels. Therefore, the BSC needs extensive hardware changes in both the DSN and the transmission equipment.

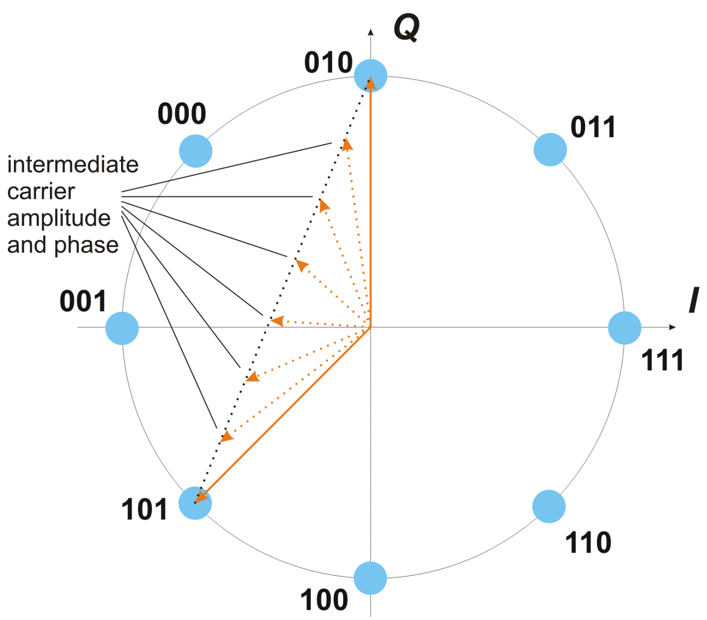
Already GPRS performance suffers from the "bottleneck" BSC. Please recall that today there are only CS-1 and CS-2 but not CS-3- and CS-4 because neither the BSC nor the Abis-interface can process the related faster channels.

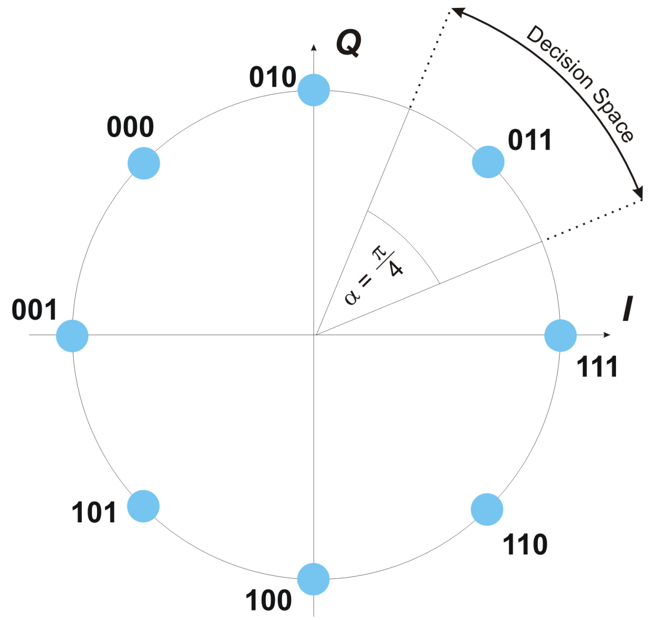
Core Network

The core network hardware and transmission modules will usually only require some hardware expansions to cope with the increased traffic, if EGPRS is successful.

8-PSK Modulation

- **8-PSK in the I/Q-Plane**





8-PSK Modulation

Introduction

With the advent of EDGE, a second modulation scheme is supported in GSM. This new modulation scheme is “3π/8 Offset 8-PSK”, a special offset variant of plain 8-PSK modulation. Before a detailed consideration of 3π/8 Offset 8-PSK, we need to explain the specifics of 8-PSK:

⇒ Unlike GMSK, plain 8-PSK is no differential modulation scheme. The position of the modulated symbols and the respective bits is fixed as illustrated in the two figures.

⇒ Unlike GMSK, 8-PSK distinguishes among 8 different symbols. Therefore, 3 bit can be conveyed within a single symbol when using 8-PSK. Provided that the same symbol rate is used, 8-PSK provides three times the throughput of GMSK.

In GSM, 3π/8 Offset 8-PSK and GMSK use the same symbol rate of 1/T = 1,625 / 6 kilo symbols/s. With 3 bit per symbol, 3π/8 Offset 8-PSK provides for a gross bit rate of 1,625 / 6 x 3 kbit/s = 812.5 kbit/s.

⇒ The decision space in 8-PSK is much smaller than in GMSK as illustrated in the right figure (⇔ 8-PSK = π/4 / GMSK = π). This makes 8-PSK modulation more vulnerable to interference than GMSK (⇔ the C/I-requirement is higher using the same data rate and FEC).

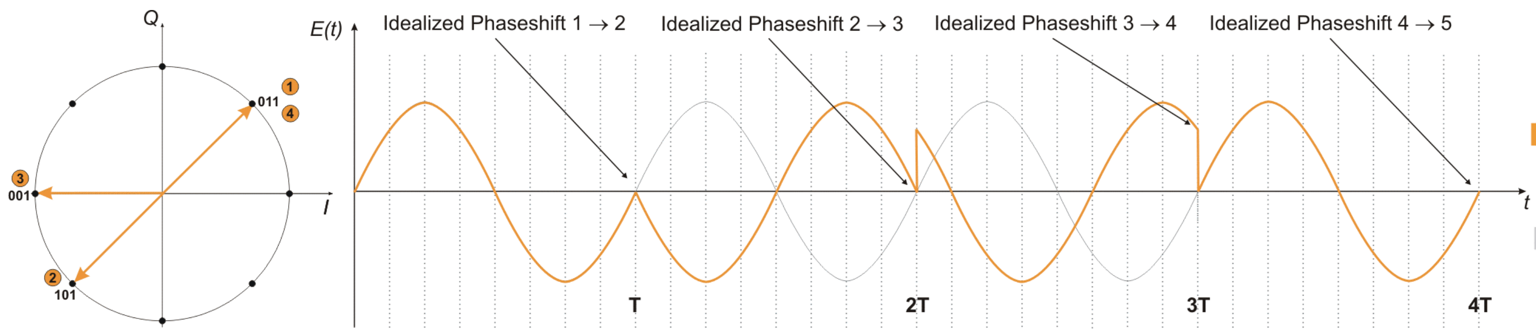
- Another disadvantage of plain 8-PSK modulation is the inherent amplitude modulation. Symbol changes always occur directly and not along the circle between any two symbols (⇔ left figure).
- To be more precise: When using 8-PSK with a symbol duration of T = 6/1,625 µs and a maximum phase shift of 180° (⇔ π) it is no longer possible to move the signal vector along the circle. The required frequency shift would be $\Delta f = \Delta\varphi / (2\pi \times T) = \pm \pi / (2\pi \times 3.692\ \mu s) = \pm 135.43$ kHz. This would exceed the available frequency spectrum of ± 100 kHz = 200 kHz.
- As a consequence of the direct shifts, the amplitude of the carrier frequency changes. In the extreme case, a phase change of 180° (⇔ π) causes the carrier amplitude to reverse its direction which in turn results in an increased bandwidth demand.

Gray Encoding

The figure illustrates 8-PSK modulation, using Gray-Encoding. With Gray-Encoding, any two adjacent symbols differ only by a single bit. Therefore, output errors can be minimized in case of an erroneous demodulation of the adjacent symbol. Gray-Encoding is also used in GSM.

[3GTS 05.04 (3)]

Phase Changes and Amplitude Variation in 8-PSK

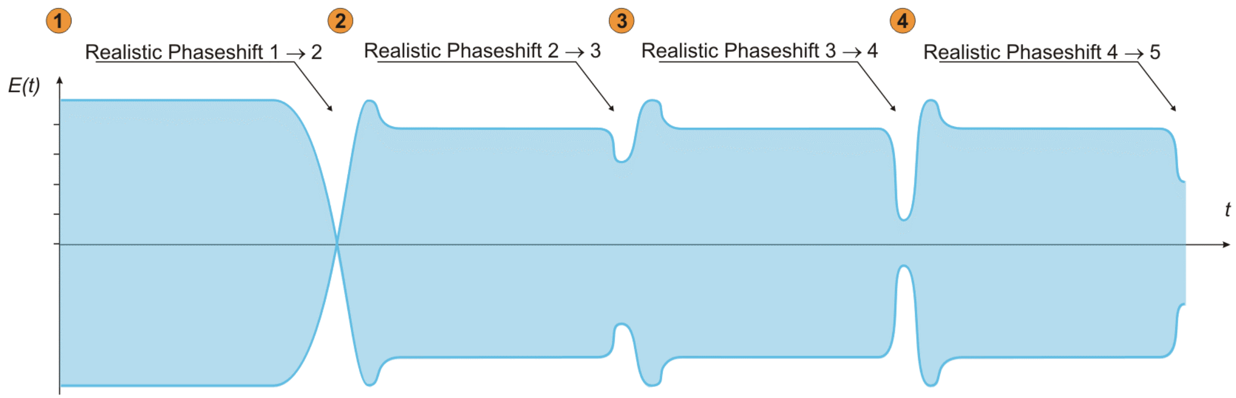


Bitsequence:	011 ($\Delta\varphi = 0$)	101 ($\Delta\varphi = \pi$)	001 ($\Delta\varphi = -1/4\,\pi$)	011 ($\Delta\varphi = -3/4\pi$)

= Phase Changes of modulated carrier

= unmodulated carrier (carrier frequency is much higher than presented)

T =Symbol Period = 3.692 µs



= Amplitude Envelope

Phase Changes and Amplitude Variation in 8-PSK

We continue our consideration of phase and amplitude variations with plain 8-PSK. The example illustrates the four symbols (011), (101), (001) and (011). As illustrated before for MSK and GMSK, the upper part of the figure shows the idealized phase shifts.

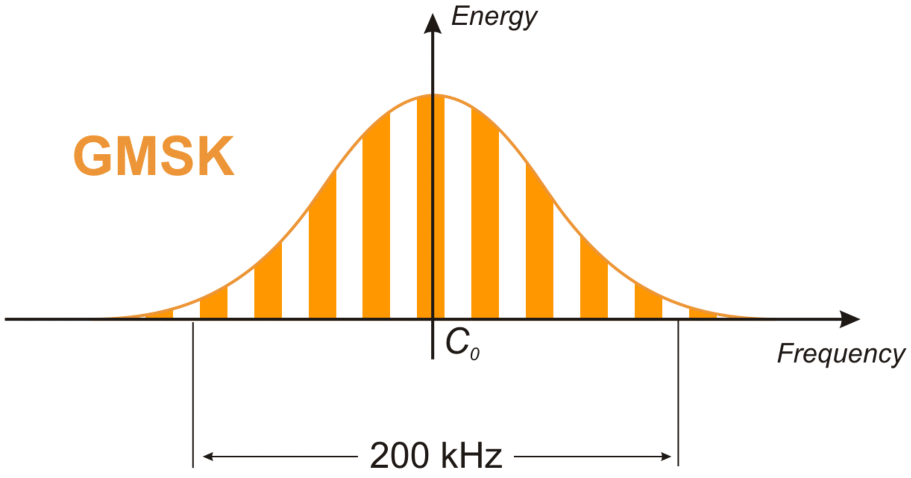
⇒ Please note that the gray line represents the position of the unmodulated carrier which is the sum of sin (φ)and cos (φ).

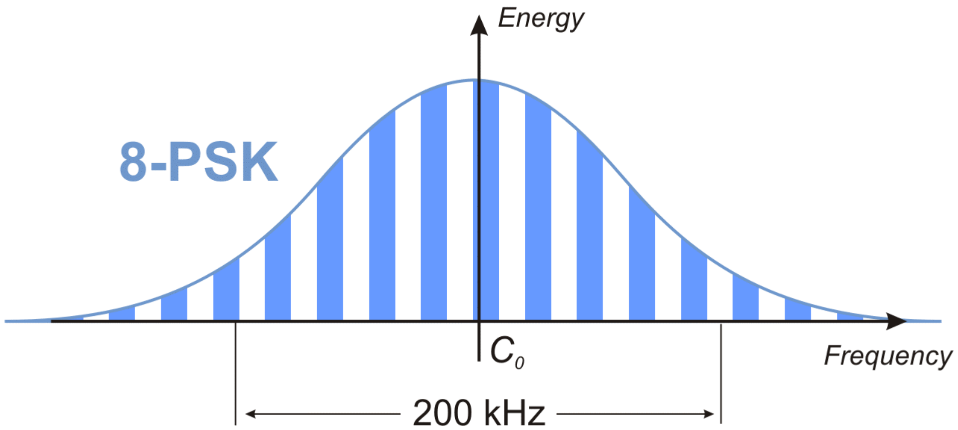
⇒ The indicated values for Δφ relate to the phase differences to the previous symbol and not to the unmodulated carrier.

⇒ In the lower part of the figure the amplitude envelope is illustrated. Please note how the amplitude changes upon symbol change due to the way how the symbol changes occur in 8-PSK.

⇒ In the worst case of a phase change of ± π , the signal reverses its direction (⇔ the vector crosses the "Zero-Point"). Accordingly, the spectrum requirements become very large which is impossible to realize in real life applications.

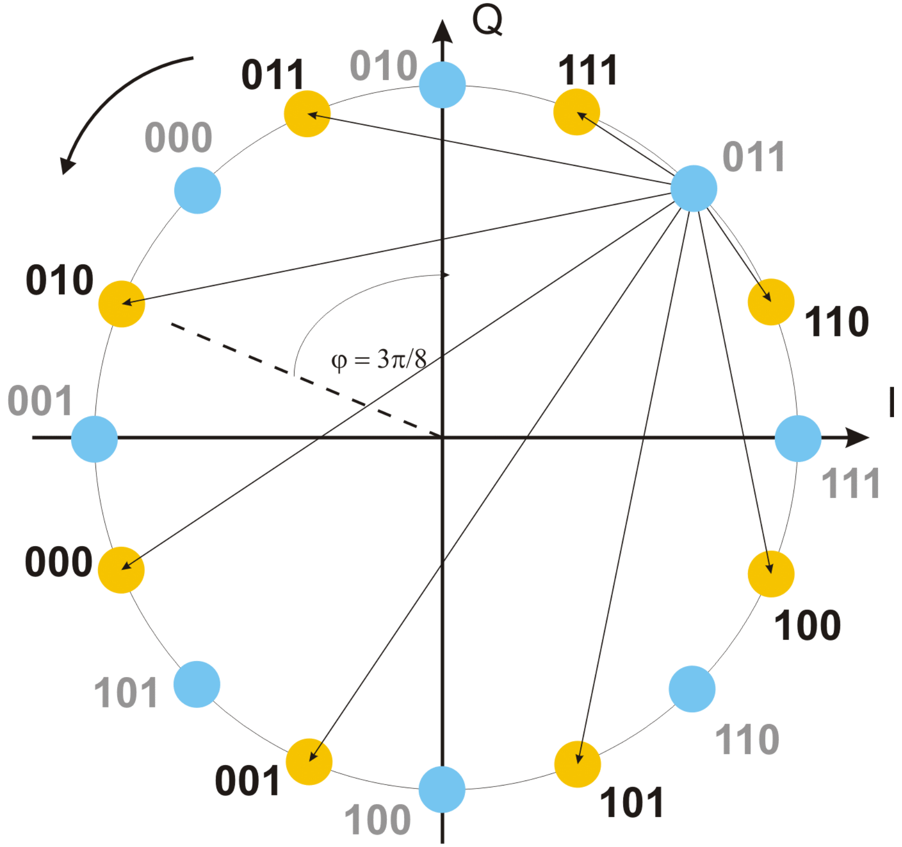
Spectrum Requirements of GMSK and 8-PSK





3π/8 Offset 8-PSK

3π/8 Offset 8-PSK Modulation
No Zero Passing



3π/8 Offset 8-PSK

As the name suggests, 3π/8 Offset 8-PSK is an offset variant of plain 8-PSK-modulation. Between any two symbols, the symbol circle shifts by an offset angle of 3π/8. As an example, the figure illustrates one symbol change from the blue-colored symbol state which is in-phase with plain 8-PSK to the orange-colored symbol state which is shifted by 3π/8 compared to the previous symbol state.
The advantage over plain 8-PSK becomes immediately apparent when looking at the possible symbol changes for (011):

There can be no "Zero"-crossings in 3π/8 Offset 8-PSK. The amplitude modulation is limited to –15 dB.

Obviously, 3π/8 Offset 8-PSK also provides three times the throughput rate of GMSK-modulation, if the symbol rate is identical. The disadvantage of 3π/8 Offset 8-PSK compared to plain 8-PSK is:

In 3π/8 Offset 8-PSK the phase of the received signal is unknown to the receiver and needs to be determined prior to demodulation which requires additional effort (⇔ is achieved in GSM through the alignment of the received symbols with the TSC).

Note: Even when using 3π/8 Offset 8-PSK and therefore limiting the maximum phase shift $\Delta\varphi$ to 7/8 π it is still not possible to move the signal vector along the circle. The required frequency shift would be $\Delta f = \Delta\varphi / (2\pi \times T) = \pm 7/8\, \pi / (2\pi \times 3.692\ \mu s) = \pm 118.5$ kHz. Like in plain 8-PSK, this would exceed the available frequency spectrum of ± 100 kHz = 200 kHz.

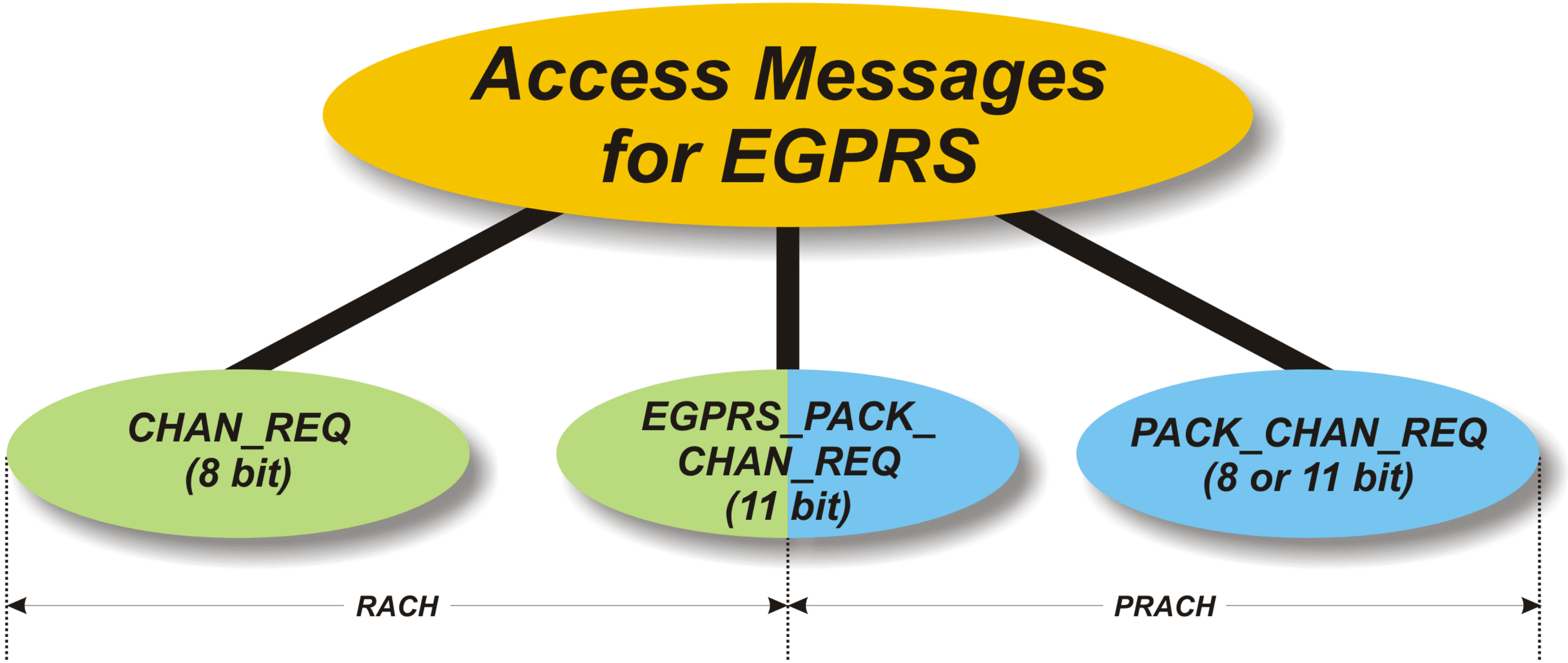
[3GTS 05.04 (3)]

Practical Exercise:

“Why is the offset angle selected with $3\pi/8$ and not, for instance, with $\pi/8$?”

Network Access Mechanisms in EGPRS

- **Applicable Network Access Messages**



Network Access Mechanisms in EGPRS

Applicable Network Access Messages

The figure illustrates the messages that the EGPRS-capable mobile station shall use to perform a network access in EGPRS. The conditions which determine which specific message shall be used are explained on the following pages.

CHAN_REQ-Message

The CHAN_REQ-message is defined in 3GTS 04.18 and in our book and course “GSM-Introduction”. Since the CHAN_REQ-message is also used for all network accesses due to circuit-switched GSM, only the GPRS-specific access reasons One-Phase Packet Access and Single-Block Packet Access are available. Only 8 bit of information are included.

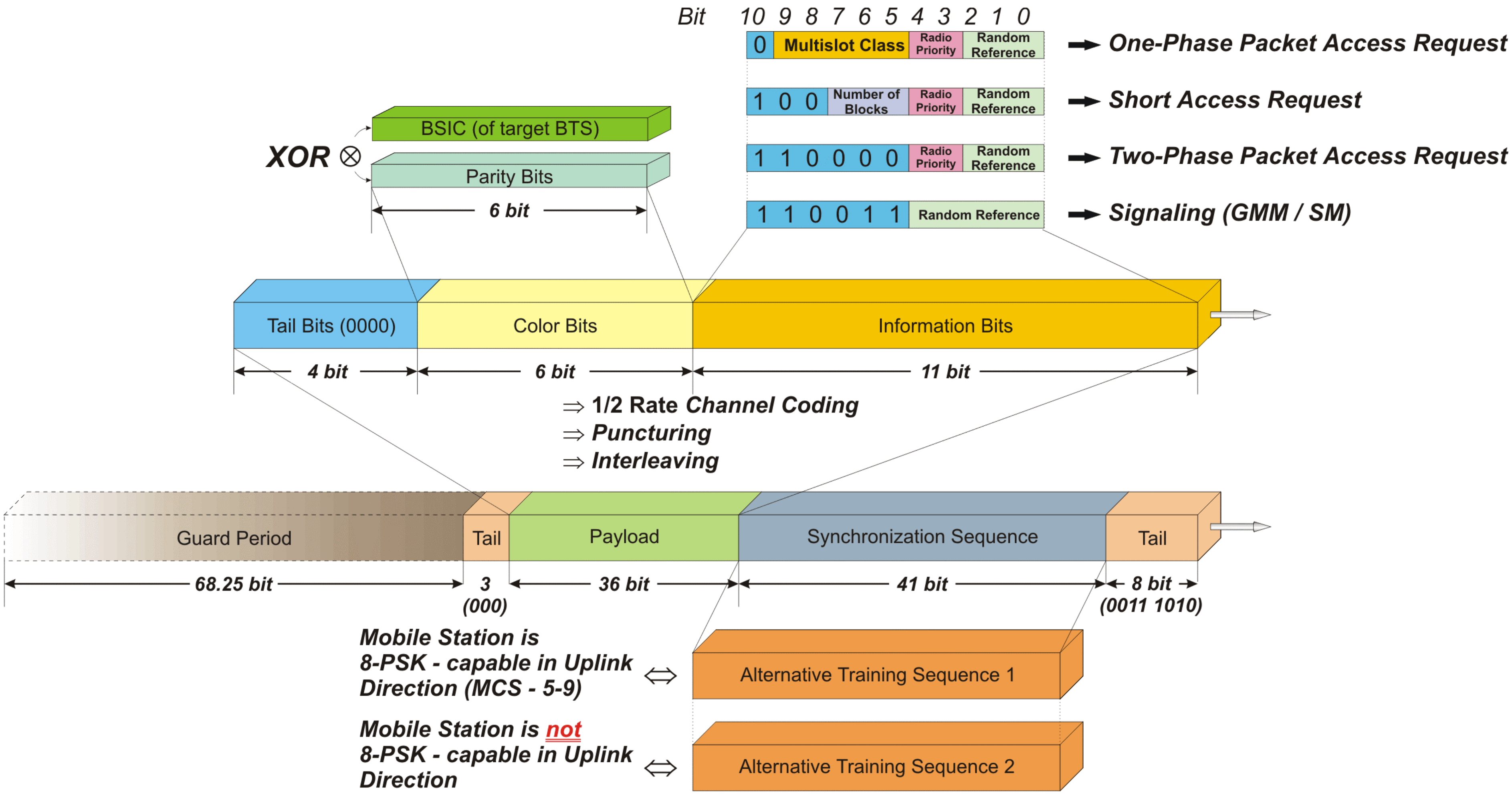
EGPRS_PACK_CHAN_REQ-Message

The EGPRS_PACK_CHAN_REQ-message is defined in 3GTS 04.60 and will be explained in detail later in this section. Opposed to the other access message types, an EGPRS_PACK_CHAN_REQ-message always contains 11 bit of information, irrespective of the setting of the parameter ACCESS_BURST TYPE (⇔ SYS_INFO13, PACK_SYS_INFO1 and PACK_SYS_INFO13).

PACK_CHAN_REQ-Message

The PACK_CHAN_REQ-message is defined in 3GTS 04.60 and in our book and course “GPRS – Signaling & Protocol Analysis / Vol. 1”. For EGPRS, only the Two-Phase Packet Access is applicable to the PACK_CHAN_REQ-message. Opposed to CHAN_REQ and EGPRS_PACK_CHAN_REQ, the PACK_CHAN_REQ-message may contain 8 or 11 information bits as determined by the parameter ACCESS_BURST_TYPE.

Format and Use of the EGPRS_PACK_CHAN_REQ-Message



Format and Use of the EGPRS_PACK_CHAN_REQ-Message

The figure illustrates the format and encoding rules of the EGPRS_PACK_CHAN_REQ-message. Please note that the EGPRS_PACK_CHAN_REQ-message is distinguished from CHAN_REQ- and PACK_CHAN_REQ-messages through different synchronization sequences. In addition, these synchronization sequences also indicate to the network, whether the mobile station supports 8-PSK modulation in uplink direction (⇔ MCS-5 – MCS-9) or not.

Access Reasons

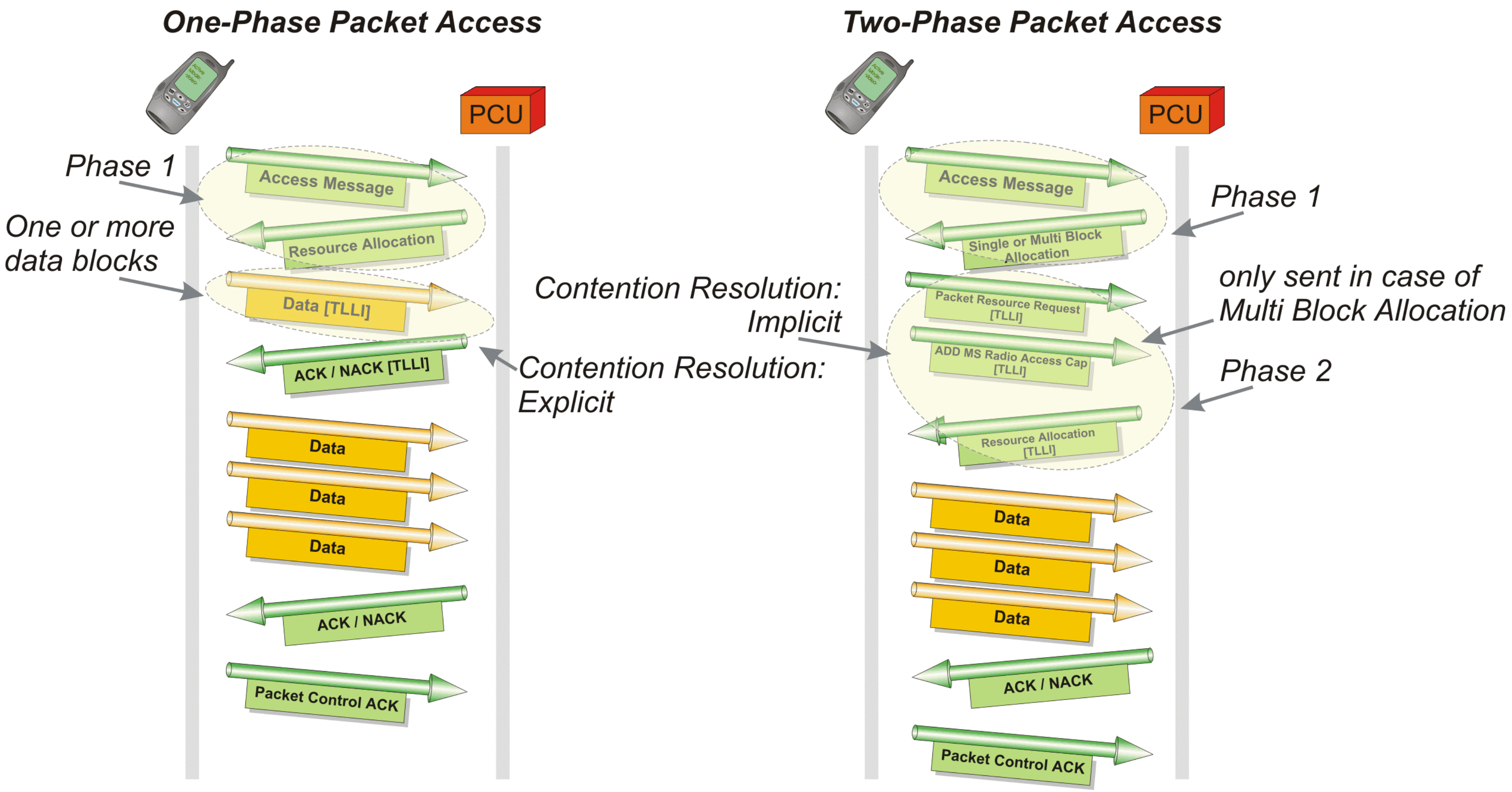
- **One-Phase Packet Access**
  Is only applicable if the mobile station has more than 8 RLC data blocks to transmit in RLC-acknowledged operation mode. The calculation of the number of required RLC data blocks is based on the current number of octets in the output queue of the mobile station and the assumption that MCS-1 will be used for the data transfer.
- **Short Access Request**
  Is only applicable if the mobile station has no more than 8 RLC data blocks to transmit in RLC-acknowledged operation mode. The calculation of the number of required RLC data blocks is based on the current number of octets in the output queue of the mobile station and the assumption that MCS-1 will be used for the data transfer.
- **Two-Phase Packet Access Request**
  Is mandatory, if the mobile station has to transmit RLC data blocks in RLC-unacknowledged operation mode but may also be used, if the mobile station has to transmit more than 8 RLC data blocks in RLC acknowledged operation mode.
- **Signaling (GMM / SM)**
  Shall only be used, if the mobile station has to send RLC data blocks which contain GMM/SM-messages, LLC-control frames (e.g. XID-frame) or page responses.

Note 1: The network decides through the setting of the EGPRS_PACK_CHAN_REQ-bit in the GPRS Cell Options information element whether the cell accepts and supports EGPRS_PACK_CHAN_REQ-messages. The GPRS Cell Options are broadcast in SYS_INFO13 and PACK_SYS_INFO13, if no PBCCH is present and in PACK_SYS_INFO1 and PACK_SYS_INFO13, if PBCCH is present.

Note 2: The setting of ACCESS_BURST_TYPE is irrelevant for the number of information bits within an EGPRS_PACK_CHAN_REQ-message.

[3GTS 04.60 / 3GTS 05.02 / 3GTS 05.03]

One- and Two-Phase Packet Access Procedure in EGPRS



One- and Two-Phase Packet Access Procedure in EGPRS

The figure illustrates the general information flow for the One- and Two-Phase Packet Access procedures in EGPRS. Please note that just like in GPRS, there is a contention resolution procedure required in both cases. Like for plain GPRS, the final decision about the network access is taken by the PCU. Even if the mobile station requests One-Phase Packet Access, the network may still decide for Two-Phase Packet Access.

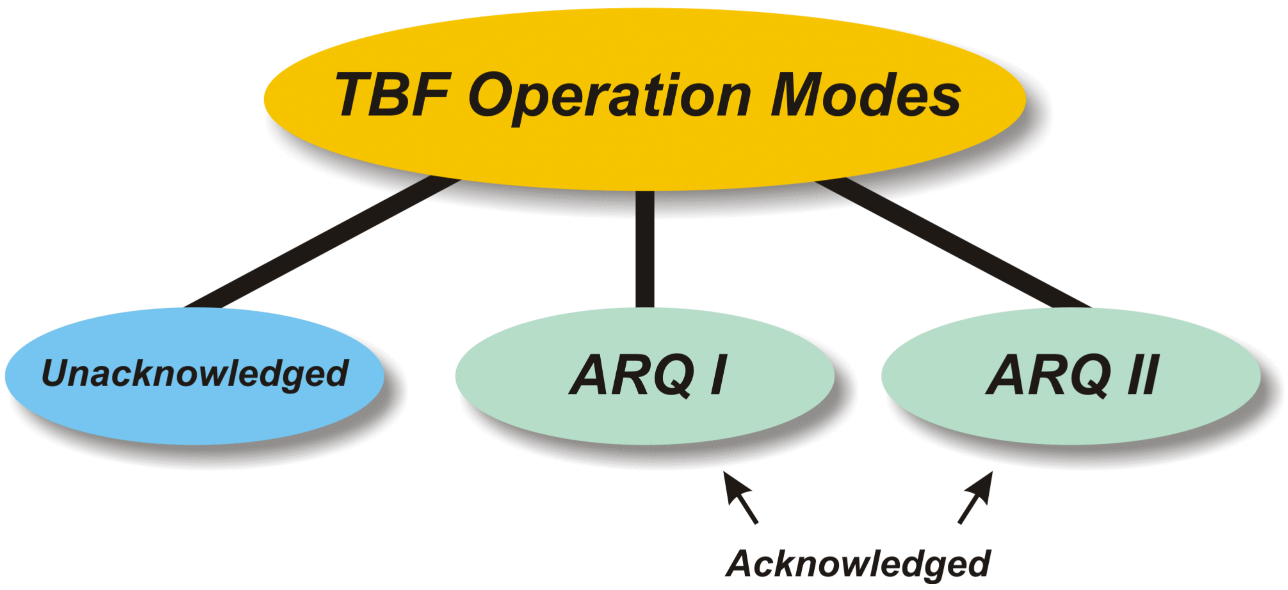
The most important difference between GPRS and EGPRS applies for the Two-Phase Packet Access procedure: While in GPRS, the network may only allocate a single uplink radio block to the mobile station in case of Two-Phase Packet Access, in EGPRS the network may allocate one or two blocks (⇔ Multi Block Allocation). However, such a multi block allocation is only applicable in case that the Two-Phase Packet Access is performed through an EGPRS_PACK_CHAN_REQ-message.

Note: If the network initially allocates 2 radio blocks to the mobile station that tries to establish an EGPRS TBF, it invokes the transfer of the mobile station's radio access capabilities for additional frequency bands. Consider that the BCCH frequency band is on 900 MHz and the network also likes to receive the MS radio access capabilities for the 1800 MHz frequency band.

[3GTS 04.60]

EGPRS TBF Operation

- TBF-Operation Modes



EGPRS TBF Operation

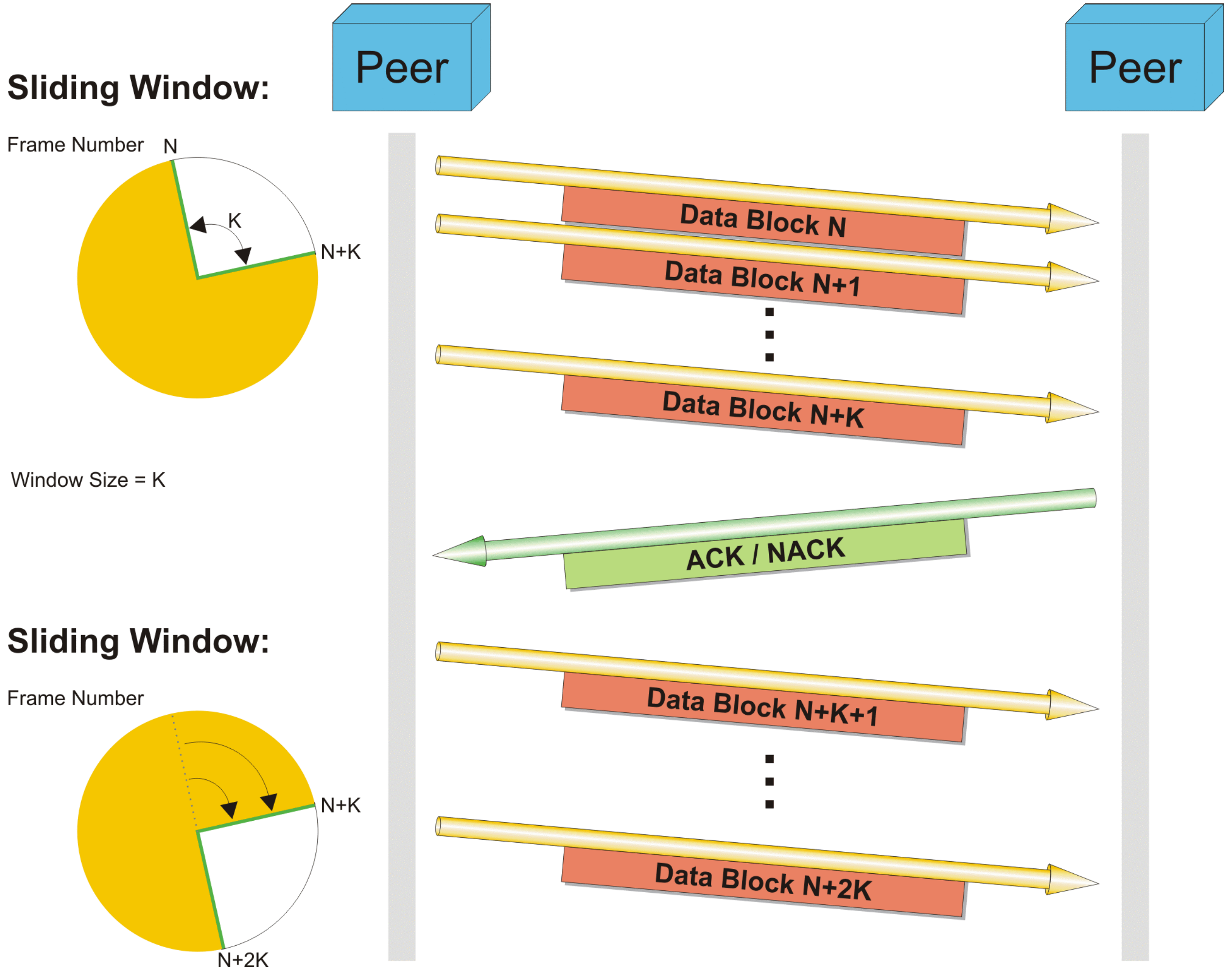
TBF-Operation Modes
In EGPRS, uplink and downlink TBF's can be operated either in:

- **Unacknowledged Operation Mode**
  Unacknowledged operation mode is only applicable if the QoS-profile indicates it.
- **Acknowledged Operation Mode using ARQ I**
  Acknowledged operation mode is only applicable if the QoS-profile indicates it. In ARQ I, the transmitter may split RLC-data blocks into a different MCS within the same data block family, if retransmissions become necessary.
- **Acknowledged Operation Mode using ARQ II (Incremental Redundancy)**
  ARQ II is using the incremental redundancy feature which is optional for the base station but mandatory for the mobile station receiver. An RLC-data block split is *not* applicable in case of ARQ II. Still, if possible without splitting, another MCS within the same data block family may be selected for retransmission, if applicable. This can only happen in case of MCS-5 ⇔ MCS-7, MCS-6 ⇔ MCS-8 / MCS-9.

> Note: The network can switch back and forth between ARQ I and ARQ II during one TBF. This is done through the RESEGMENT-bit which is part of the PACK_UL_ASS-, PACK_UL_ACK- and PACK_TS_RECONF-messages.

[3GTS 04.60]

Acknowledged Operation – Important Aspects



Acknowledged Operation – Important Aspects

In our figure, the peer on the left side shall transmit data blocks to the peer on the right side. At some times, this right peer is expected to send acknowledgement messages to the peer on the left side:

The Window Size 'k'

The window size 'k' is a very important parameter as it determines how many consecutive data blocks a sender may transmit to the receiver until some kind of acknowledgement message *must* be received by the sender. Therefore, only specific frame numbers are allowed for transmission. The window size may also be measured in number of octets by other protocols like in TCP.
If the sender has transmitted data blocks up to the window size (in our example the data block with number (N+k)) then the sender shall wait for an acknowledgement from the receiver. Only then the sliding window may move on.

Maximum Number of Retransmissions

Most protocols deploy a special counter for the maximum number of retransmissions of a given frame before the connection is torn down.

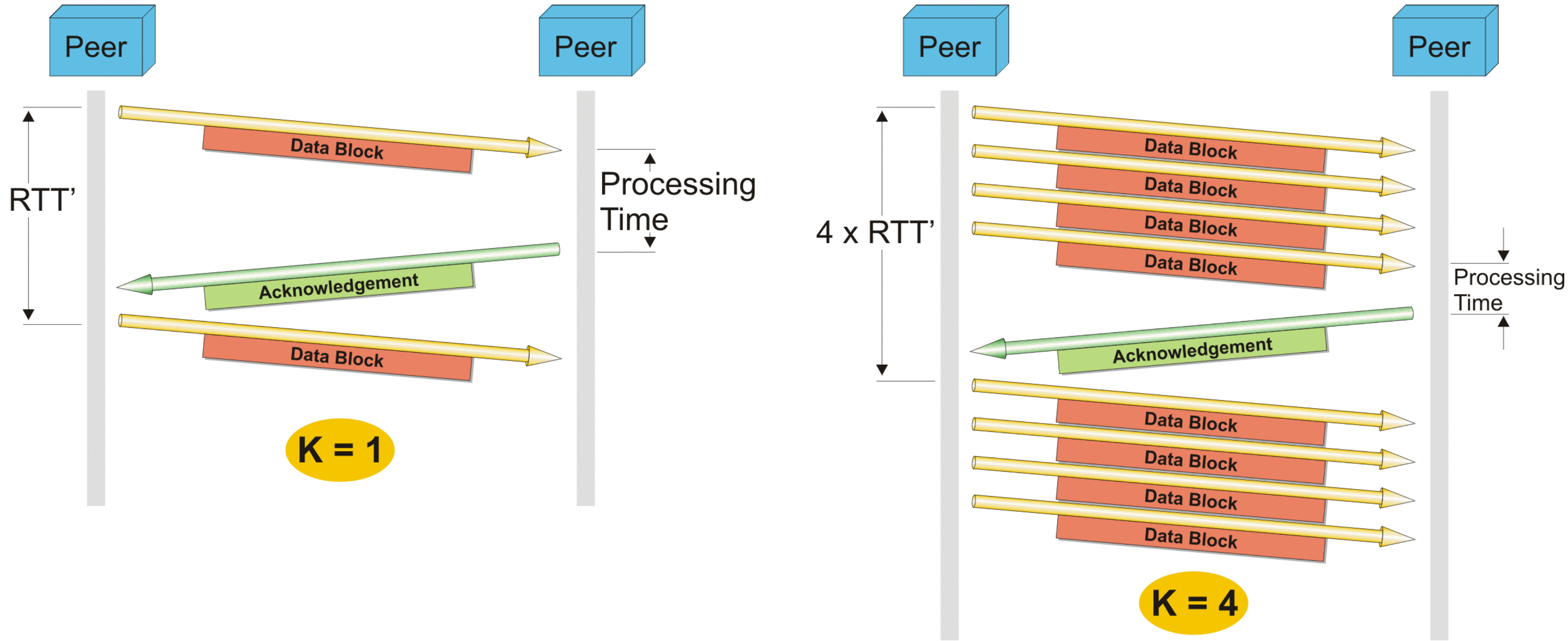
Note: In the RLC/MAC protocol of GPRS and EGPRS there is no counter for the maximum number of retransmissions of an RLC data block due to erroneous reception. This issue is taken care of by other timers and counters that expire when the radio contact gets lost. This implies that under good radio conditions, the number of retransmissions of a single frame is expected to be reasonably small. This is certainly true for EGPRS but could –at least in theory- cause problems in plain GPRS.

Acknowledgements

In EGPRS, PACK_UL_ACK-messages are used to selectively acknowledge uplink data blocks. That is, PACK_UL_ACK-messages are sent by the PCU to the mobile station. Vice versa, EGPRS_PACK_DL_ACK-messages are used to selectively acknowledge downlink data blocks. That is, EGPRS_PACK_DL_ACK-messages are sent by the mobile station.

[3GTS 04.60]

Roundtrip Time ⇔ Window Size



Roundtrip Time ⇔ Window Size

One of the most critical performance parameters for both GPRS and EGPRS is the roundtrip time. The roundtrip time relates to the time period that it takes to convey one user data PDU from one peer to the other, end to end, and is called RTT.
In that respect, the data transfer over the air interface takes a very important part for the following reasons:

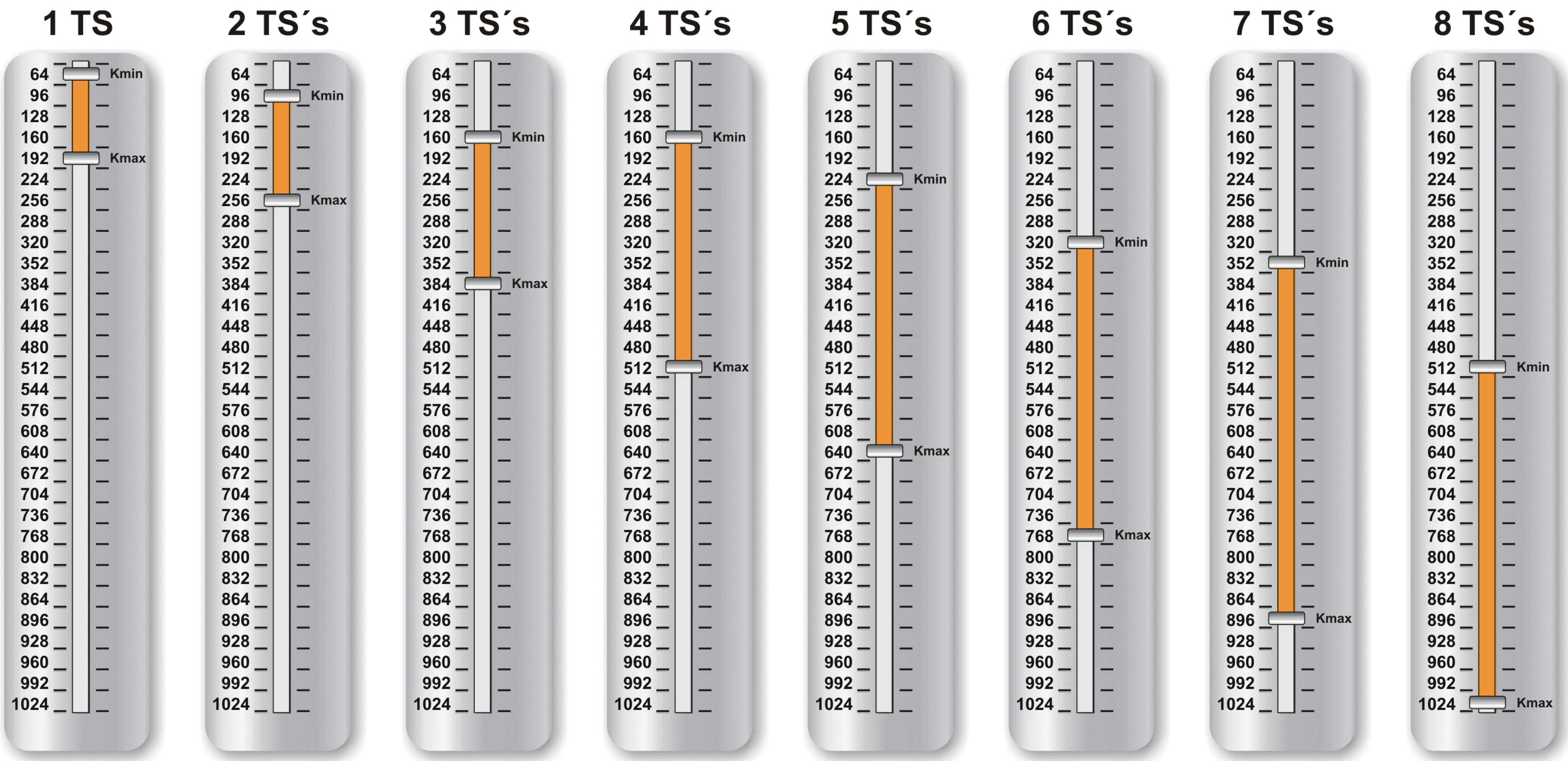
⇒ **Access to the Peer**: The uplink network access or the access to the mobile station takes a considerable long time.
⇒ **Segmentation**: On the air interface, the smallest PDU's are used which is due to the characteristics of the GSM air interface.

In addition, window size and roundtrip time are related. This is illustrated in the figure:

⇒ If the window size is extremely small (k = 1) then the sender needs to wait for the acknowledgement of the first RLC data block before the next RLC data block can be sent. The indicated time difference RTT' does not represent the user data roundtrip time but the roundtrip time for RLC/MAC.
⇒ On the other hand, if the window size is chosen with a higher value (k = 4), RTT' and therefore RTT is decreased. The sender can transmit 4 consecutive RLC data blocks before it needs to wait for an acknowledgement.

In general the following rule applies: The larger the window size, the smaller the roundtrip time becomes.

The Window Size in EGPRS



The Window Size in EGPRS

In GPRS, the window size is a fixed value k = 64 that applies in both directions, uplink and downlink.

⇒ In EGPRS, the window size is variable and it is controlled by the PCU.

⇒ The maximum and the recommended minimum window size depend on the number of timeslots that are used for a given TBF in either direction. The recommended minimum window size considers a target roundtrip time for RLC/MAC (⇔ RTT') of 120 ms.

⇒ The figure emphasizes the recommended minimum values but the window size could also be selected with k = 64, since the recommended values are not mandatory.

⇒ In any case, the PCU conveys the window size to be used to the mobile station e.g. in a PACK_UL_ASS-message through the parameter EGPRS_WINDOW_SIZE (5 bit).

⇒ In case of simultaneous operation of an uplink and a downlink TBF, the window size may be different.

⇒ Starting from an initial window size, the window size may become larger (as selected by the PCU) but never smaller. Still, the maximum allowed window size must not be exceeded.

Note:

- Mobile stations shall be able to support the maximum window size according to their multislot class. This relates obviously to the number of supported uplink timeslots.
- This requirement relates to extensive memory demand within the mobile station. For a multislot class 12 mobile station with MCS-4 the respective memory size needs to be 352 bit x 512 frames = 180,224 bit (⇔ 176 kbit). If this mobile station also supports 8-PSK in uplink, the required memory is 2 x 592 bit x 512 frames = 606,208 bit (⇔ 592 kbit), considering MCS-9. Please recall that this memory is part of layer 2.
- If incremental redundancy (⇔ ARQ II) is operated in downlink direction, the mobile station is able to indicate that it has no more memory in the layer 1 to perform incremental redundancy by setting the MS_OUT_OF_MEMORY-bit = 1 in an EGPRS_PACK_DL_ACK-message.

[3GTS 04.60 (9.1.9.2, Annex I)]

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