GSM

alebo

úvod do mobilných bunkových komunikačných systémov

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KTL FEI STU

2010

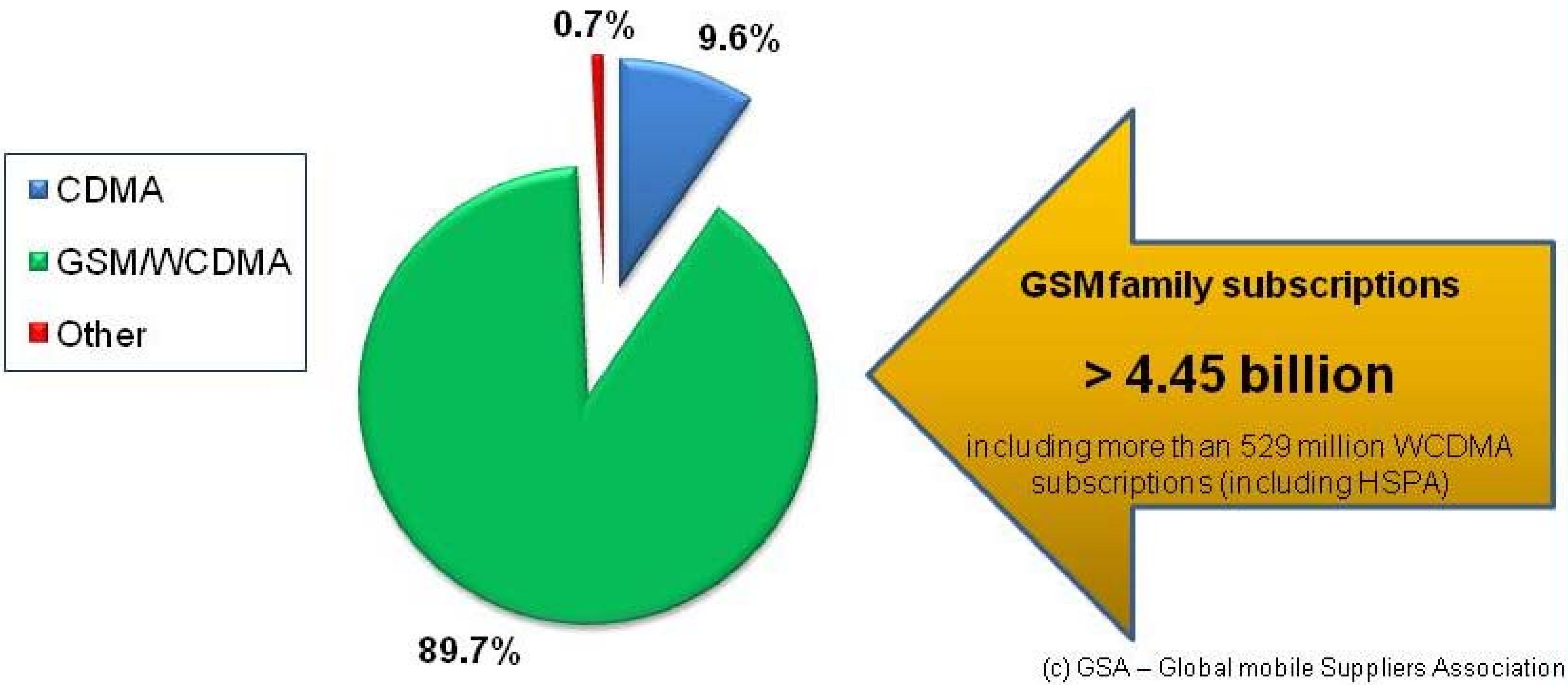
Mobile subscriptions market share worldwide

- *Total mobile market = > 4.96 billion subscriptions: Q2 10*

GSA

www.gsacom.com

Mobile market share worldwide Q2 2010



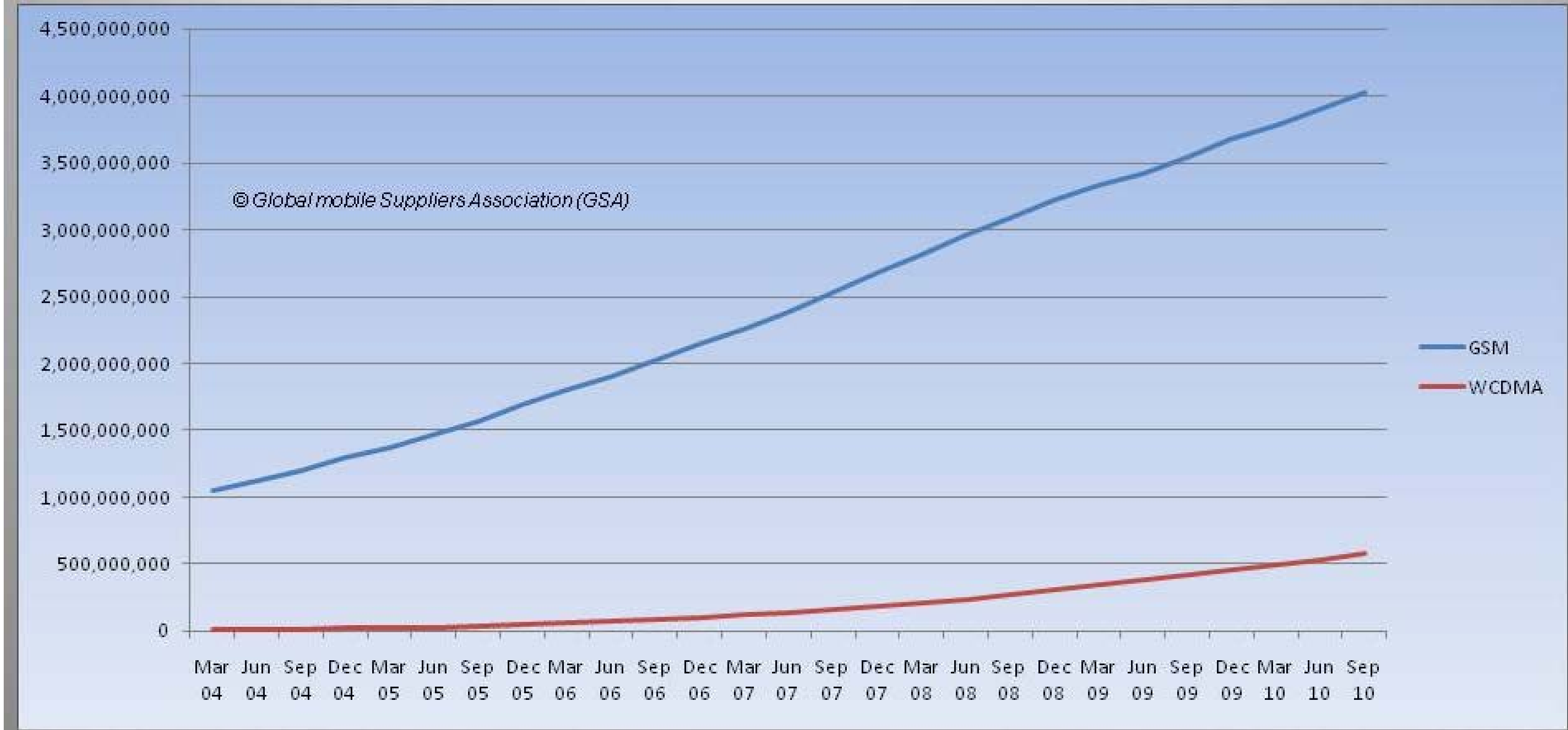
(c) GSA – Global mobile Suppliers Association

Data Source
informa
telecoms & media

- ***GSM/WCDMA market share Q2 09 was 89.3%***

Mobile subscriptions growth: 2004 – 2010
GSM and WCDMA technology

www.gsacom.com



Source: Informa Telecoms & Media WCIS as at October 11, 2010

Prehľad prednášok (3)

- Zdieľanie komunikačného kanála
- Požiadavky na mobilnú sieť
- Dizajnové výzvy
- GSM
  - história
  - základné princípy
  - architektúra
  - vzdušné rozhranie
  - základné mechanizmy (attach, LAU, HO, cell change, ...)
  - služby
  - nadstavby (HSCSD, GPRS)
  - evolúcia (EDGE)
  - budúcnosť (MUROS TR 45.914, eEDGE)

Požiadavky

- Good subjective speech quality
  - in all use cases (mobile, indoor, dense area, rural area, …)
- Low terminal and service cost
- High capacity
- Support for international roaming
- Spectral efficiency

+

- High speed data services

Dizajn

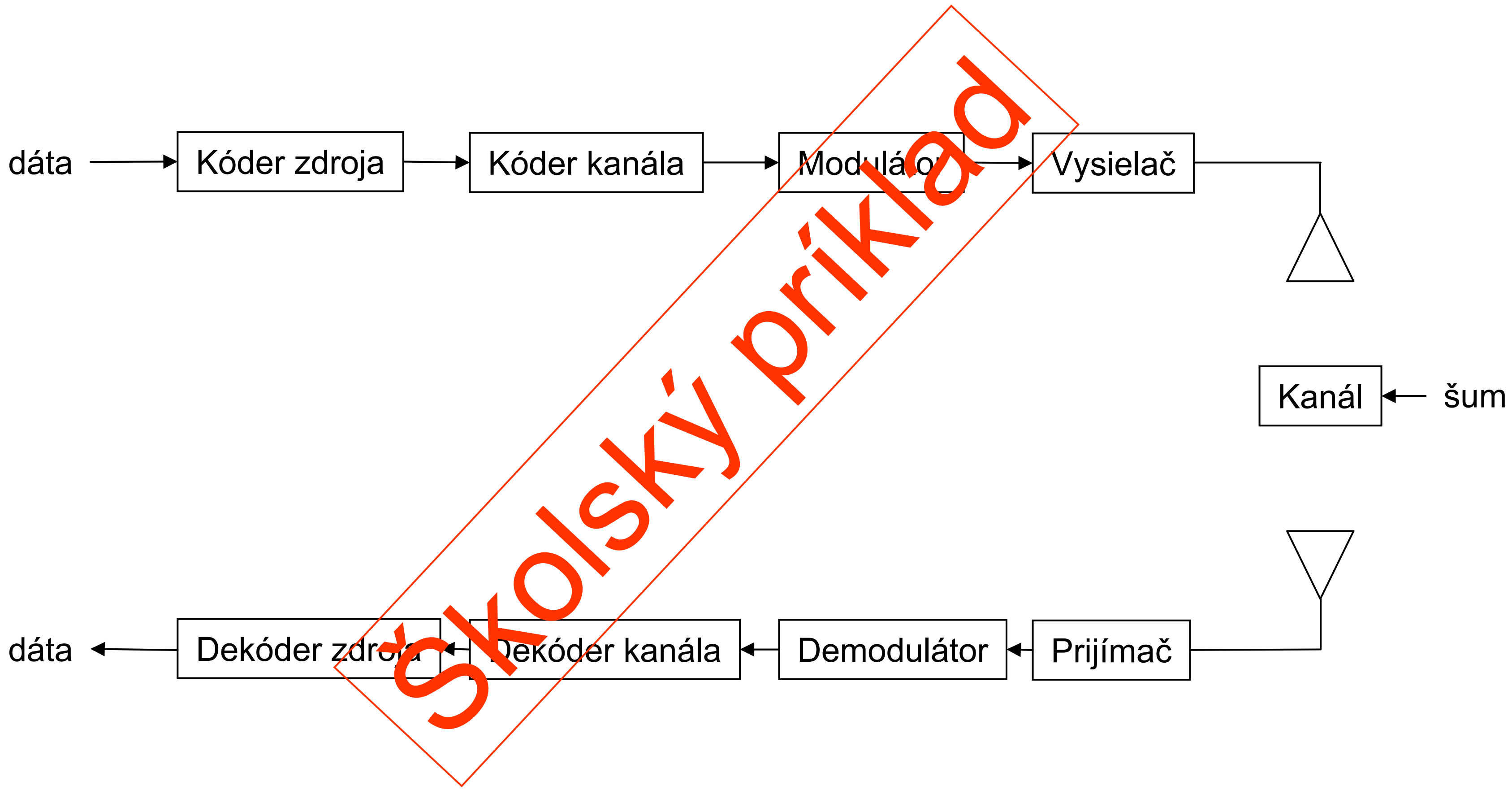
- počet účastníkov na bunku
- typy služieb
- kvalita služby
- veľkosť bunky
- nosná frekvencia
- multiplex
- duplex

Zdieľanie komunikačného kanála

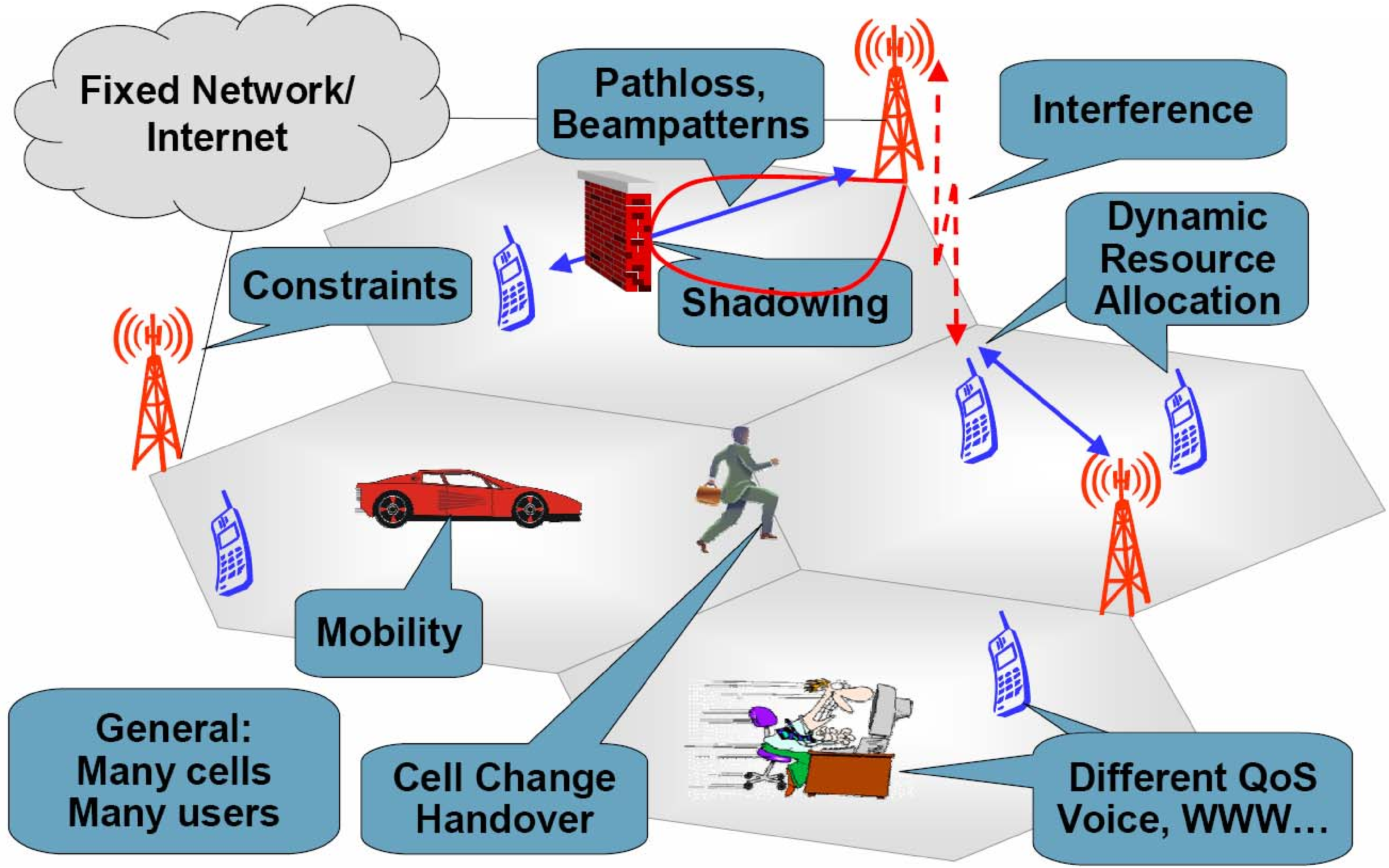
- Channelization
  - Frequency (FDMA)
  - Time (TDMA)
  - Code (CDMA)
  - Space (SDMA)

- Packet mode
  - Contention based random multiple access
  - Token passing
  - Polling
  - Resource reservation (scheduled) packet-mode protocols

Komunikačný systém



Mobilná bunková sieť - realita



História GSM

- 1982
  - Nordic Telecom and Netherlands PTT propose to CEPT (Conference of European Post and Telecommunications) to study and develop a pan-European public land mobile system

    - Groupe Spécial Mobile (GSM)
  - European Commission issues a directive which requires member states to reserve frequencies in the 900 MHz band for GSM to allow for roaming

- 1986
  - GSM radio transmission techniques are chosen

História GSM

- 1987
  - 13 operators and administrators from 12 areas in the CEPT GSM sign the charter GSM (Groupe Spéciale Mobile), with a launch date of 1 July 1991
  - The original French name was later changed to Global System for Mobile Communications, but the original GSM acronym stuck
  - GSM spec drafted
- 1989
  - The European Telecommunications Standards Institute (ETSI) defined GSM as the internationally accepted digital cellular telephony standard
  - GSM becomes an ETSI technical committee

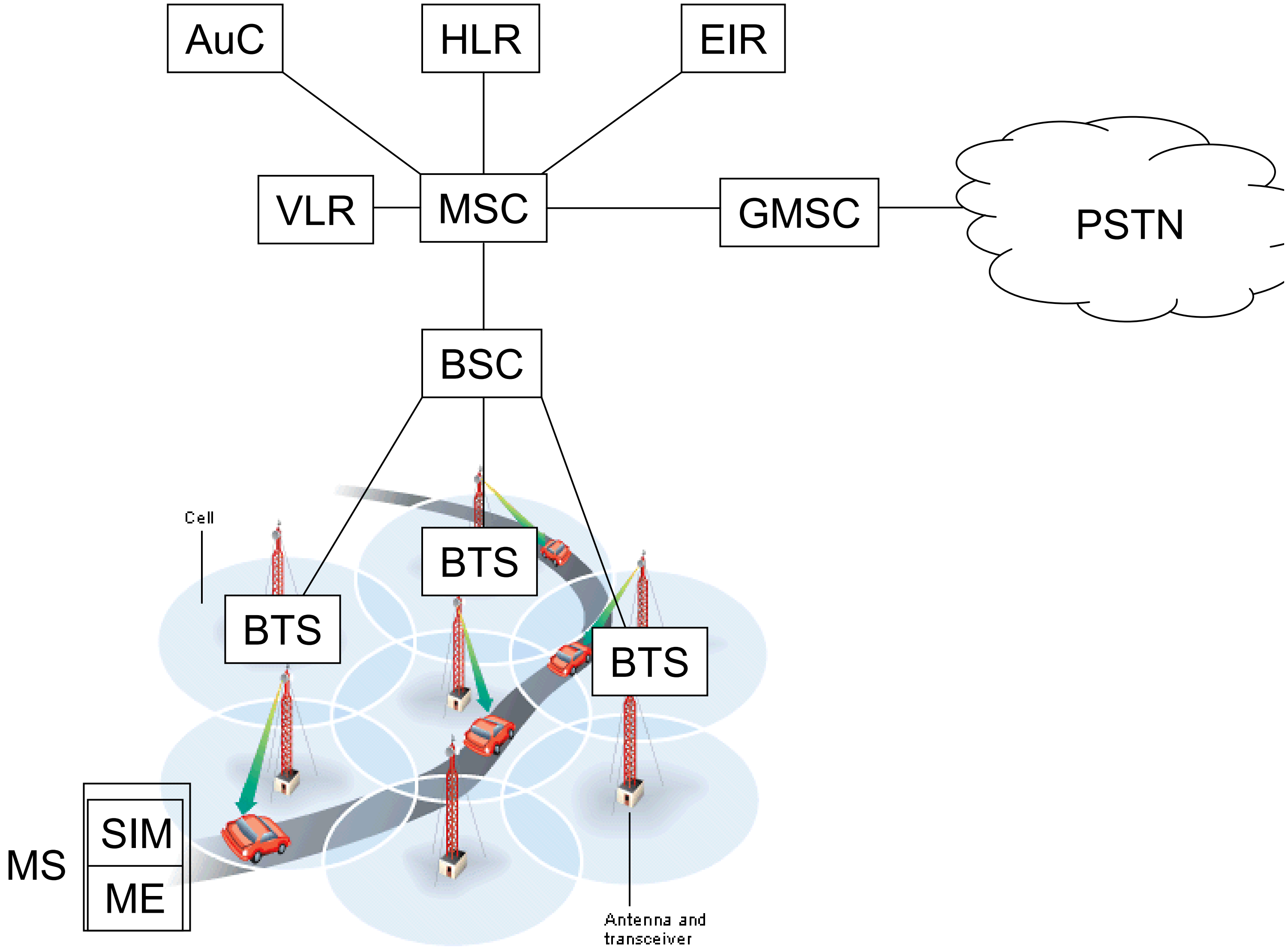
História GSM

- 1990
  - Phase 1 GSM 900 specifications are frozen
  - DCS adaptation starts
  - Validation systems implemented
- 1991
  - First GSM spec demonstrated
  - DCS specifications are frozen
- 1992
  - January - First GSM network operator is Oy Radiolinja Ab in Finland
  - December 1992 - 13 networks on air in 7 areas

História GSM

- 1993
  - Roaming agreements between several operators established
  - December 1993 - 32 networks on air in 18 areas
- 1996
  - Pre-paid SIM cards launched
- 1998
  - First HSCSD trials in Singapore
- 1999
  - First GPRS networks go live
- 2003
  - First EDGE networks go live
- 2004
  - First billion of GSM subscribers reached

Architektúra GSM



Komponenty

- Mobile Station (MS)
  - Subscriber Identity Module (SIM)
    - International Mobile Subscriber Identity (IMSI)
    - authentication key
  - Mobile Equipment (ME)
    - International Mobile Equipment Identity (IMEI)
- Base Transceiver Station (BTS)
  - contains the radio transceivers
  - handles the radio-link protocols

Komponenty

- Base Station Controller (BSC)
  - manages radio resources for one or more BTS nodes
    - channel setup, handovers, frequency hopping, …
  - provides the connection between the MS and the MSC
- Mobile Switching Center (MSC)
  - responsible for one or more BSC nodes
  - controls the traffic among all the BSC nodes
  - provides the connection to the fixed networks (PSTN, ISDN)
  - manages registration, authentication, call establishment and routing

Komponenty

- Home Location Register (HLR)
  - stores subscription information and current location of all subscribers in the network
- Visitor Location Register (VLR)
  - contains selected information from HLR necessary for call provision of the subscribed services, for each mobile currently located in the geographical area controlled by the VLR
- Equipment Identity Register (EIR)
  - contains the IMEI of all registered mobile equipment
- Authentication Center (AuC)
  - contains all the authentication and encryption information, needed for every mobile user

EIR

- India shuts off millions of black market handsets - Dec. 2009
- potential 25 million handsets set to go offline
- thriving black market for cloned devices typically imported from China
- Mumbai terror attacks (2008)
  - The terrorists are understood to have used black market mobile phones to remain in contact

EIR

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Frequency Bands

- Primary (P-GSM 900, 124 channels)
  - 890-915 MHz (uplink)
  - 935-960 MHz (downlink)

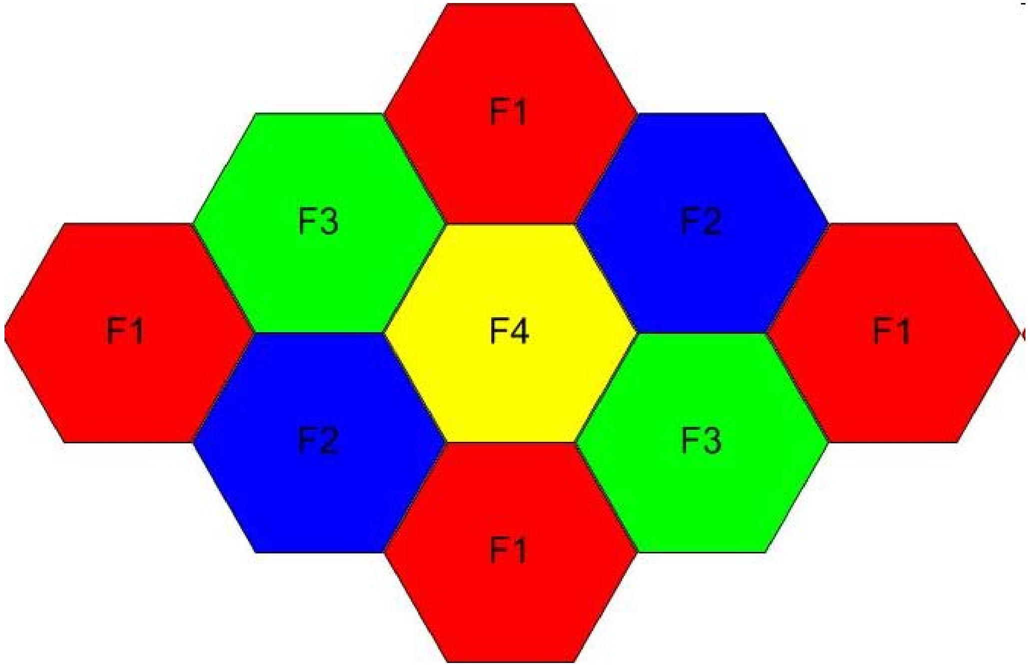
- Extension (E-GSM 900, 50 more channels)
  - 880-890 MHz (uplink)
  - 925-935 MHz (downlink)

- DCS 1800 (GSM 1800) (374 channels)
  - 1710-1785 MHz (uplink)
  - 1805-1880 MHz (downlink)

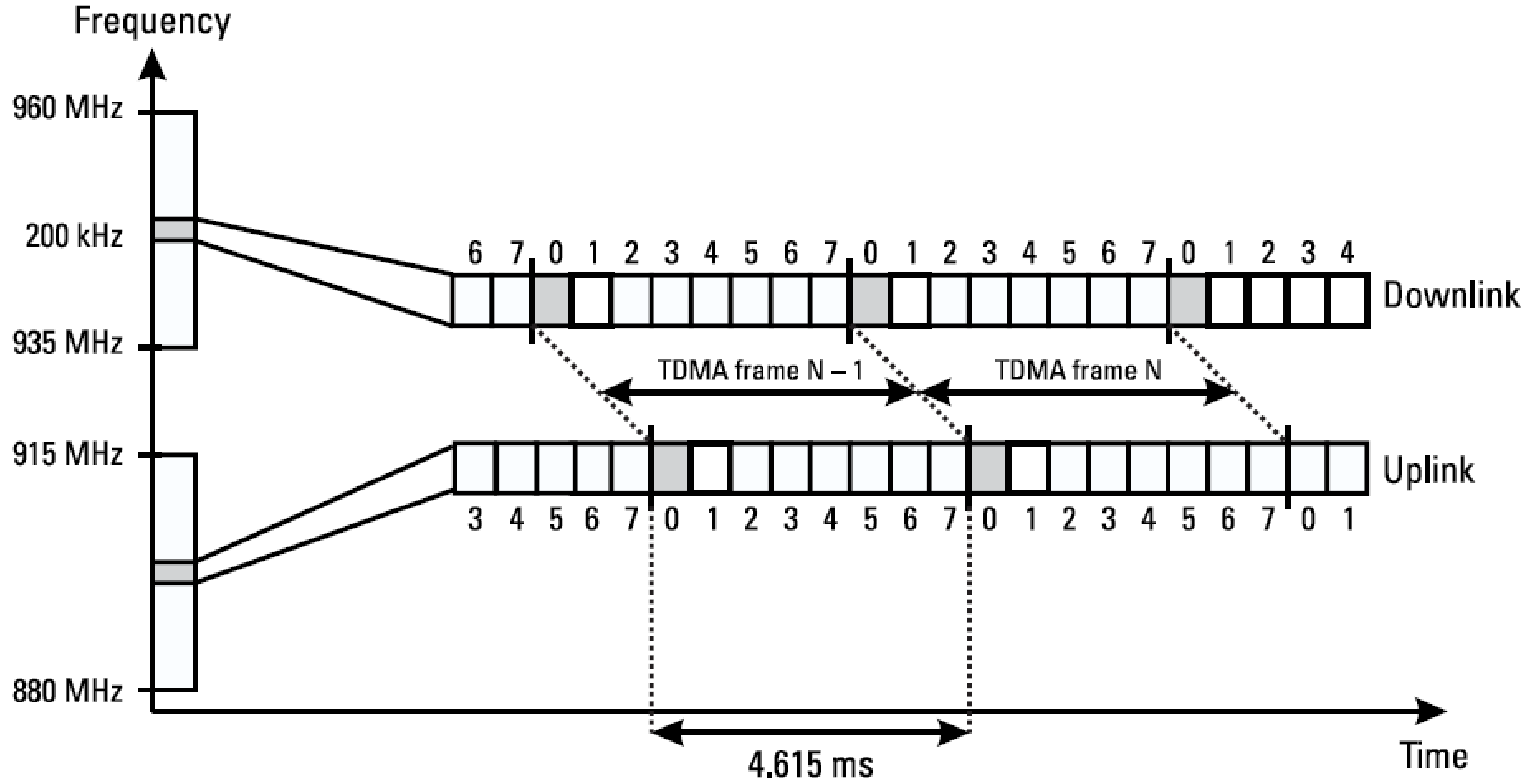
- PCS 1900 (GSM 1900) (6 bands)

Frequency reuse

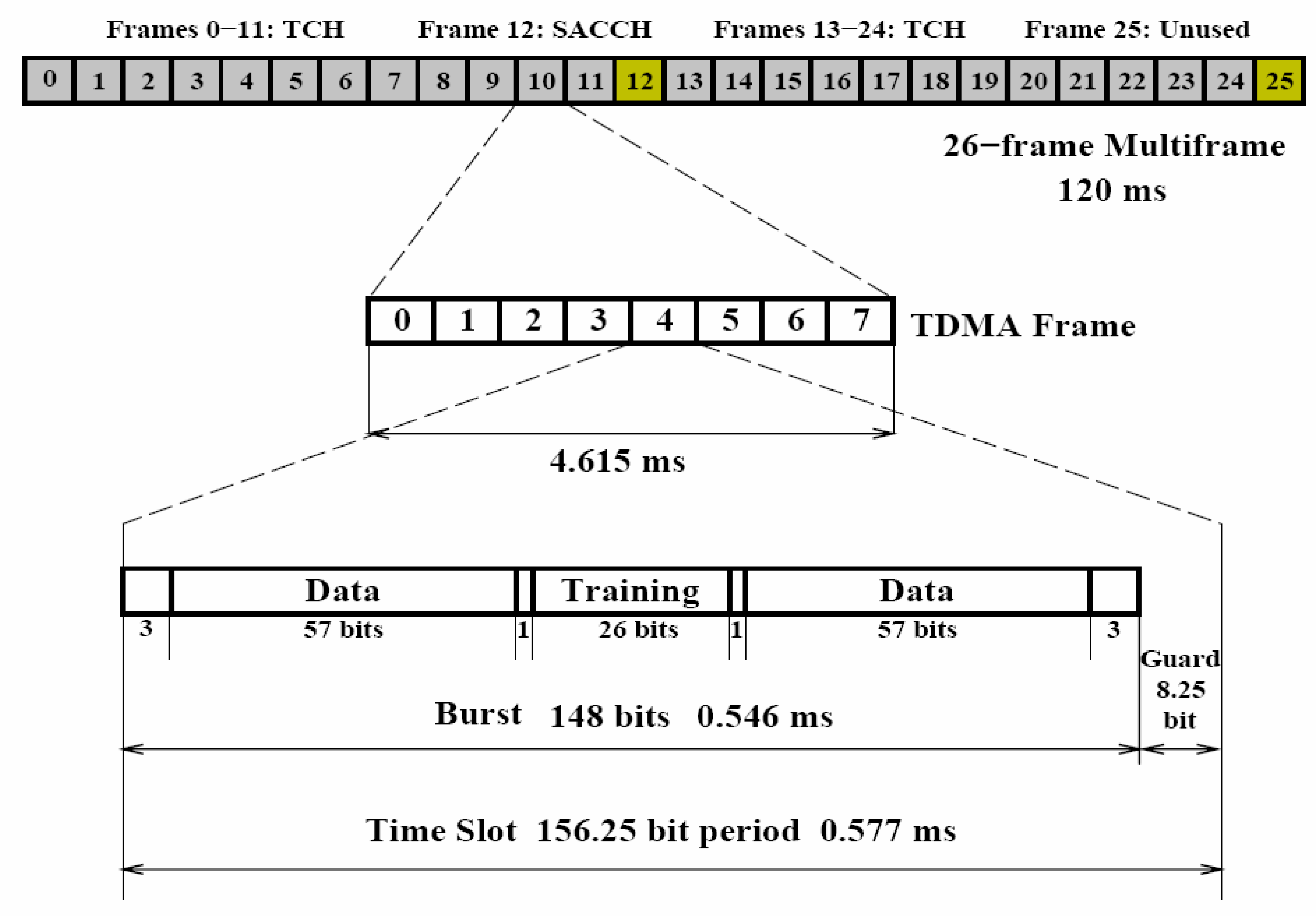
- Each cell on a different frequency



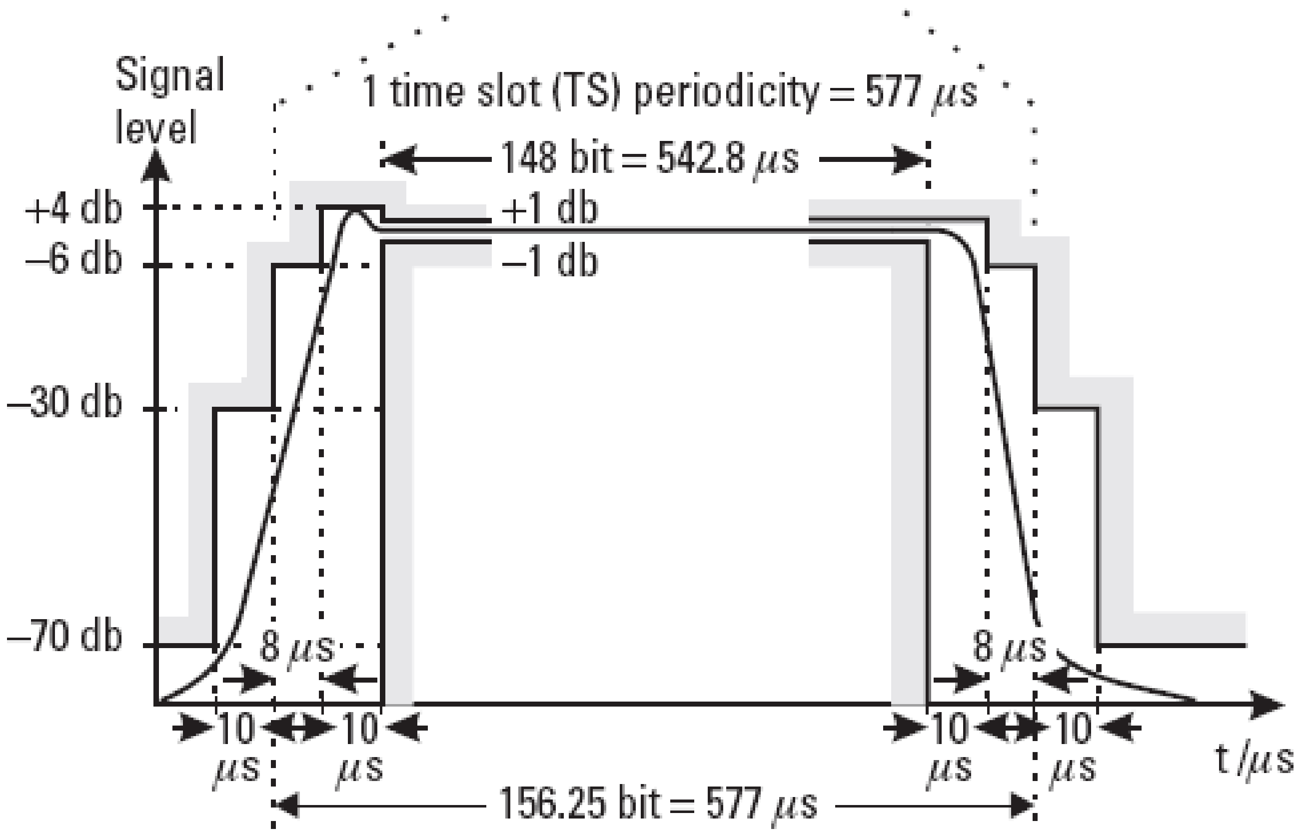
Air interface



Frame structure



Slot overview



Burst

- Data transmitted during a single time slot.
- Each burst allows 8,25 bits for guard time within a slot.
  - to prevent bursts from overlapping and interfering with transmissions in other time slots
  - subtracting this from the 156,25 bits, there are 148 bits usable for each burst

- There are 4 main types of bursts in TDMA:
  - Normal Burst (NB)
  - Frequency Correction Burst (FB)
  - Synchronization Burst (SB)
  - Access Burst (AB)

Bursts

Normal burst

Tail	Information	Training sequence	Information	Tail
3	58	26	58	3

Access burst

Tail	Training sequence	Information	Tail
3	26	36	3

Synchronisation burst

Tail	Information	Training sequence	Information	Tail
3	39	64	39	3

Frequency correction burst

All zeros
148

Physical layer

- Access mode: TDMA/FDMA
- Radio channel spacing: 200 kHz
- Uplink/downlink frequency spacing: 45 MHz
- Modulation: GMSK
- Symbol rate: 270,833 ksps
- Overall bit rate per channel: 24,7 kbps
- Full-rate codec bit rate: 13 kbps
- Speech codec type: RPE-LTP

22,8 vs 24,7

- 24 out of 26 frames used for TCH
- slot bitrate = 24,7 kbps

- effective bitrate per TCH = 24,7*24/26 = 22,8 kbps

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
TCH	TCH	TCH	TCH	TCH	TCH	TCH	TCH	TCH	TCH	TCH	TCH	SACCH	TCH	TCH	TCH	TCH	TCH	TCH	TCH	TCH	TCH	TCH	TCH	TCH	IDLE

Packet data traffic channels

Modulation	Maximum instantaneous bit rate (kbit/s) when using the normal symbol rate (see 3GPP TS 45.004)	Maximum instantaneous bit rate (kbit/s) when using the higher symbol rate (see 3GPP TS 45.004)
GMSK	22,8	-
QPSK	-	55,2
8-PSK	69,6	-
16QAM	92,8	110,4
32QAM	116	138

Modulation

- Minimum Shift Keying (MSK) is a digital modulation scheme in which the phase of the remains continuous while the frequency changes

- Gaussian-filtered Minimum Shift Keying (GMSK) differs from MSK in that a Gaussian Filter of an appropriate bandwidth is used before the modulation stage

MSK – Minimum Shift Keying

- MSK is a continuous phase FSK (CPFSK) where the frequency changes occur at the carrier zero crossings

- MSK is unique due to the relationship between the frequency of a logic 0 and 1
  - The difference between the frequencies is always ½ the data rate.
  - This is the minimum frequency spacing that allows 2 FSK signals to be coherently orthogonal.

MSK – How It Works

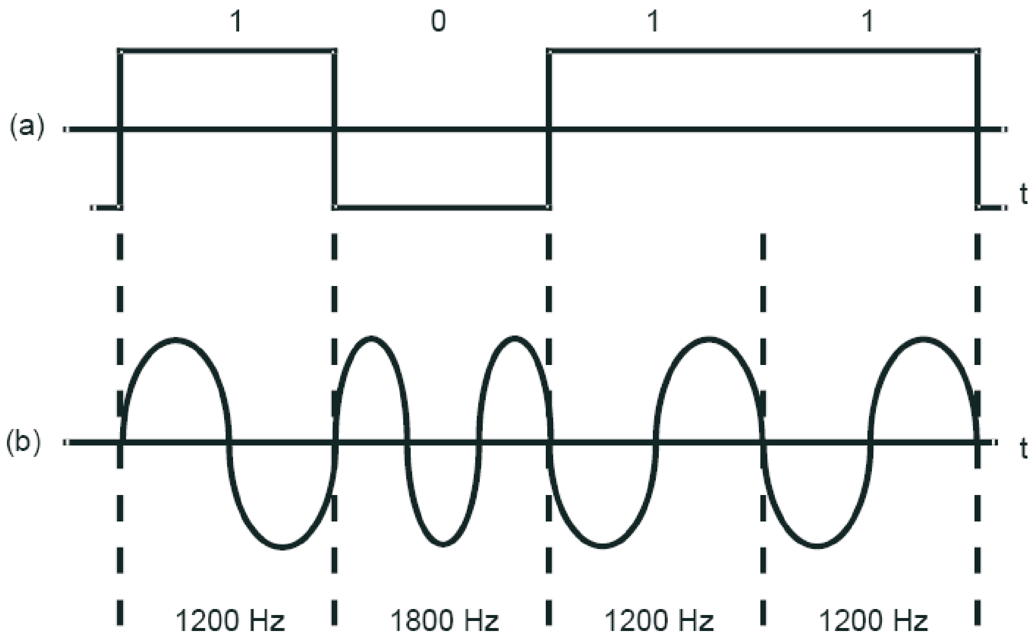
- baseband modulation starts with a bitstream of 0’s and 1’s and a bit-clock

- baseband signal is generated by first transforming the 0/1 encoded bits into -1/1 using an NRZ filter

- signal is then frequency modulated to produce the complete MSK signal

Example of MSK

- 1200 bits/sec baseband MSK data signal
- Frequency spacing = 600Hz



a) NRZ data b) MSK signal

Pros of MSK

- Since the MSK signals are orthogonal and minimal distance, the spectrum can be more compact
- The detection scheme can take advantage of the orthogonal characteristics
- Low ISI (compared to GMSK)

Cons of MSK

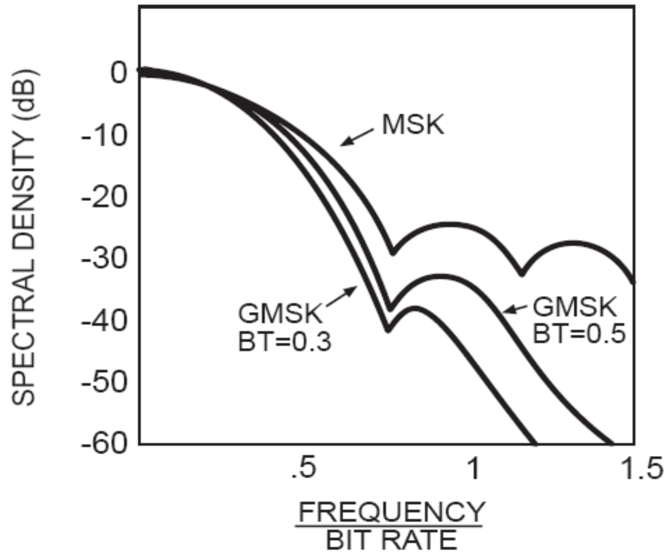
- The fundamental problem with MSK is that the spectrum has side-lobes extending well above the data rate (next slide)
- For wireless systems which require more efficient use of RF channel BW, it is necessary to reduce the energy of the upper side-lobes
- Solution – use a pre-modulation filter:
  - Straight-forward Approach: Low-Pass Filter
  - More Efficient/Realistic Approach: Gaussian Filter

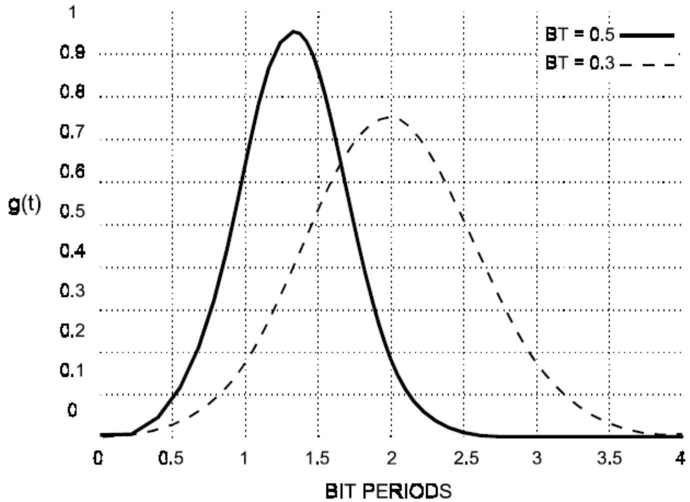
The Need for GMSK

- Gaussian Filter
  - Impulse response defined by a Gaussian Distribution – no overshoot or ringing (see lower figure)
  - BT – refers to the filter's -3dB BW and data rate by:

$$BT = \frac{f_{-3dB}}{BitRate}$$

  - Notice that a bit is spread over more than 1 bit period. This gives rise to ISI.
  - For BT=0,3, adjacent symbols will interfere with each other more than for BT=0,5
  - GMSK with BT=∞ is equivalent to MSK.
  - Trade-off between ISI and side-lobe suppression (top and bottom figures)
  - The higher the ISI, the more difficult the detection will become.

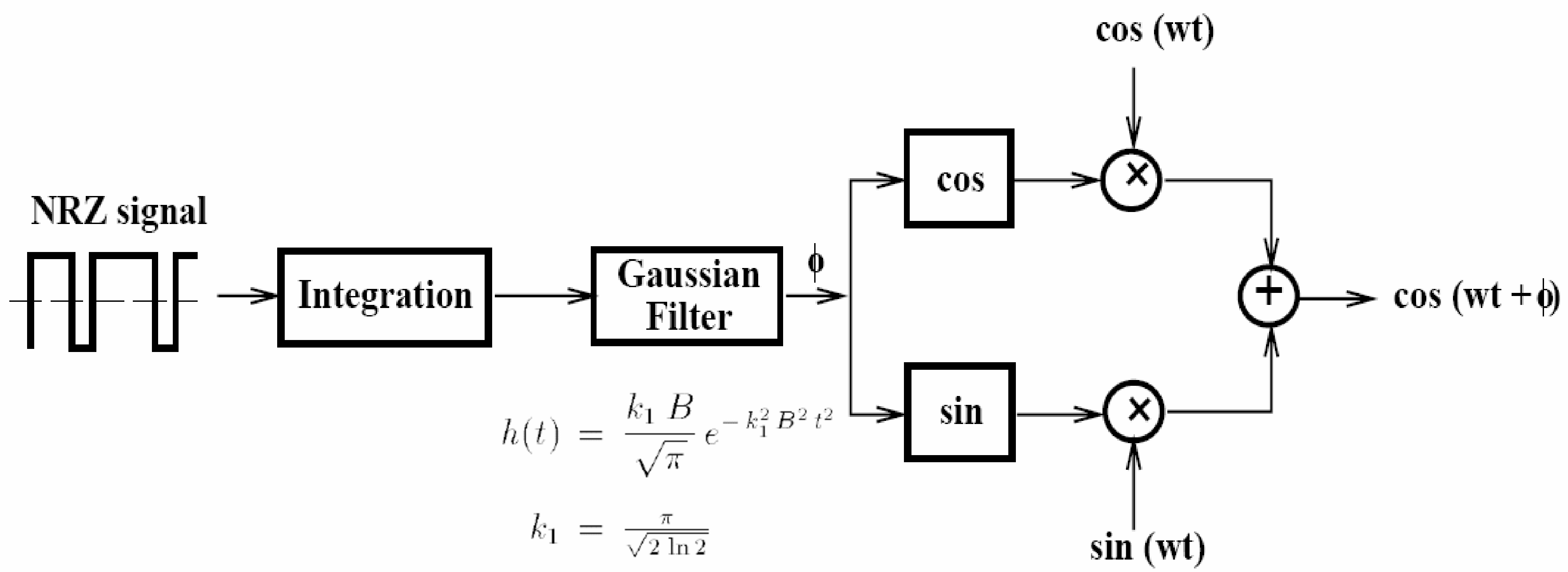




GMSK – Applications

- An important application of GMSK is GSM, which is a time-division multiple-access system
- For this application, the BT is standardized at 0.3, which provides the best compromise between increased bandwidth occupancy and resistance to ISI
- 99% of the RF power of GMSK signals is specified to confine to 250 kHz (+/- 25kHz margin from the signal) $\rightarrow$ side lobes need to be virtually zero outside this frequency band and ISI ~ 0

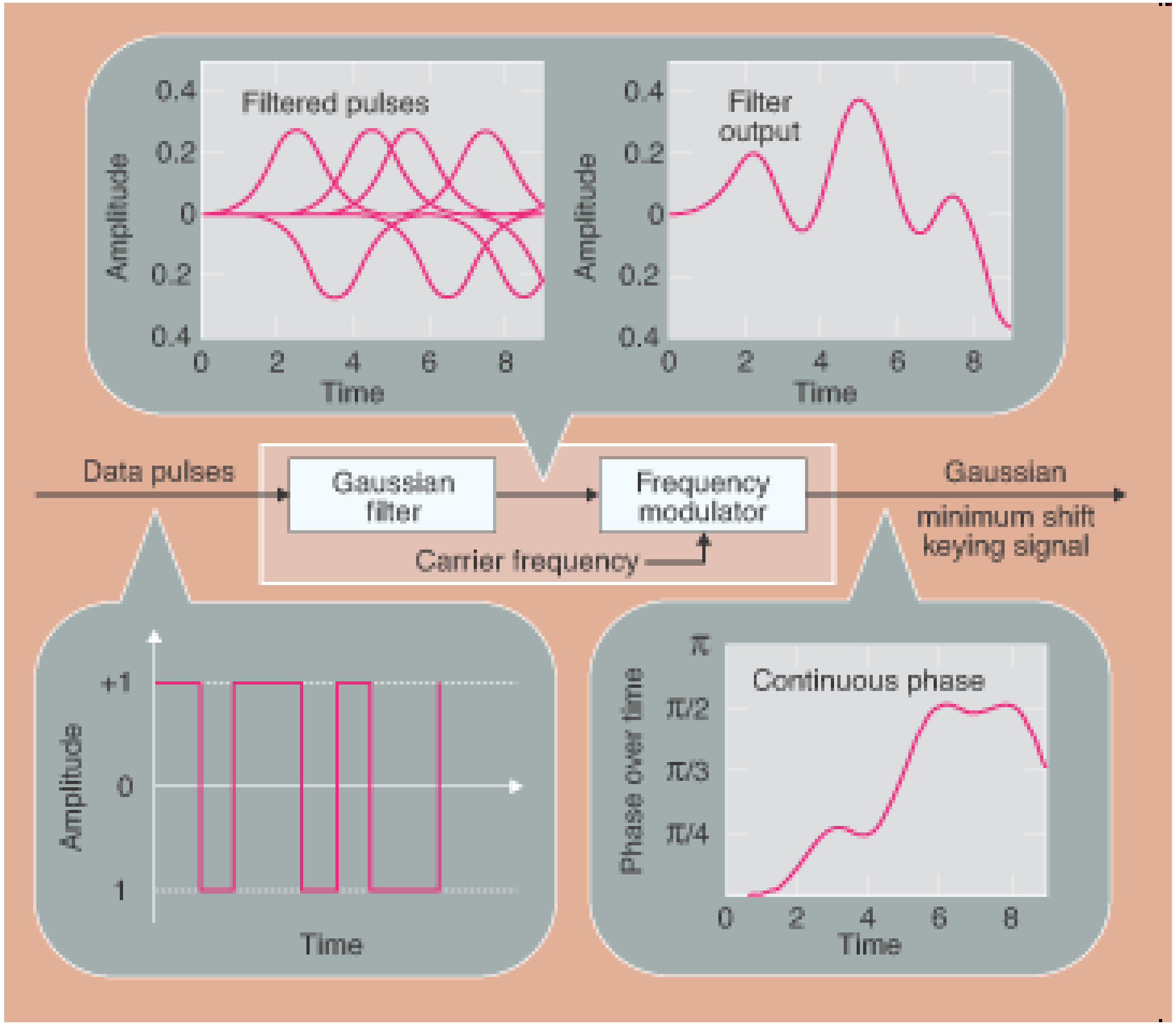
GMSK Modulator



$$h(t) = \frac{k_1 B}{\sqrt{\pi}} e^{-k_1^2 B^2 t^2}$$

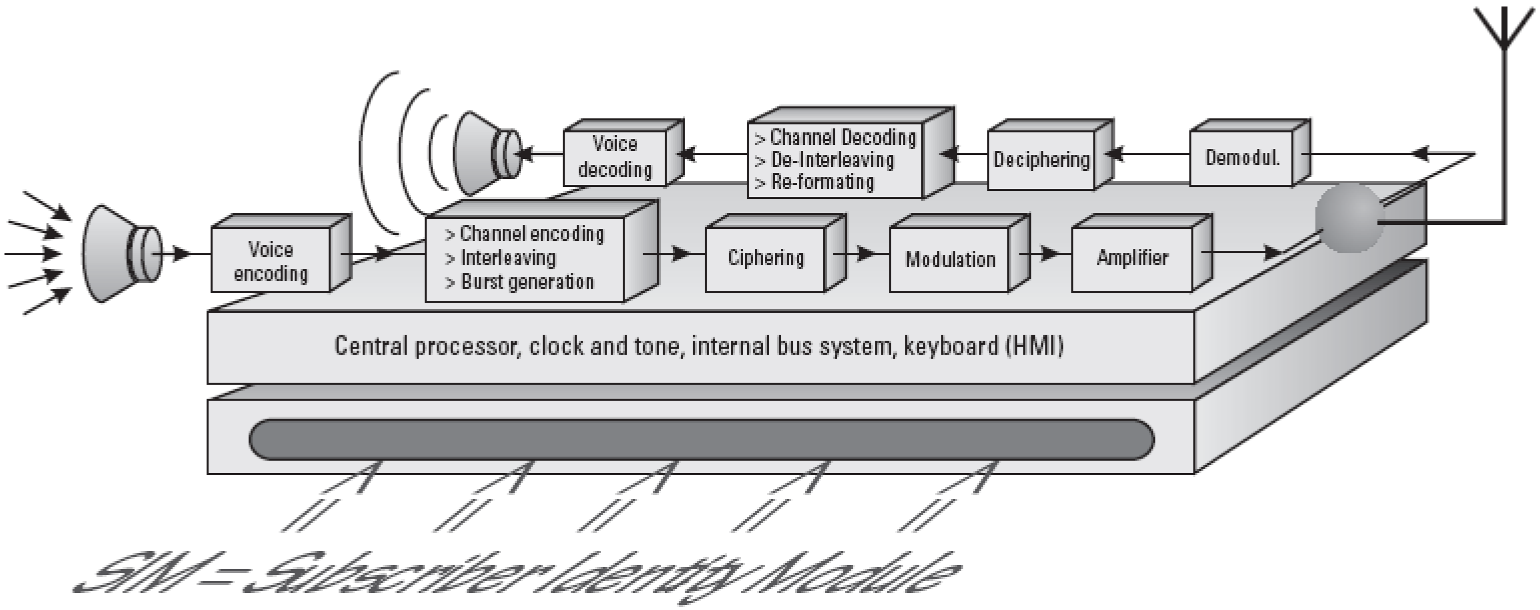
$$k_1 = \frac{\pi}{\sqrt{2 \ln 2}}$$

GMSK

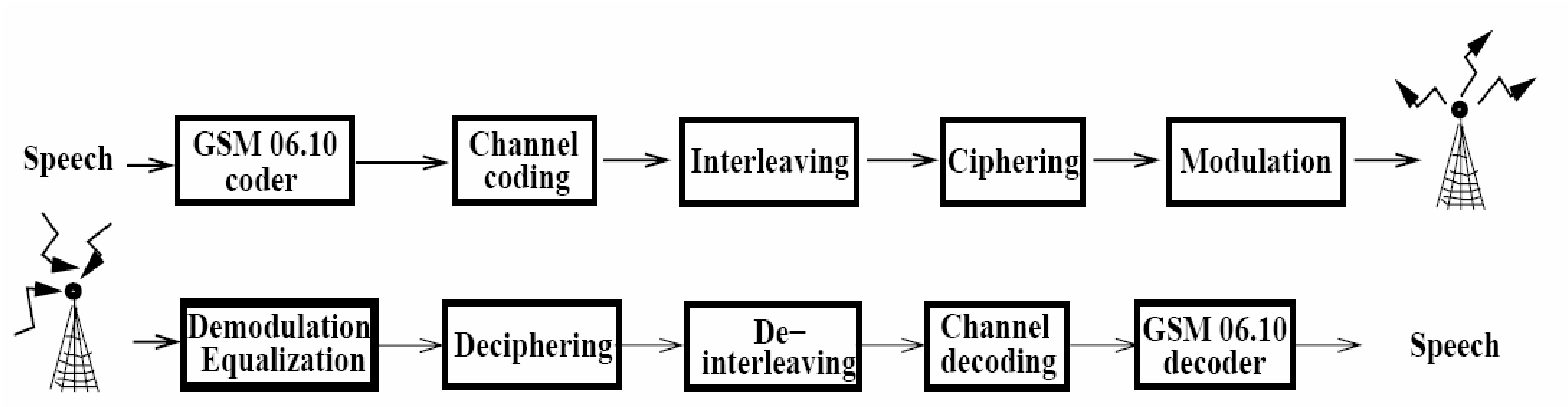


Filtered pulses
Amplitude
0.4
0.2
0
0.2
0.4
0
2
4
6
8
Time
Filter output
Amplitude
0.4
0.2
0
0.2
0.4
0
2
4
6
8
Time
Data pulses
Gaussian filter
Frequency modulator
Carrier frequency
Gaussian minimum shift keying signal
Amplitude
+1
0
1
Time
Continuous phase
Phase over time
π
π/2
π/3
π/4
0
2
4
6
8
Time

Mobile Station

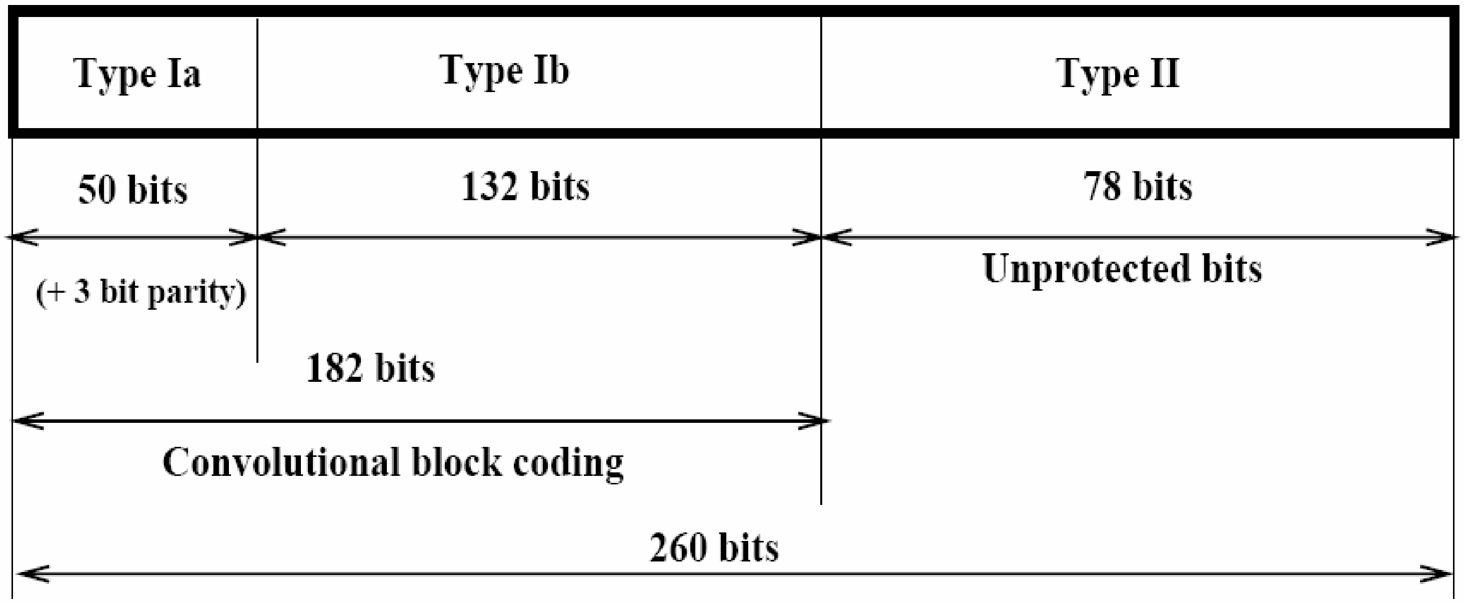


Speech processing



Speech processing

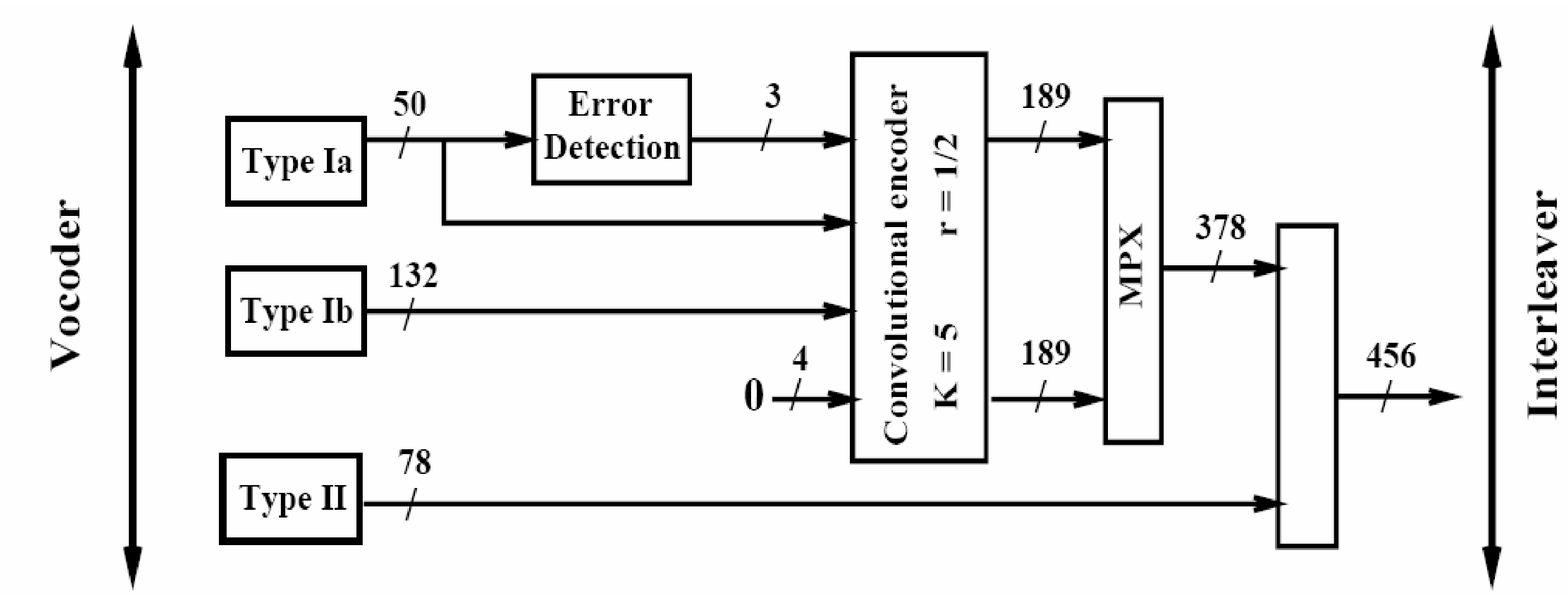
- speech coding algorithm
  - speech block of 260 bits every 20 ms
  - equals a bit rate of 13 kbps



Channel Coding

- Recall that the speech codec produces a 260 bit block for every 20 ms speech sample. From subjective testing, it was found that some bits of this block were more important for perceived speech quality than others. The bits are thus divided into three classes:
- **Class Ia** 50 bits - most sensitive to bit errors
  Class Ib 132 bits - moderately sensitive to bit errors
  Class II 78 bits - least sensitive to bit errors
- Class Ia bits have a 3 bit Cyclic Redundancy Code added for error detection. If an error is detected, the frame is judged too damaged to be comprehensible and it is discarded. It is replaced by a slightly attenuated version of the previous correctly received frame. These 53 bits, together with the 132 Class Ib bits and a 4 bit tail sequence (a total of 189 bits), are input into a 1/2 rate convolutional encoder of constraint length 4. Each input bit is encoded as two output bits, based on a combination of the previous 4 input bits. The convolutional encoder thus outputs 378 bits, to which are added the 78 remaining Class II bits, which are unprotected. Thus every 20 ms speech sample is encoded as 456 bits, giving a bit rate of 22.8 kbps.
- To further protect against the burst errors common to the radio interface, each sample is diagonally interleaved. The 456 bits output by the convolutional encoder are divided into 8 blocks of 57 bits, and these blocks are transmitted in eight consecutive time-slot bursts. Since each time-slot burst can carry two 57 bit blocks, each burst carries traffic from two different speech samples.

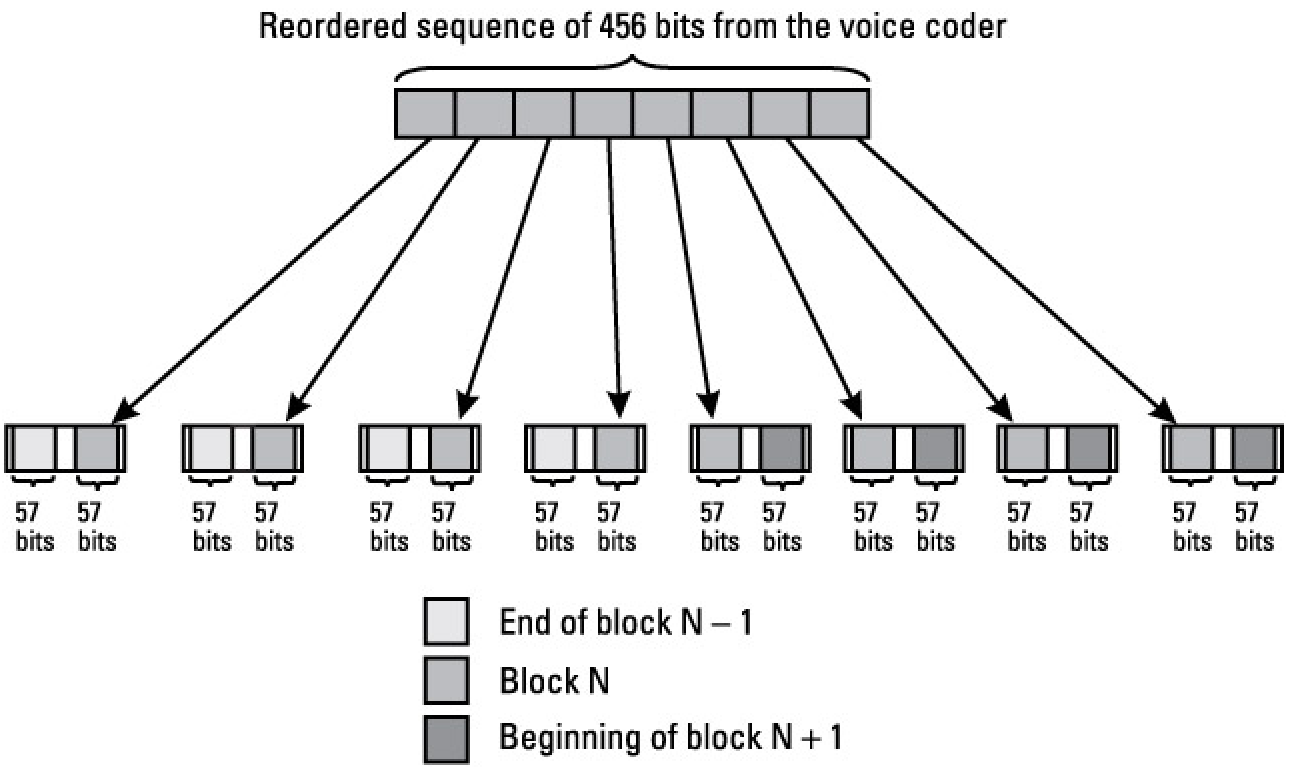
Speech processing



$$G_1 = D^4 + D^3 + 1$$

$$G_2 = D^4 + D^3 + D + 1$$

Interleaving



Channel concept

- Physical vs. Logical channel
- Traffic vs. Control channel
- Common vs. Dedicated channel

Traffic Channels (TCH)

- Encoded Speech
  - Full Rate Speech TCH (TCH/FS) - 13 kb/s
  - Half Rate Speech TCH (TCH/HS) - 5.6 kb/s

- Data
  - Full rate Data TCH (TCH/F14.1) - 14.4 kb/s
  - Full rate Data TCH (TCH/F9.6) - 9.6 kb/s
  - Full rate Data TCH (TCH/F4.8) - 4.8 kb/s
  - Half rate Data TCH (TCH/F4.8) - 4.8 kb/s
  - Full rate Data TCH (TCH/F2.4) - ≤2.4 kb/s
  - Half rate Data TCH (TCH/H2.4) - ≤2.4 kb/s

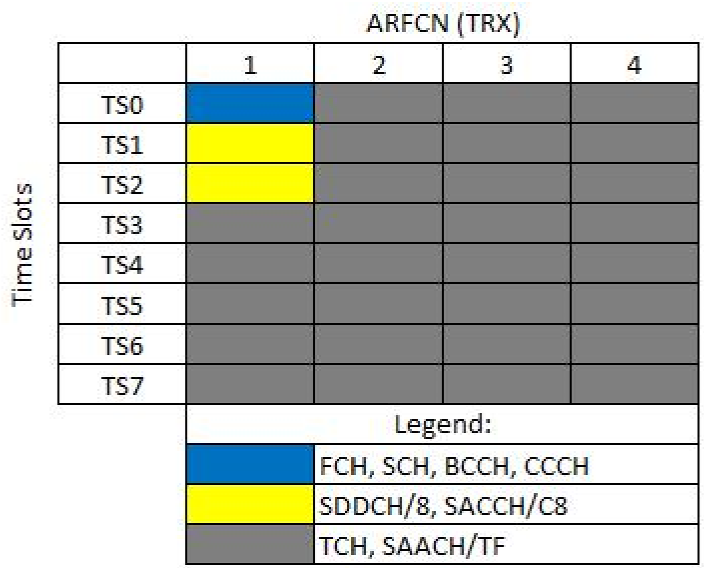
Control Channels (CCH)

- **Broadcast Channels (BCH)**
  Broadcast Control Channel (BCCH)
  Frequency Correction Channel (FCCH)
  Synchronization Channel (SCH)
  Cell Broadcast Channel (CBCH)

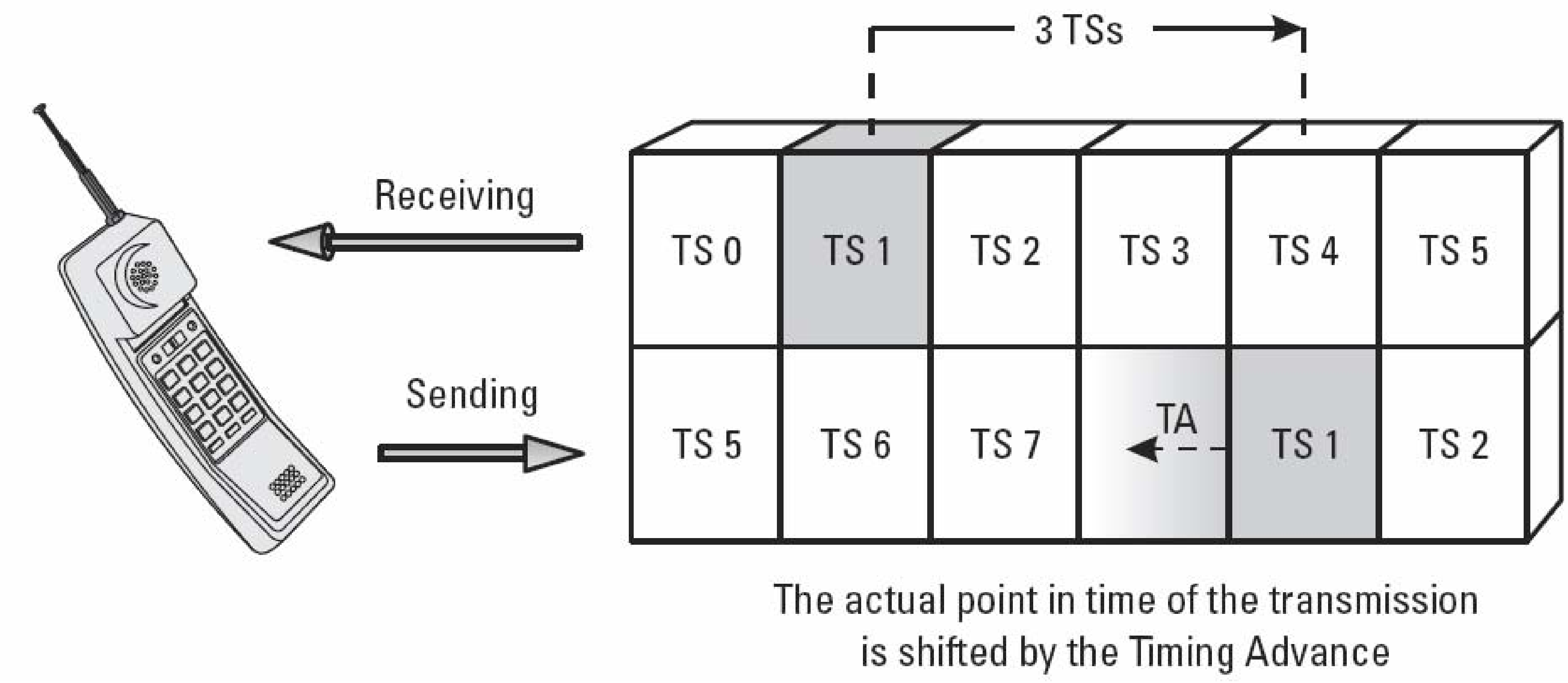
- **Common Control Channels (CCCH)**
  Paging Channel (PCH)
  Random Access Channel (RACH)
  Access Grant Channel (AGCH)

- **Standalone Dedicated Control Channel (SDCCH)**
  Associated Control Channel (ACCH)
  Fast Associated Control Channel (FACCH)
  Slow Associated Control Channel (SACCH)

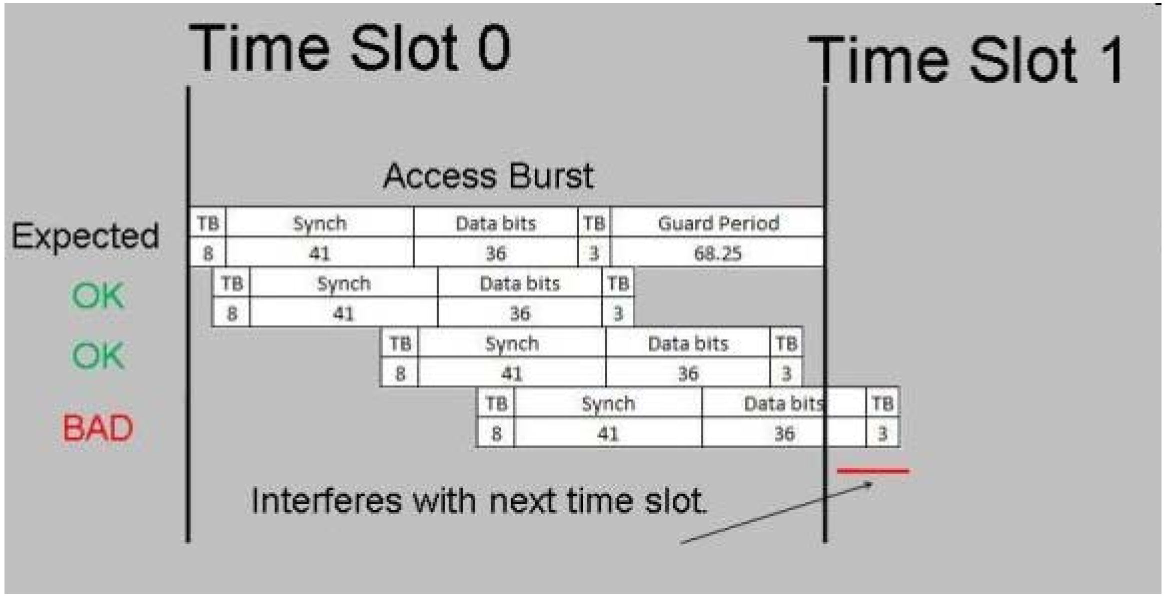
4-TRX BTS


ARFCN (TRX)
1
2
3
4
Time Slots
TS0
TS1
TS2
TS3
TS4
TS5
TS6
TS7
Legend:
FCH, SCH, BCCH, CCCH
SDDCH/8, SACCH/C8
TCH, SAACH/TF

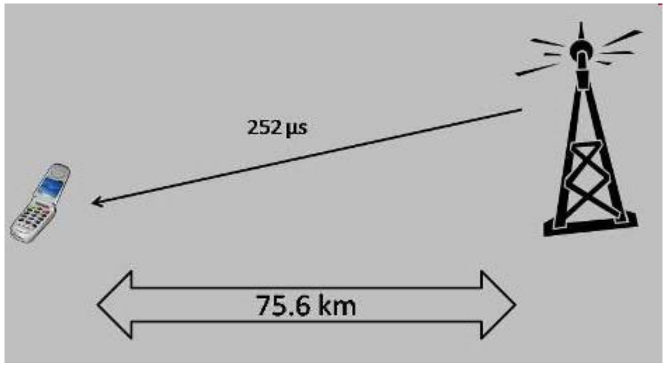
Timing advance



Timing advance

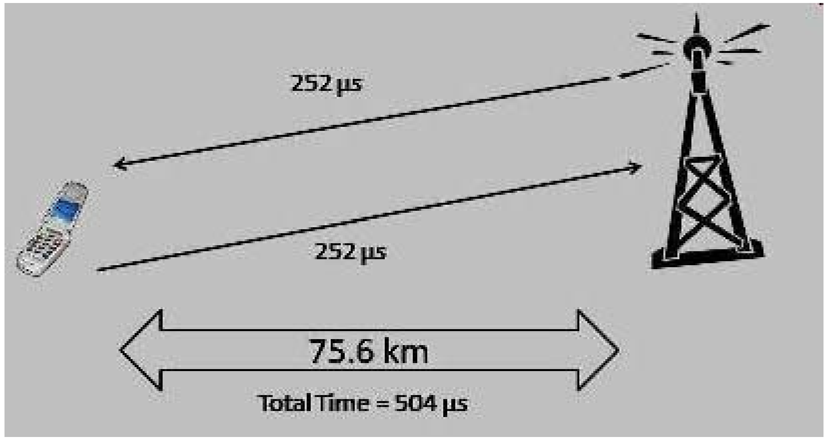


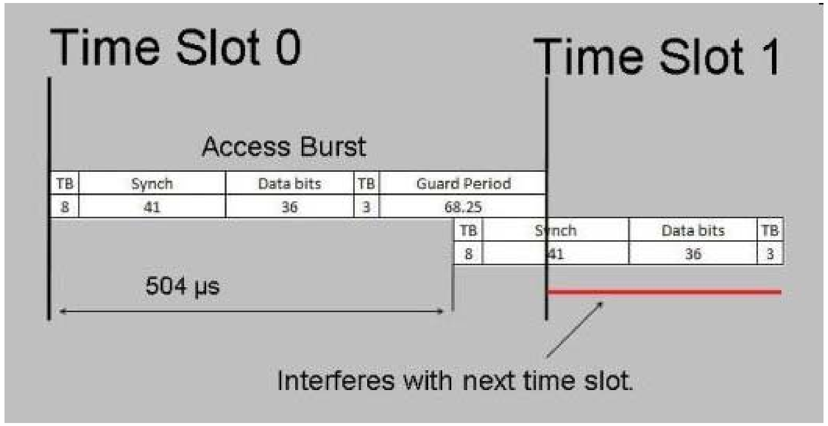
- guard time = 68,25 bits
- 1 bit = 3,69 μs
- max delay of 252 μs
- max BTS↔MS distance = 75,6 km



Timing advance

- 75,6 km / 2 = 37,8 km

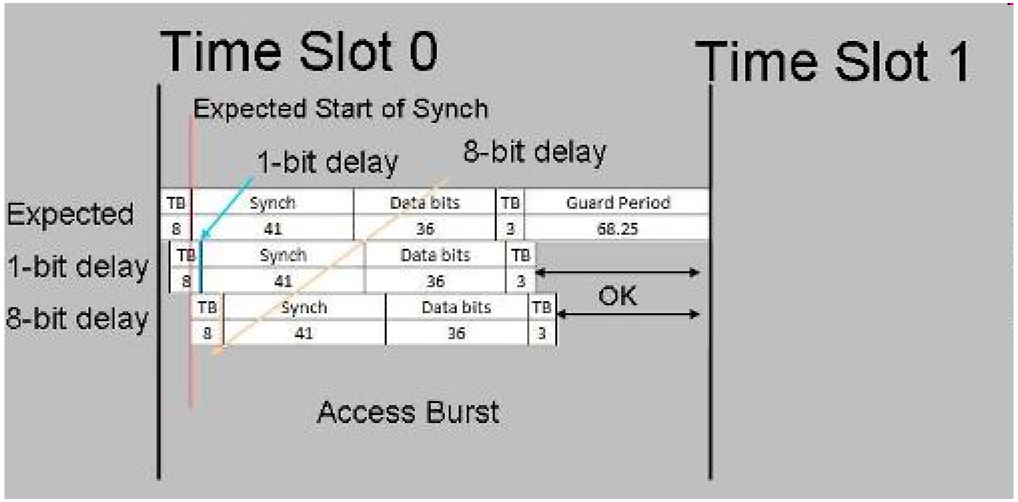




Timing advance

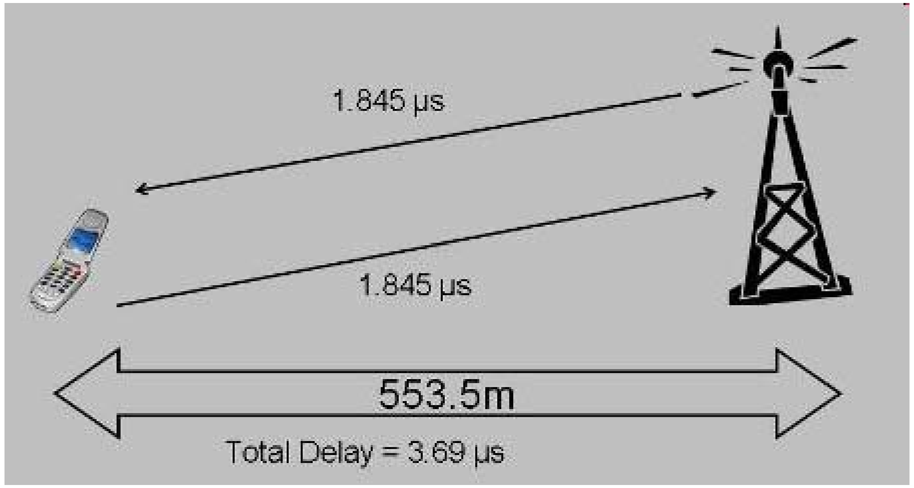
- if the BSC sees that the synch is late by a **single bit**, then it knows that the **propagation delay** is **3.69µs**

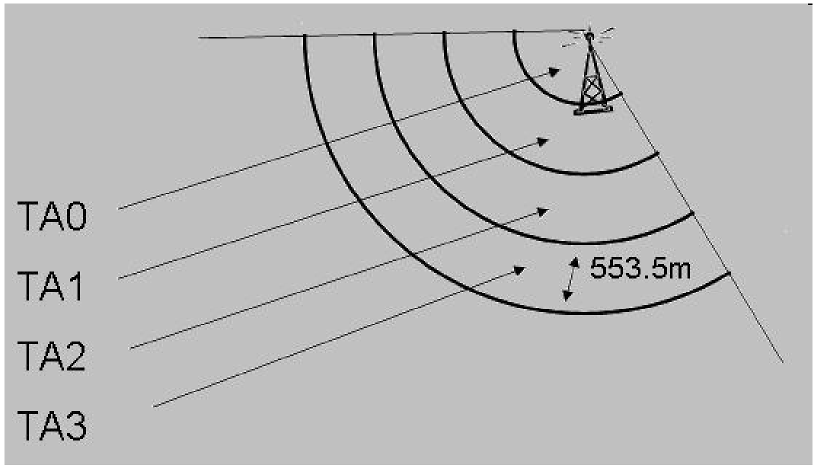
TA	From	To
0	0µs	3.69µs
1	3.69µs	7.38µs
2	7.38µs	11.07µs
3	11.07µs	14.76µs
...	...	...
63	232.47µs	236.16µs



Timing advance

TA Ring	Start	End
0	0	553.5m
1	553.5m	1107m
2	1107m	1660.5m
3	1660.5m	2214m
...	...	...
63	34.87km	35.42km

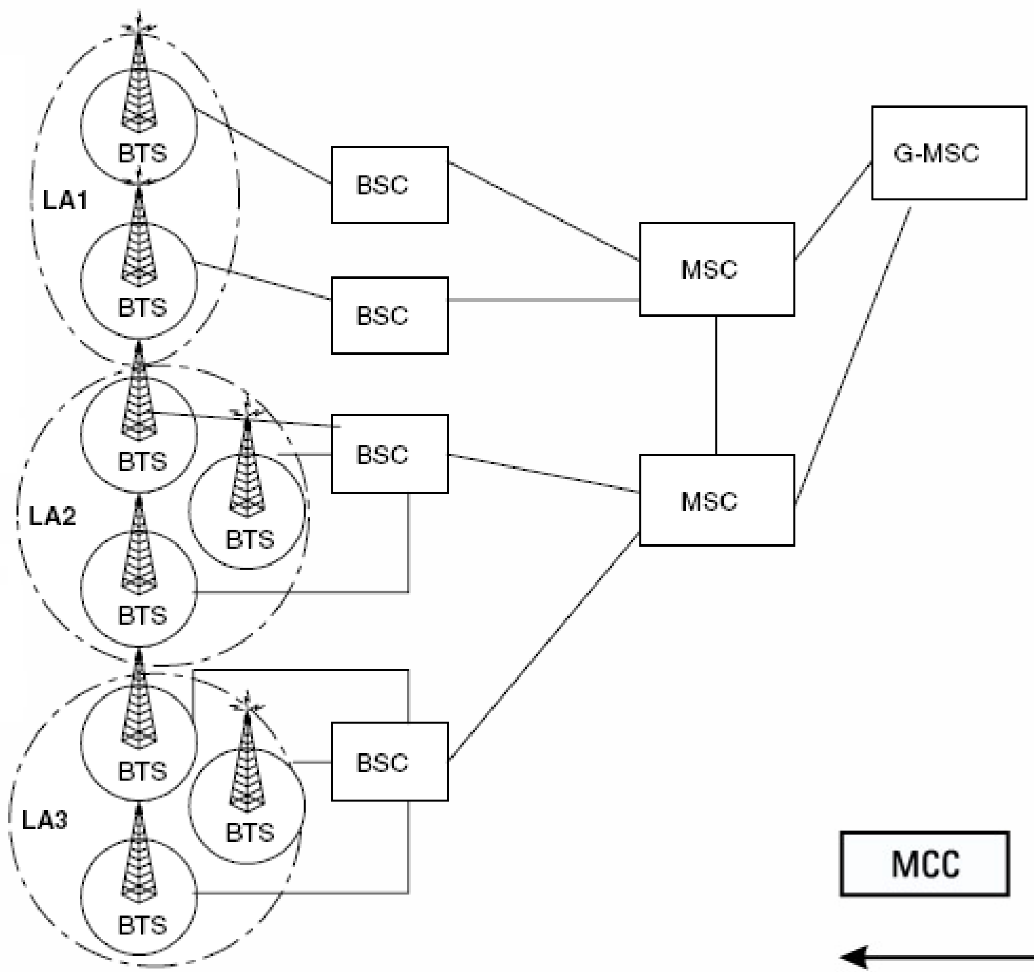


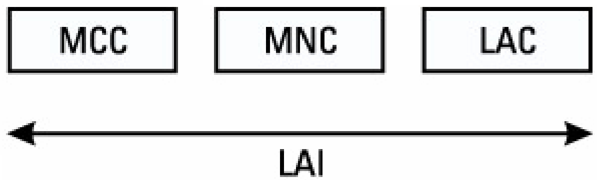


Procedúry

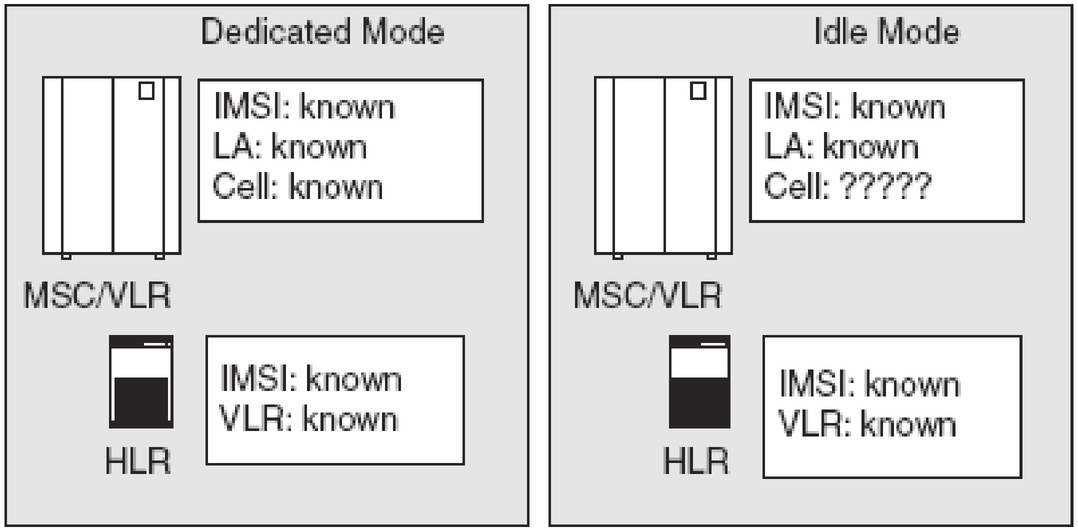
- Mobility Management
- Initial Access
- IMSI attach
- Call setup
- Location Area Update
- Cell change
- Handover

Location area

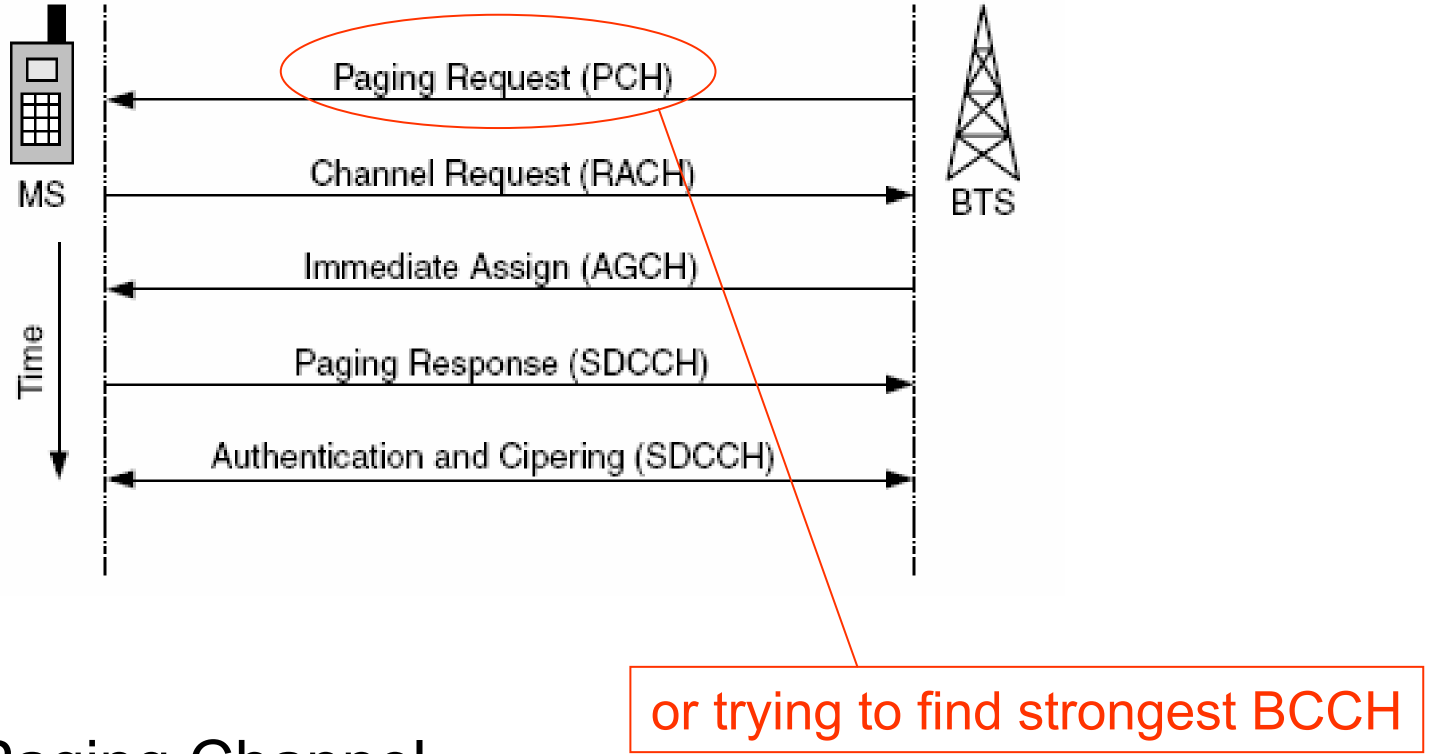




Mobility Management

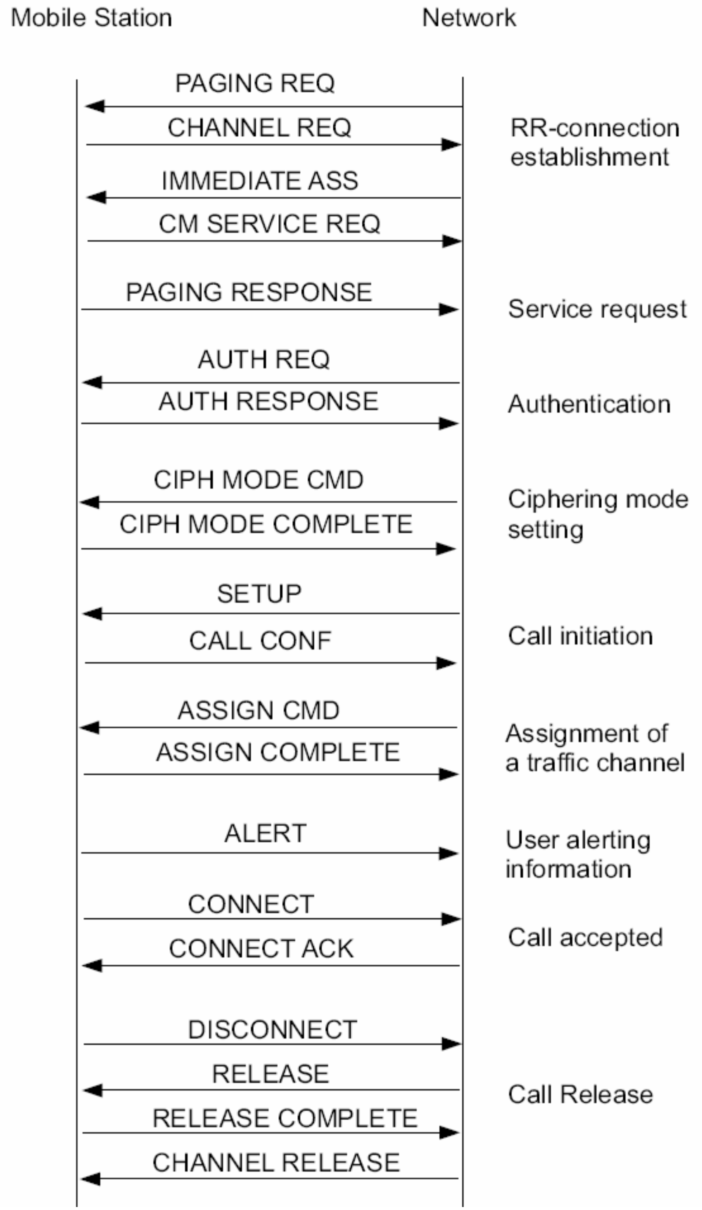


Initial Access

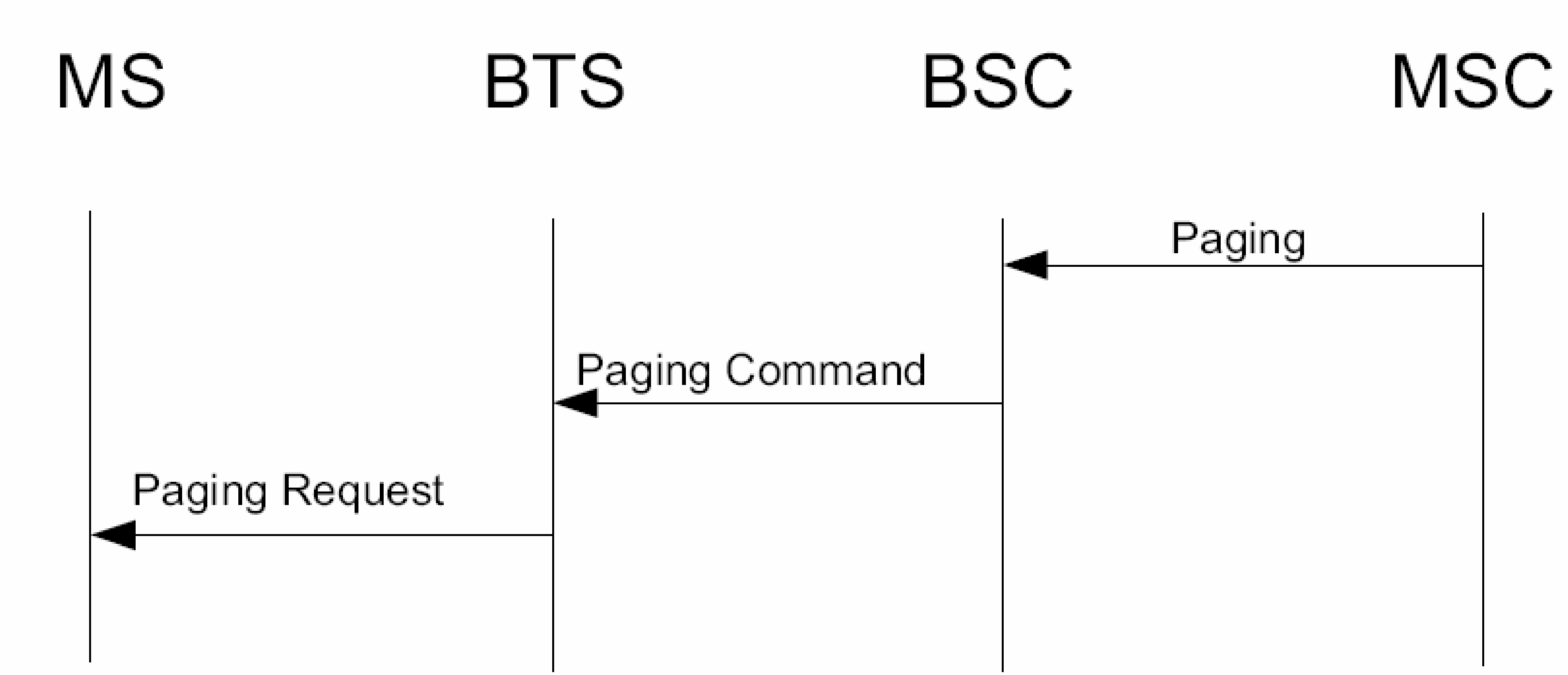


PCH Paging Channel
RACH Random Access Channel
AGCH Access Grant Channel
SDCCH Stand-alone Dedicated Control Channel

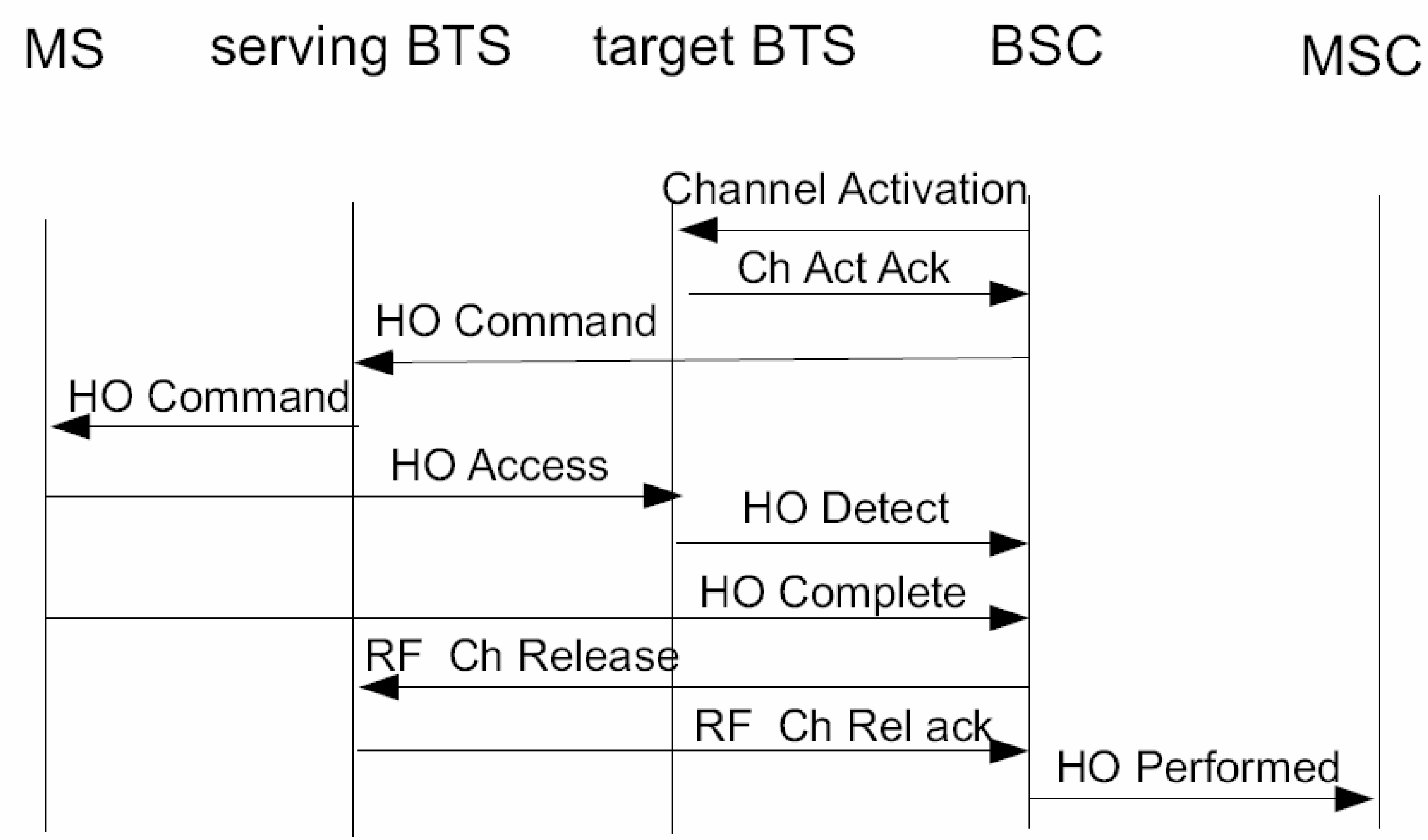
Call setup


Mobile Station
Network
PAGING REQ
CHANNEL REQ
IMMEDIATE ASS
CM SERVICE REQ
RR-connection establishment
PAGING RESPONSE
Service request
AUTH REQ
AUTH RESPONSE
Authentication
CIPH MODE CMD
CIPH MODE COMPLETE
Ciphering mode setting
SETUP
CALL CONF
Call initiation
ASSIGN CMD
ASSIGN COMPLETE
Assignment of a traffic channel
ALERT
User alerting information
CONNECT
CONNECT ACK
Call accepted
DISCONNECT
RELEASE
RELEASE COMPLETE
CHANNEL RELEASE
Call Release

Paging



Handover


MS
serving BTS
target BTS
BSC
MSC
Channel Activation
Ch Act Ack
HO Command
HO Command
HO Access
HO Detect
HO Complete
RF Ch Release
RF Ch Rel ack
HO Performed

HSCSD

- High Speed Circuit Switched Data
- 14,4 kbps per slot
- up to 8 slots = 115,2 kbps
- charging still on time basis

General Packet Radio Service

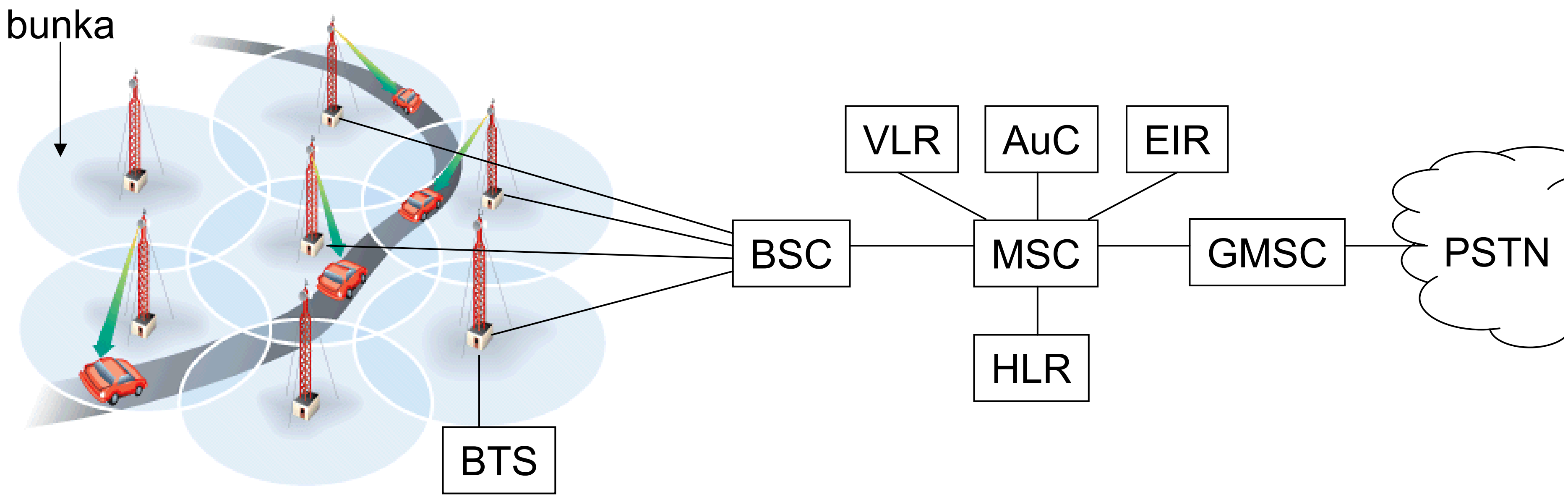
- resources (time slots) allocated only if needed

- users can share a single slot
- one user can use >1 slot in 1 frame

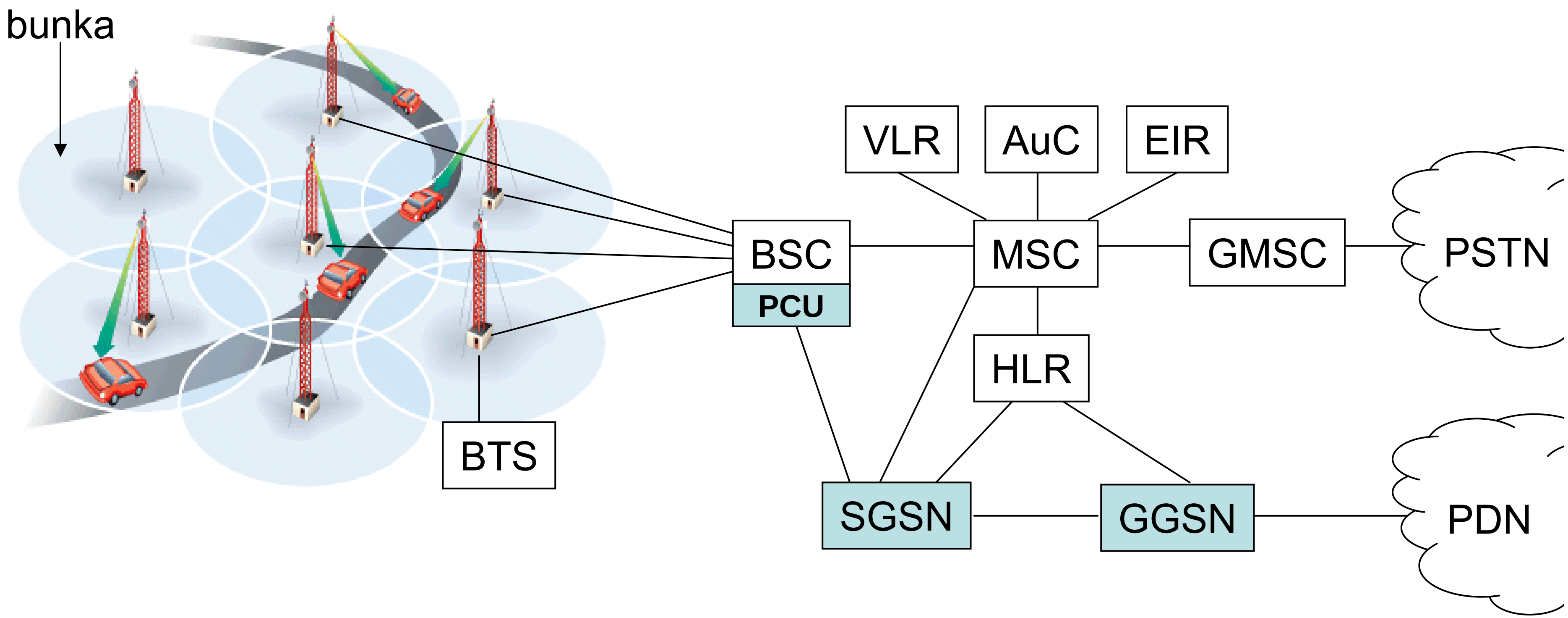
- adaptive coding
  - based on BER

- charging possible on data volume basis

Architektúra GSM



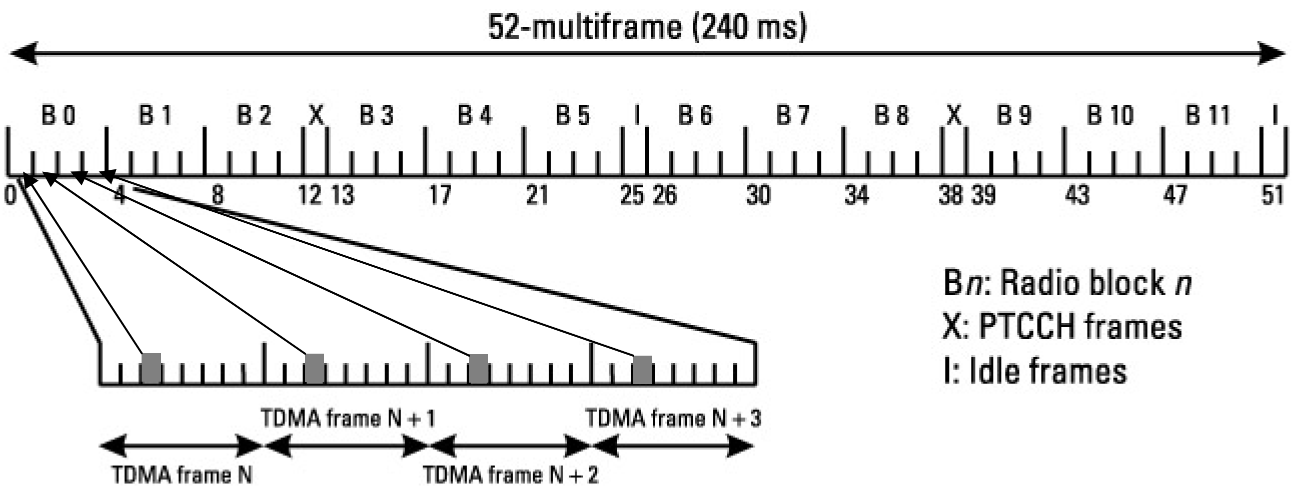
Architektúra GSM/GPRS



Multislot Classes

Multislot class	Maximum number of slots			Type
	Rx	Tx	Sum	
1	1	1	2	1
2	2	1	3	1
3	2	2	3	1
4	3	1	4	1
5	2	2	4	1
6	3	2	4	1
7	3	3	4	1
8	4	1	5	1
9	3	2	5	1
10	4	2	5	1
11	4	3	5	1
12	4	4	5	1
13	3	3	NA	2
14	4	4	NA	2
15	5	5	NA	2
16	6	6	NA	2
17	7	7	NA	2
18	8	8	NA	2
19	6	2	NA	1
20	6	3	NA	1
21	6	4	NA	1
22	6	4	NA	1
23	6	6	NA	1
24	8	2	NA	1
25	8	3	NA	1
26	8	4	NA	1
27	8	4	NA	1
28	8	6	NA	1
29	8	8	NA	1

GPRS – frame structure



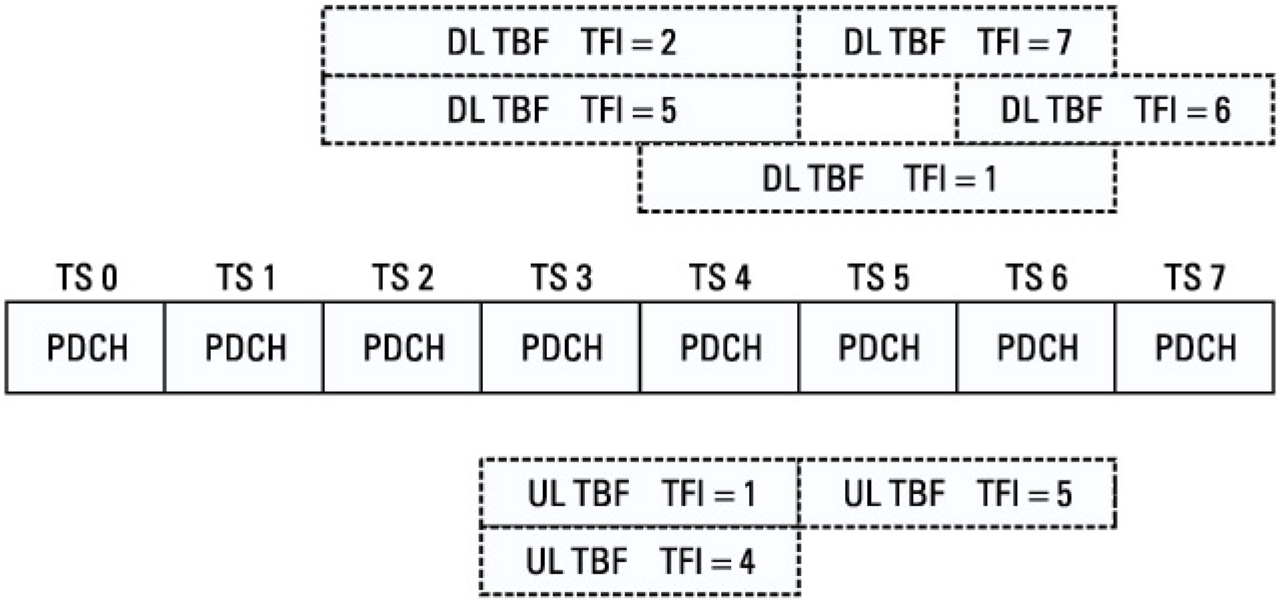
PDCH = Packet Data Channel

Temporary Block Flow

- physical connection between MS & network
- characterized by one or several PDCHs allocated by the network to an MS for the duration of the data transfer
- once the data transfer is finished, the TBF is released
- downlink TBF
  - transfer of data from the network to the MS
- uplink TBF
  - transfer of data from the MS to the network

- TBFs belonging to different MS can share the same PDCH

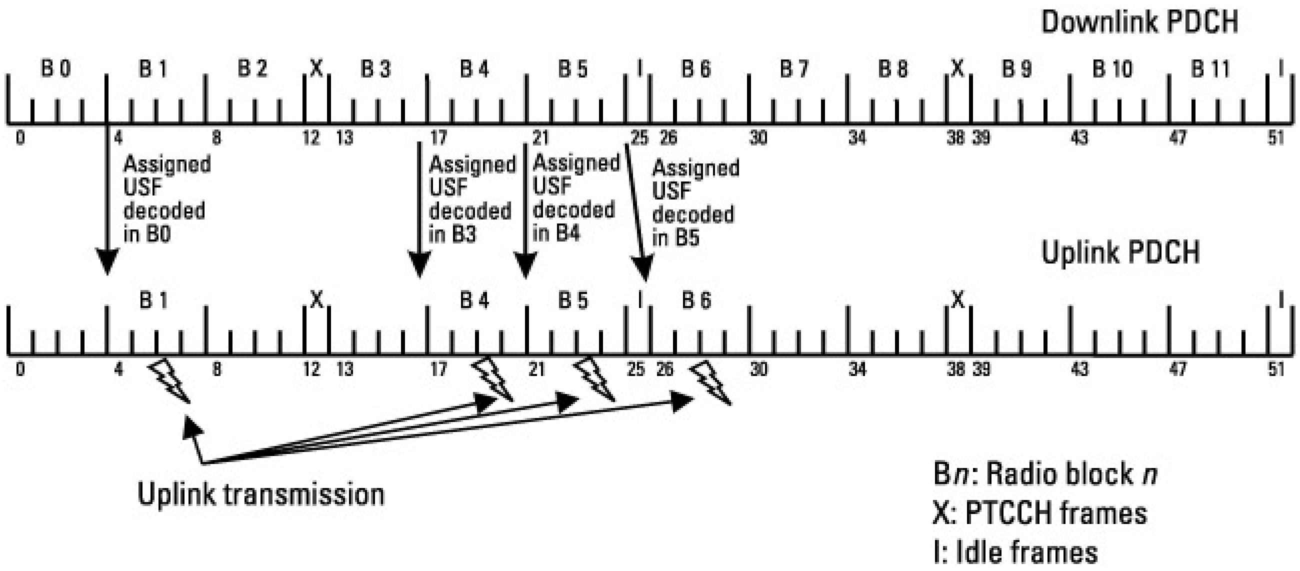
TBF - DL



TFI = Temporary Flow Identifier

TBF - UL

- Dynamic allocation
- Extended dynamic allocation
- Fixed allocation



USF = Uplink State Flag

Dynamic Allocation problem

- Class 12 MS
  - max of 4 receive time slots per frame
  - max of 4 transmit time slots per frame
  - total of transmit & receive time slots per frame max 5

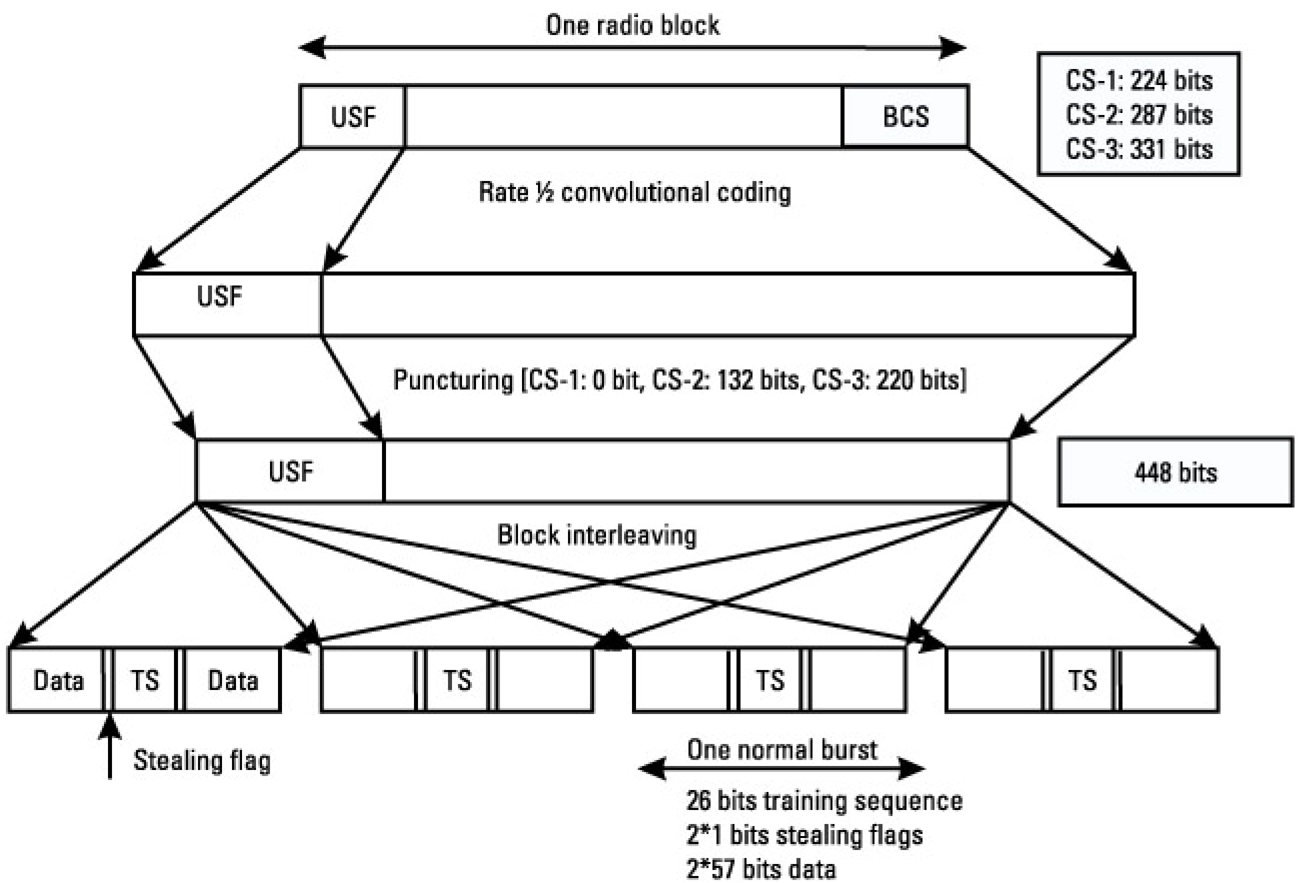
Coding Schemes

Scheme	Code Rate	Coded Bits	Punctured Bits	RB - USF - BCS	Data Rate (Kbps)
CS-1	1/2	456	0	181	9.05
CS-2	≈2/3	588	132	268	13.4
CS-3	≈3/4	676	220	312	15.6
CS-4	1	456	-	428	21.4

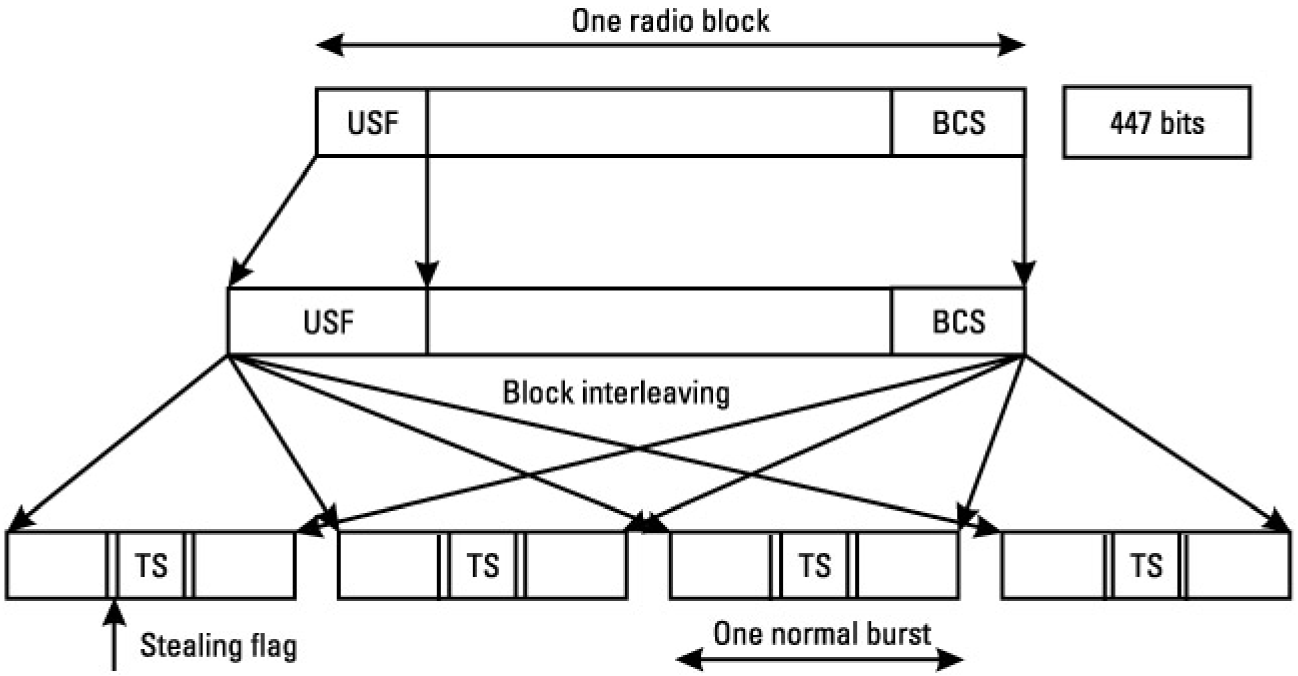
$$G_0 = D^4 + D^3 + 1$$

$$G_1 = D^4 + D^3 + D + 1$$

CS1, CS2, CS3


One radio block
USF
BCS
CS-1: 224 bits
CS-2: 287 bits
CS-3: 331 bits
Rate ½ convolutional coding
USF
Puncturing [CS-1: 0 bit, CS-2: 132 bits, CS-3: 220 bits]
USF
448 bits
Block interleaving
Data
TS
Data
TS
TS
TS
Stealing flag
One normal burst
26 bits training sequence
2*1 bits stealing flags
2*57 bits data

CS4



One radio block
USF
BCS
447 bits
USF
BCS
Block interleaving
TS
TS
TS
TS
Stealing flag
One normal burst

EDGE

- Enhanced Data Rate for GSM Evolution
- introduction of 8PSK modulation
- introduction of Incremental Redundancy ARQ scheme
- adaptive modulation & coding

MCS

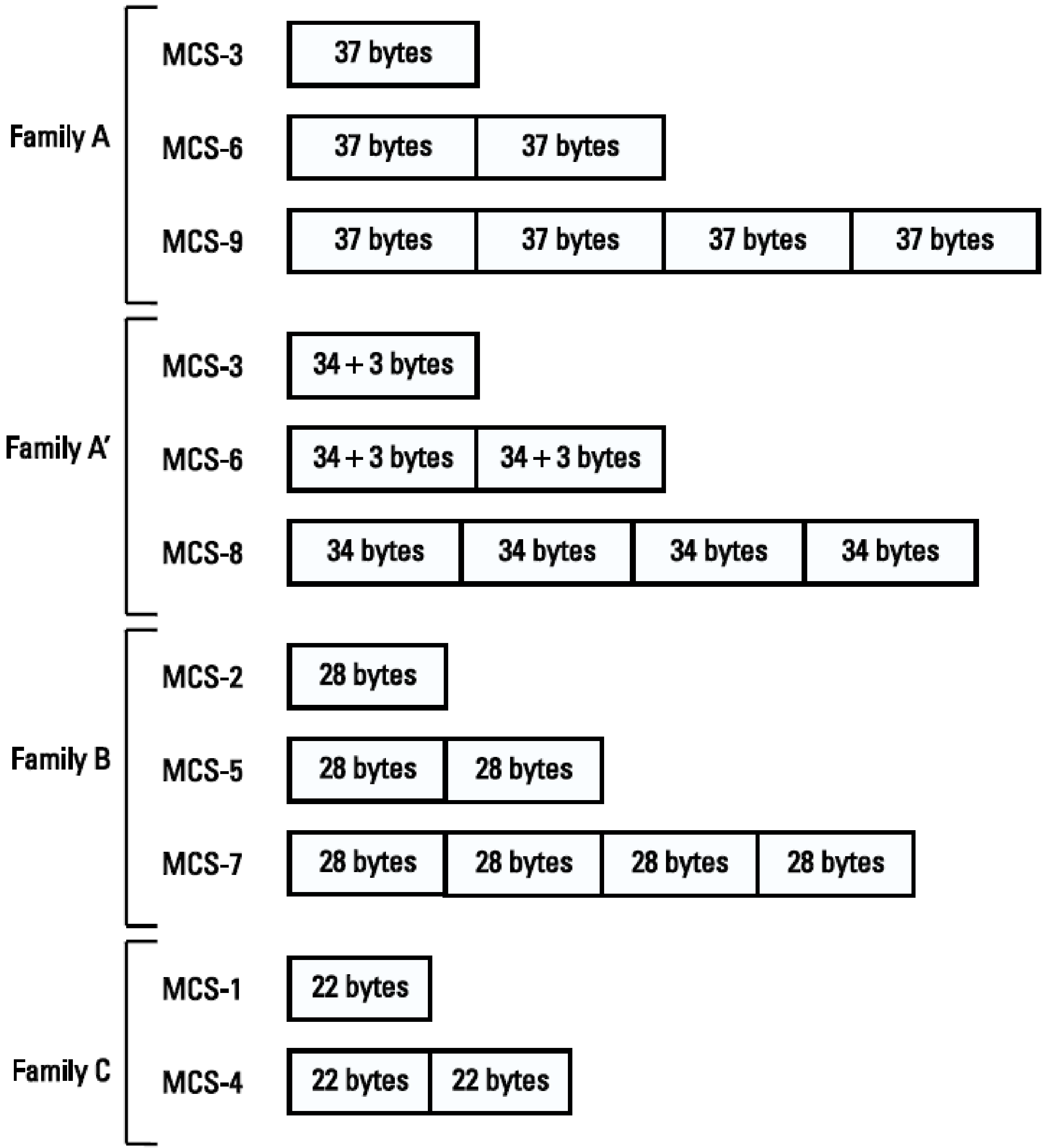
Modulation and Coding Scheme	Modulation	Maximum Throughput (Kbps)
MCS-9	8-PSK	59.2
MCS-8	8-PSK	54.4
MCS-7	8-PSK	44.8
MCS-6	8-PSK	29.6
MCS-5	8-PSK	22.4
MCS-4	GMSK	17.6
MCS-3	GMSK	14.8
MCS-2	GMSK	11.2
MCS-1	GMSK	8.8

Convolutional coding

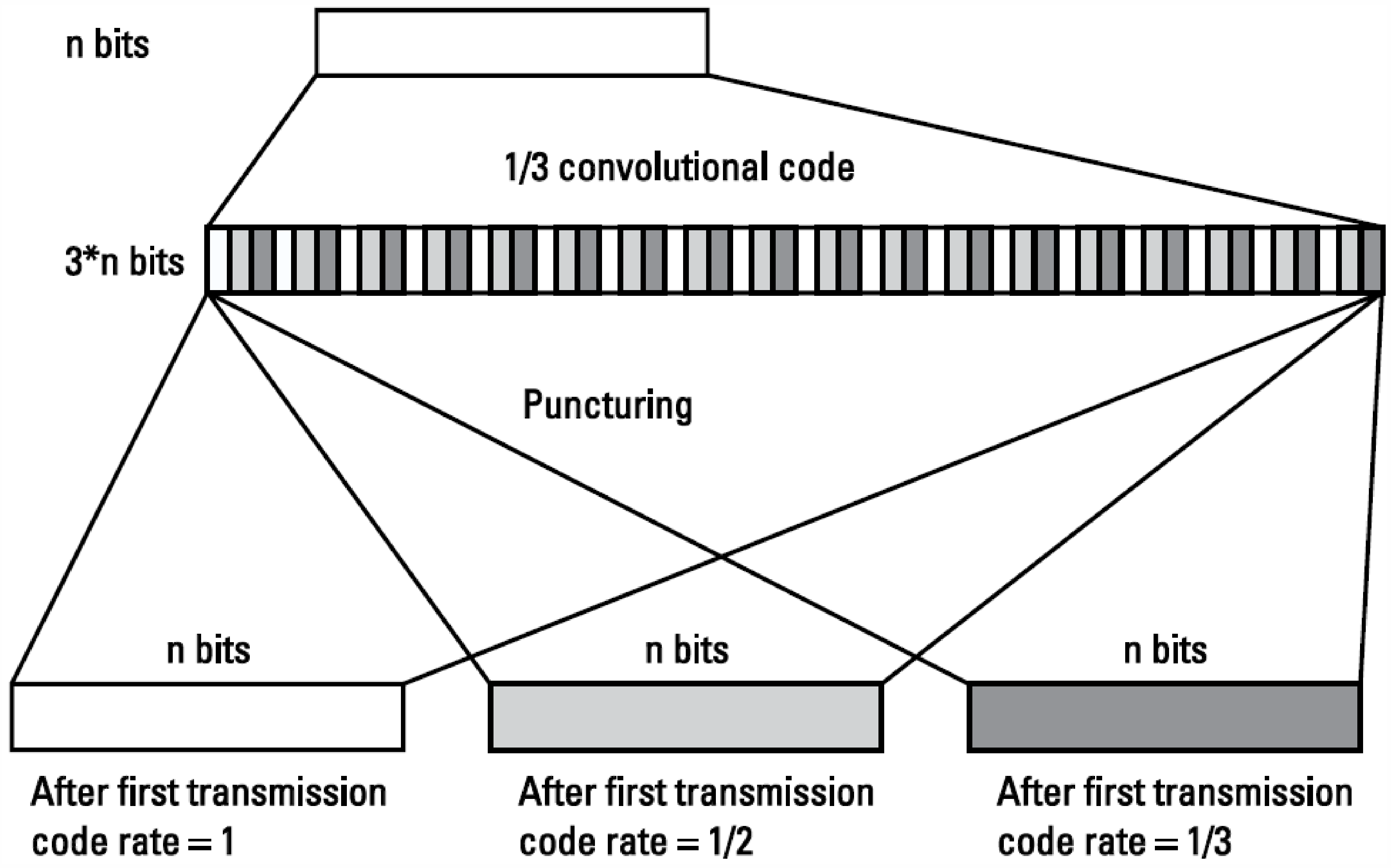
Modulation and Coding Schemes	Polynomials	Code Rate
All MCSs	$G4 = D^6+D^5+D^3+D^2+1$	1/3
	$G5 = D^6+D^4+D+1$	
	$G7 = D^6+D^3+ D^2+D+1$	

Re-use of MCSs

Family	Modulation and Coding Scheme
A	MCS9 MCS6 MCS3
A′	MCS8 MCS6 MCS3
B	MCS7 MCS5 MCS2
C	MCS4 MCS1


Family A
MCS-3
37 bytes
MCS-6
37 bytes 37 bytes
MCS-9
37 bytes 37 bytes 37 bytes 37 bytes
Family A'
MCS-3
34 + 3 bytes
MCS-6
34 + 3 bytes 34 + 3 bytes
MCS-8
34 bytes 34 bytes 34 bytes 34 bytes
Family B
MCS-2
28 bytes
MCS-5
28 bytes 28 bytes
MCS-7
28 bytes 28 bytes 28 bytes 28 bytes
Family C
MCS-1
22 bytes
MCS-4
22 bytes 22 bytes

Incremental Redundancy



IR for EDGE

MCS	Coding Rate After First Transmission	Coding Rate After Second Transmission	Coding Rate After Third Transmission
MCS-1	1/2	1/3	
MCS-2	0.64	1/3	
MCS-3	0.83	0.42	1/3
MCS-4	1	1/2	1/3
MCS-5	0.32	1/3	
MCS-6	1/2	1/3	
MCS-7	3/4	3/8	1/3
MCS-8	0.9	0.45	1/3
MCS-9	1	1/2	1/3

M-PSK

$$m(t) = A_0 \cos\left(2\pi f_0 t + \varphi(t)\right)$$

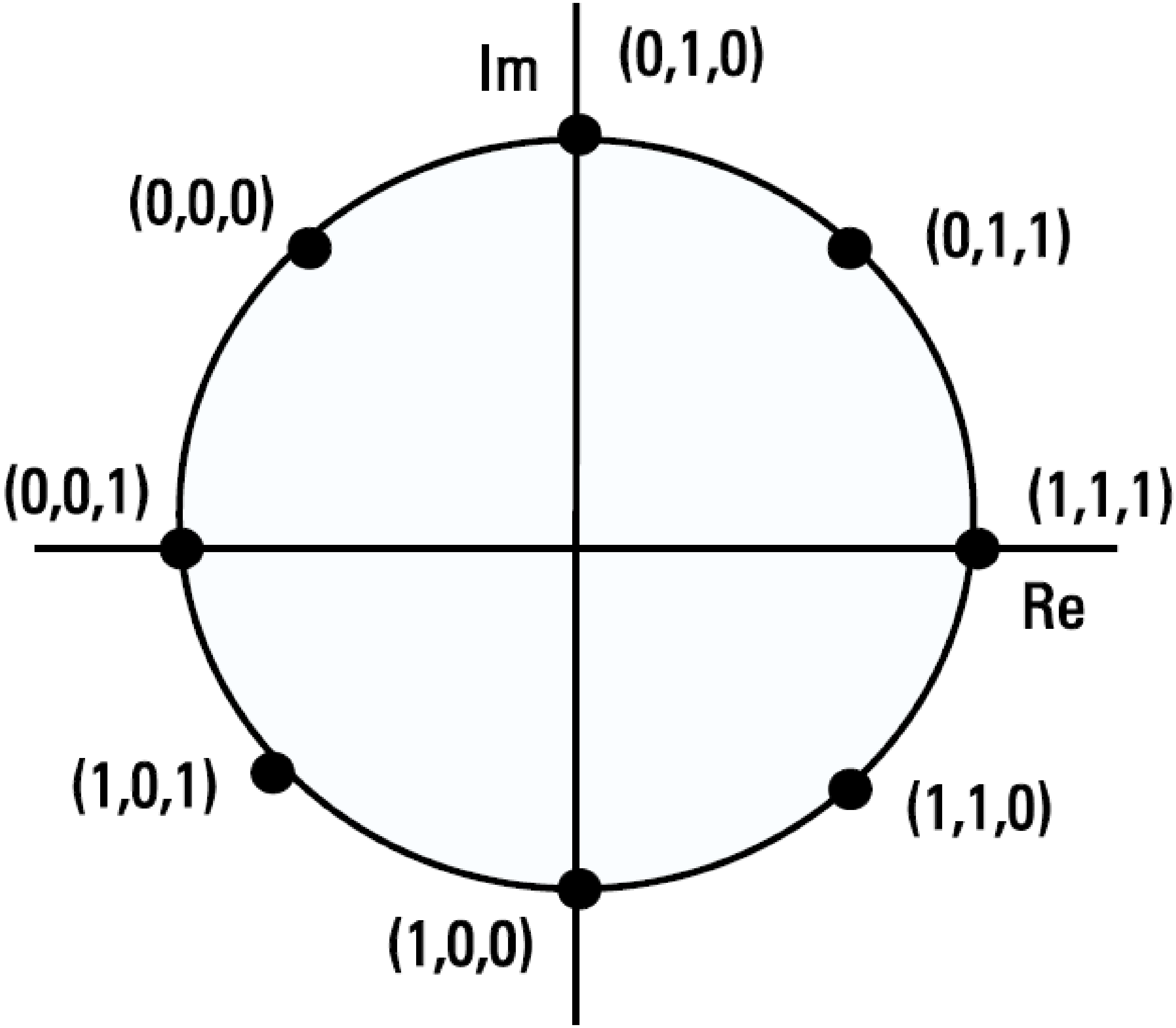
$$\varphi(t) = \sum_k \phi_k \delta(t - kT)$$

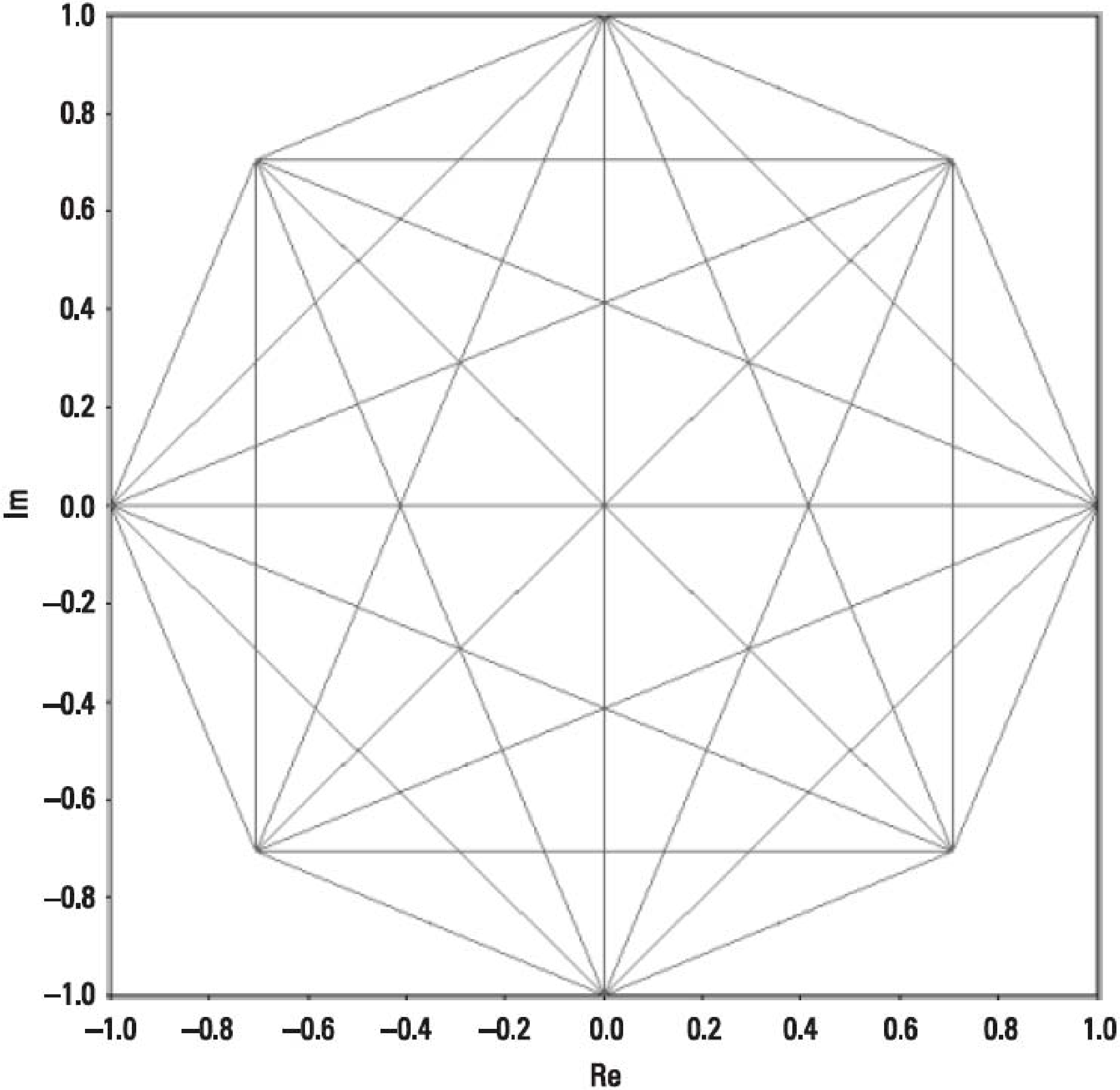
$$\begin{cases} \delta(0) = 1 \\ \delta(t) = 0 \text{ for } t \neq 0 \end{cases}$$

8PSK

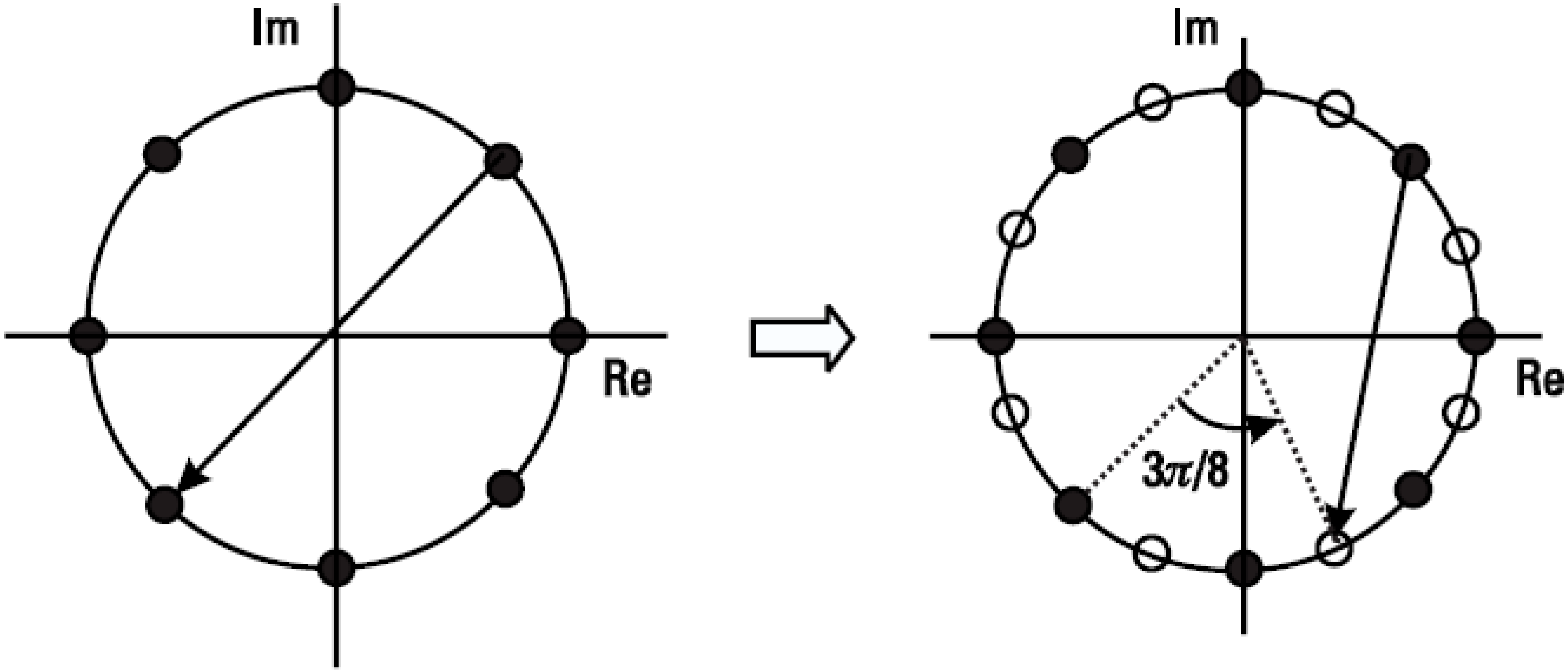
$$2.m.\pi/8$$

$$0 \leq m \leq 7$$

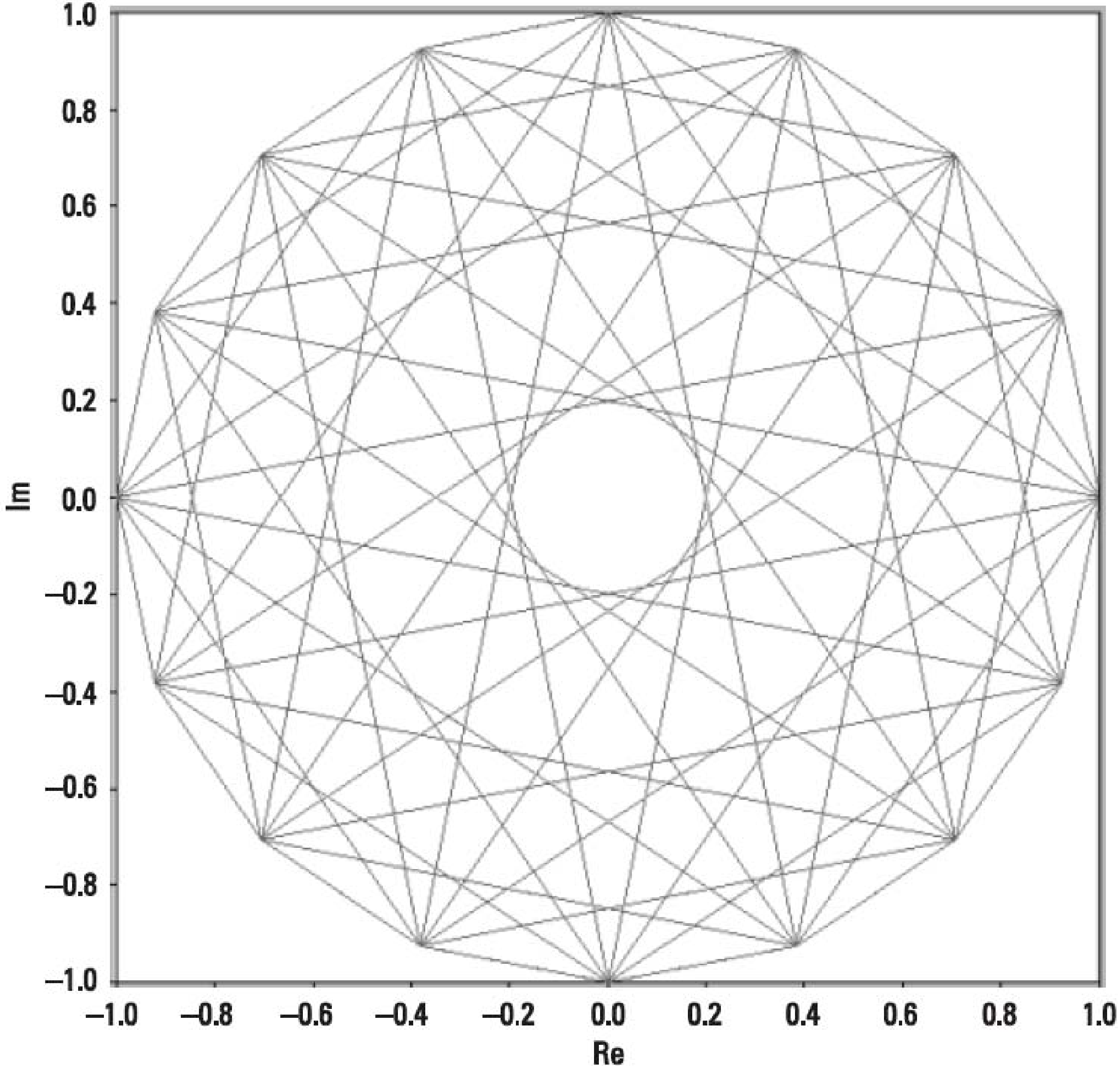



1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
Im
−1.0 −0.8 −0.6 −0.4 −0.2 0.0 0.2 0.4 0.6 0.8 1.0
Re

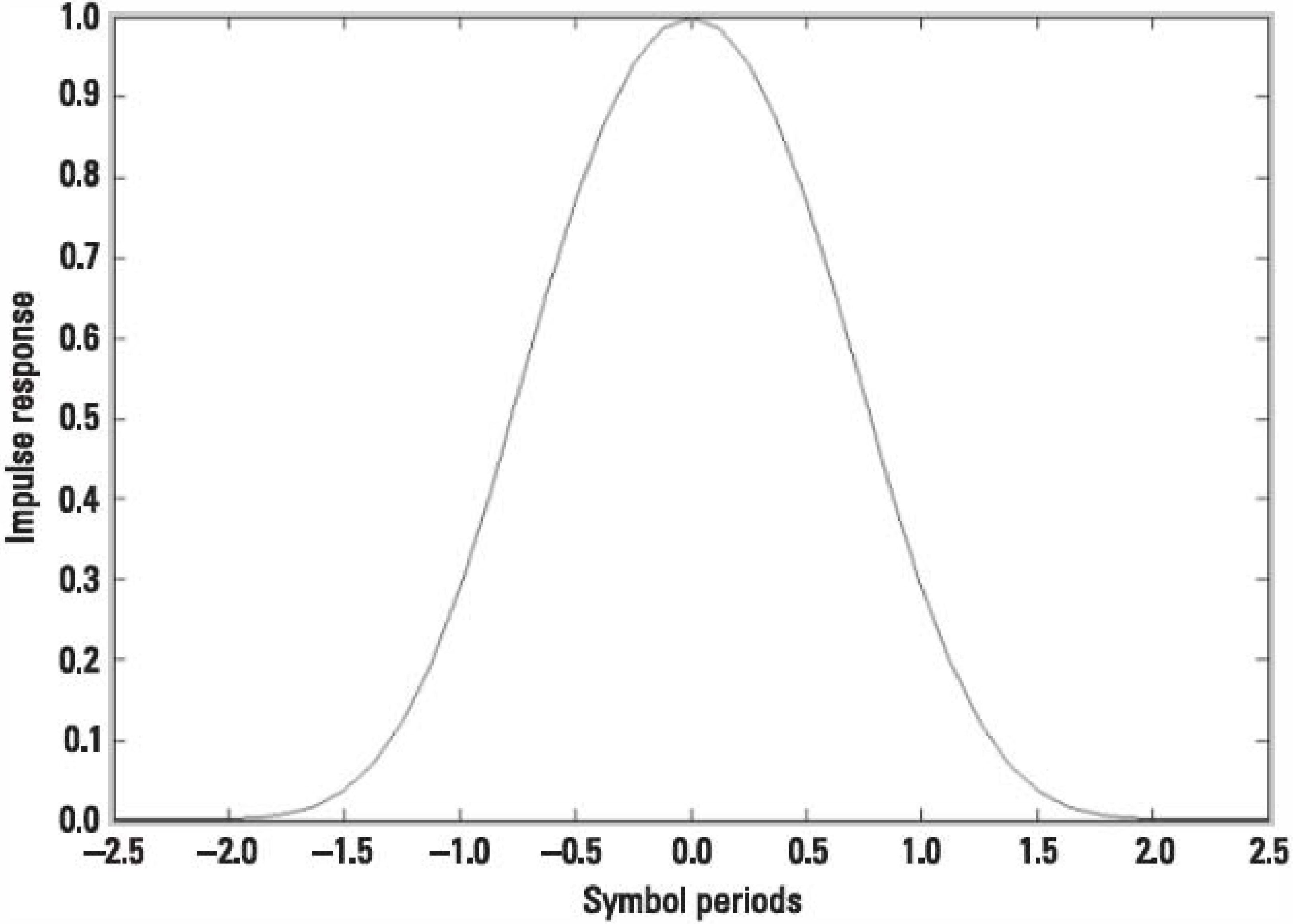
8PSK for EDGE



at each symbol period


1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
Im
−1.0
−0.8
−0.6
−0.4
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
Re

Filtering



Impulse response
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
−2.5
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
2.5
Symbol periods

Filter impulse response

$$c_0(t) = \begin{cases} \prod_{i=0}^{3} S(t+iT), \text{for } 0 \le t \le 5T \\ 0 \end{cases}$$

$$g(t) = \frac{1}{2T}\left(Q\left(2\pi \cdot 0.3 \frac{t-5T/2}{T\sqrt{\ln(2)}}\right) - Q\left(2\pi \cdot 0.3 \frac{t-3T/2}{T\sqrt{\ln(2)}}\right)\right)$$

$$S(t) = \begin{cases} \sin\left(\pi \int_0^t g(t')\,dt'\right), \text{for } 0 < t \le 4T \\ \sin\left(\frac{\pi}{2} - \pi \int_0^{t-4T} g(t')\,dt'\right), \text{for } 4T < t \le 8T \\ 0, \text{else} \end{cases}$$

$$Q(t) = \frac{1}{\sqrt{2\pi}} \int_t^{\infty} e^{-\frac{\tau^2}{2}}\, d\tau$$

GSM Evolution

Voice capacity

Data rates / capacity

MUROS / VAMOS

Doubling the GSM voice capacity

MUROS? VAMOS?

- MUROS = Multi-User Re-using One Slot
- VAMOS = Voice services over Adaptive Multi-user channels on One Slot
- 1 time slot shared by at least 2 full rate users (or 4 half rate users)
- doubling the voice capacity of GSM

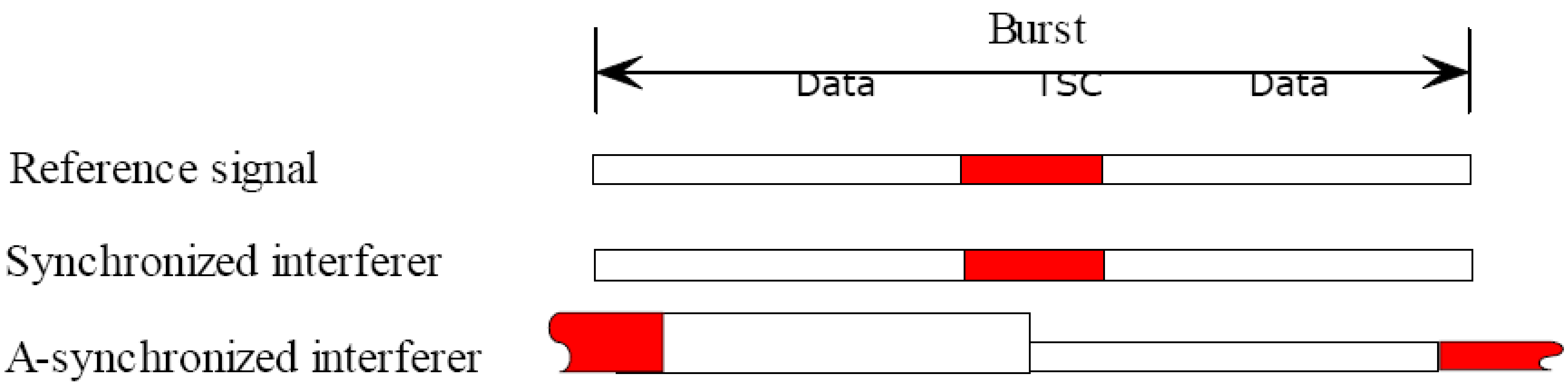
DARP (Rel.6)

- DARP = Downlink Advanced Receiver Performance
- allows for tighter frequency re-use
- Joint Demodulation vs. Blind Interference Cancellation

- JD (or Multi User Detection, MUD)
  - for synchronous networks
  - works well for GMSK as well as 8PSK
  - very complex

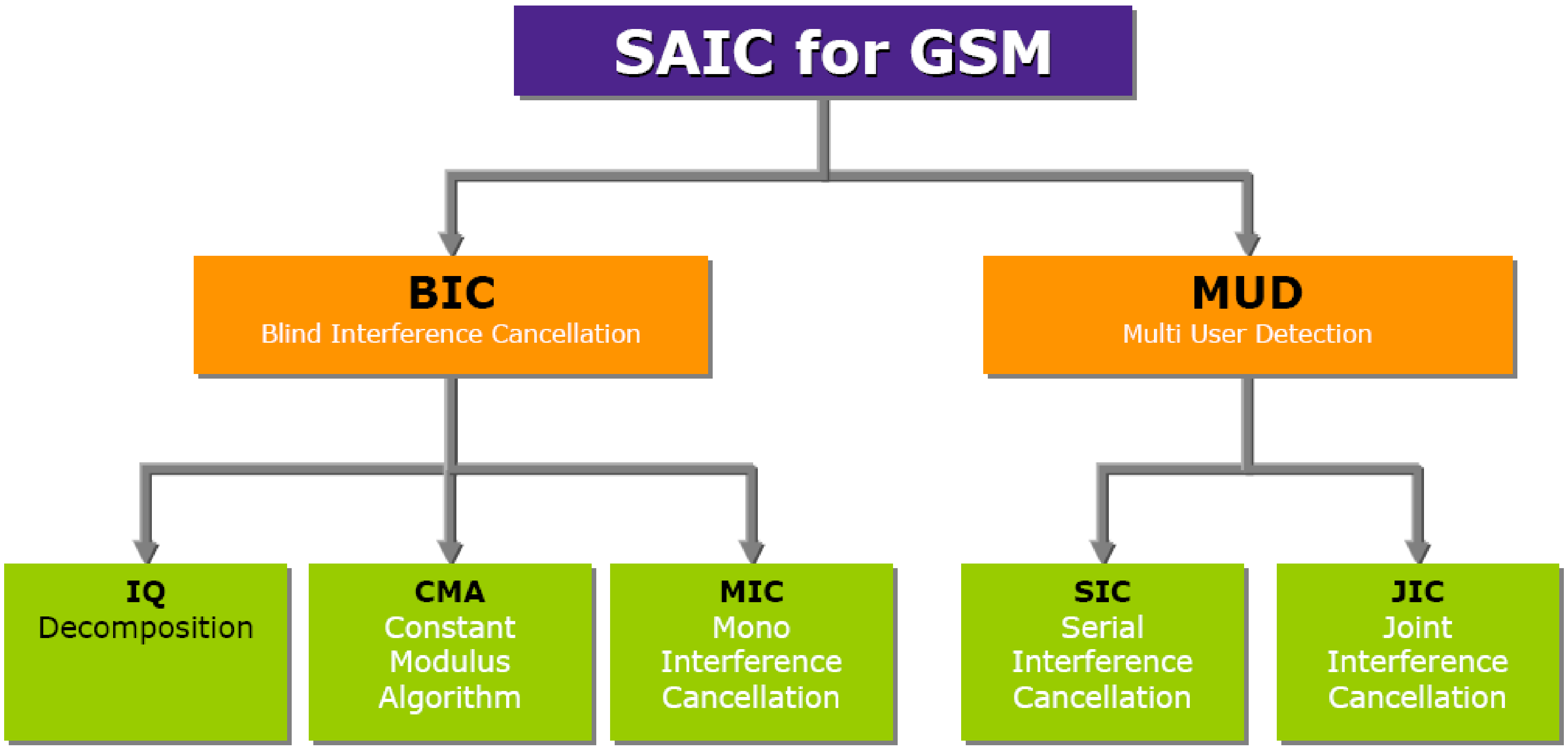
- BIC
  - for asynchronous networks too
  - only for GMSK

Synchronous vs Asynchronous

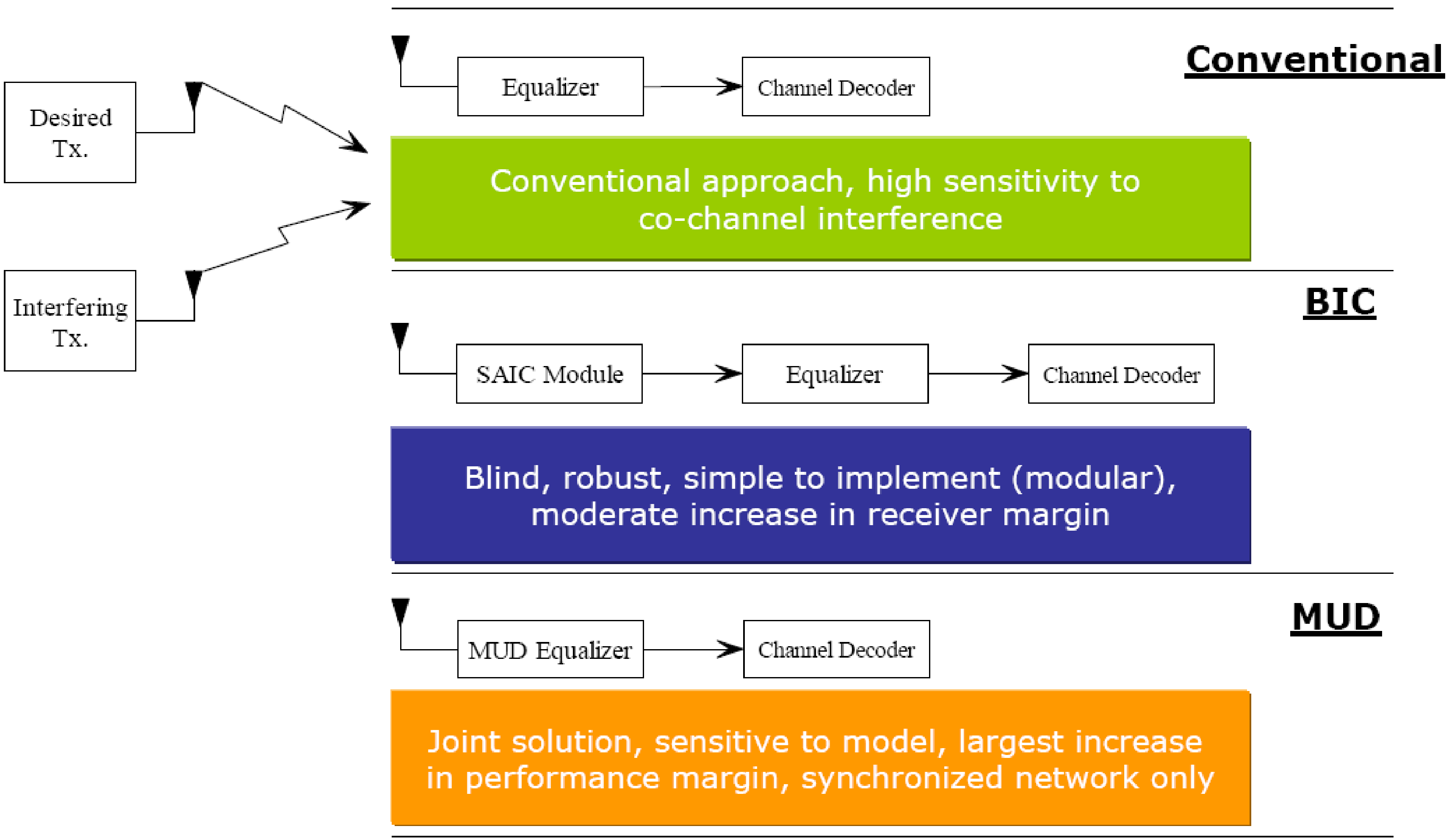


DARP = SAIC

- SAIC = Single Antenna Interference Cancellation



DARP Architecture



DARP summary

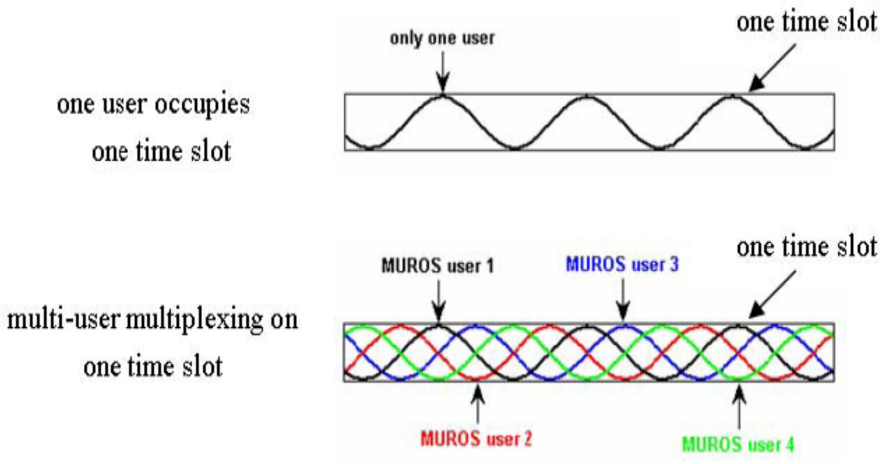
Rx architecture	Complexity	Performance [dB]
Conventional	K	0
BIC	1.1K	2
MUD (Joint)	(2-4)K	5

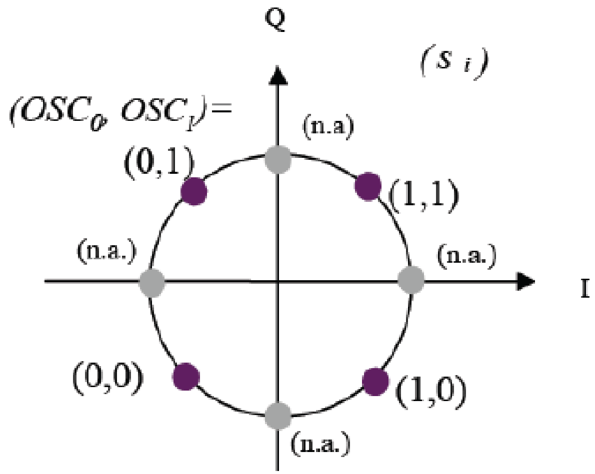
K – circa 10 MIPS for a dual MAC machine

The 3K difference for Joint solution => 30 MIPS
Typically shorten Base Band talk time by up to 20% (voice call)

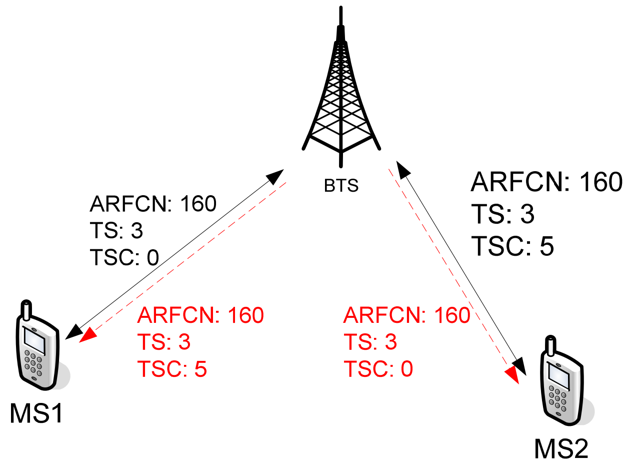
→up to 50% increase of capacity

MUROS Concepts





- Different Training sequences (TSC)



MUROS in Uplink

- multi-user MIMO
- 2 Rx antennas at the BTS
- higher complexity
  - but BTS is not as limited as the MS in processing capacity
- IRC (Interference Rejection Combining) in BTS on UL
  - IRC is even better than SAIC due to RX diversity and more processing power in the TRX

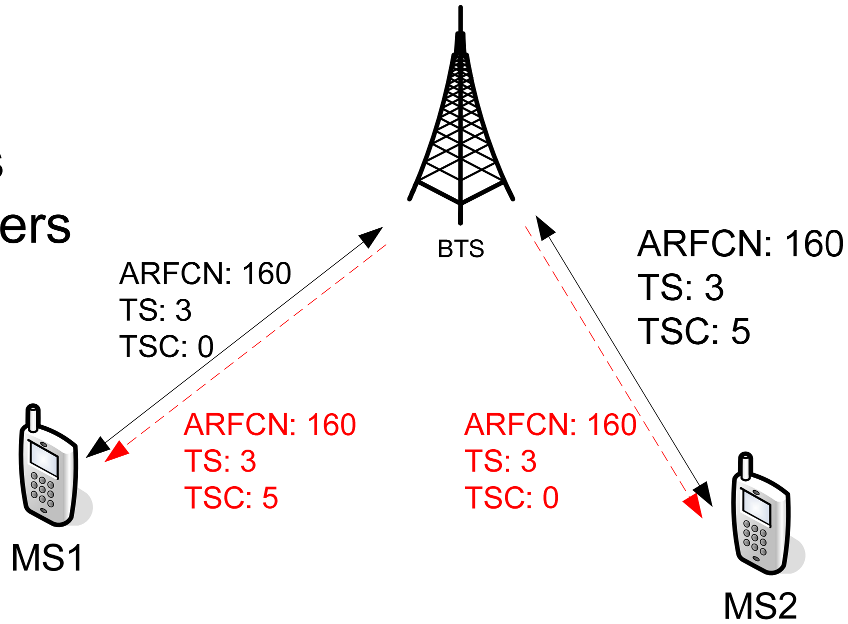
MUROS candidates

- DARP
- Orthogonal Sub Channels (OSC)
- Adaptive symbol constellation
- Higher Order Modulations

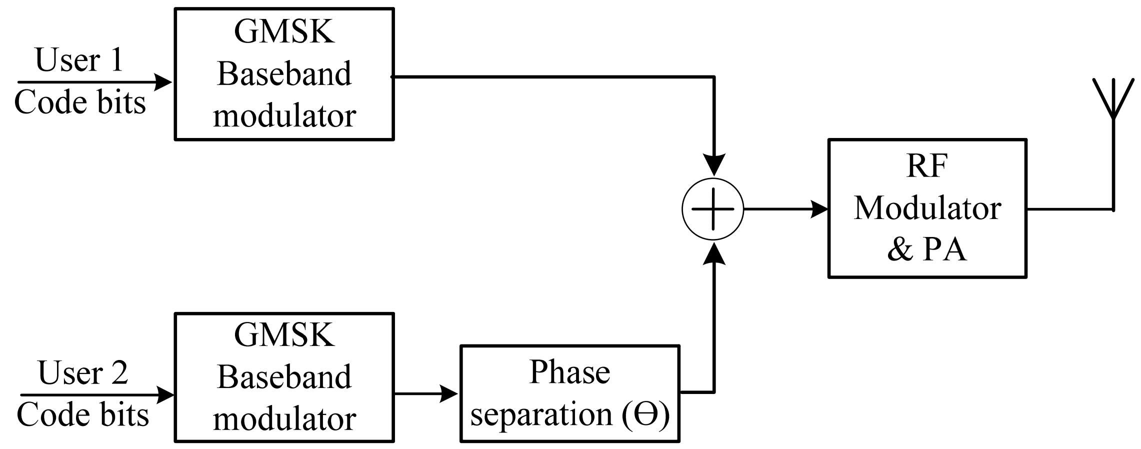
DARP

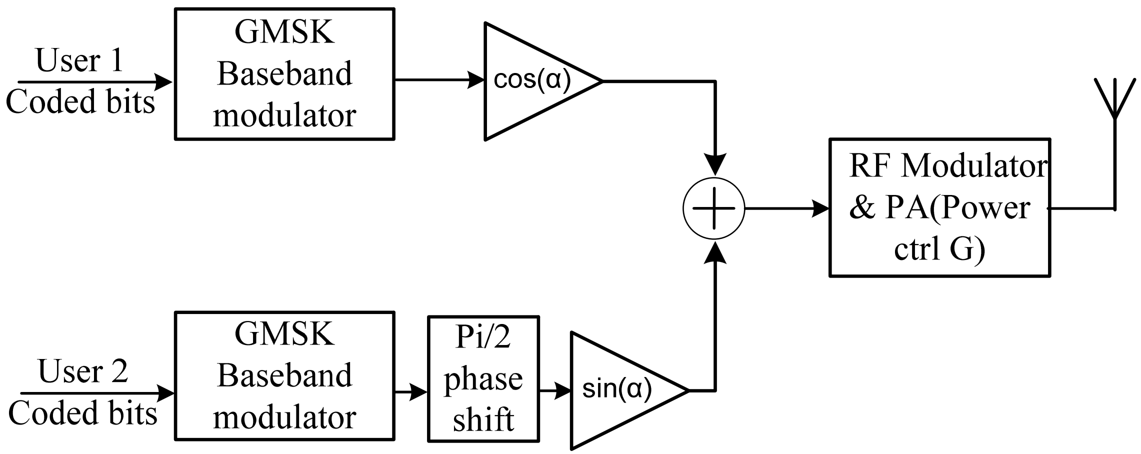
- MS1 considers the MS2 signal as co-channel interference
- works quite OK with CCI ≈ 0dB
- signals intended for the two different MS should ideally be phase shifted by π/2

- on the UL each MS would use a different training sequence code
- network may use techniques such as joint detection to separate the two users on the uplink



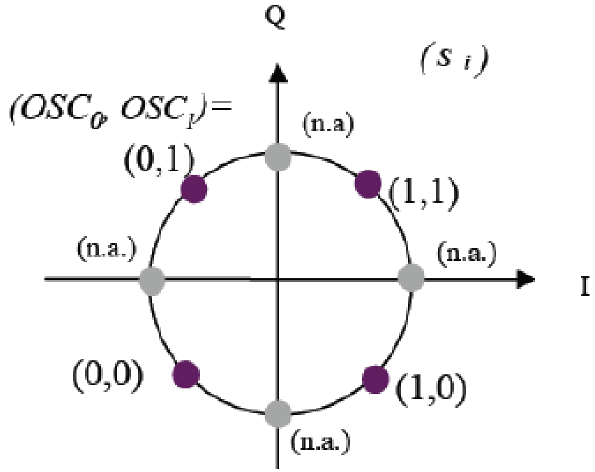
DARP modulation (DL)





Orthogonal Sub Channels

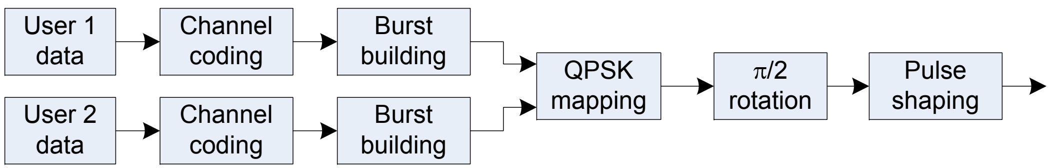
- BTS uses QPSK type of constellation that may be a subset of 8PSK constellation



- QPSK/2 per user

- new TSC for 2nd channel

- UL as for DARP – unique TSC



Adaptive symbol constellation

- UL as for DARP & OSC
- DL = modulator using a rotating hybrid quaternary complex symbol constellation
- new TSC for DL as well

$$\left.\begin{array}{l}\alpha = 0 \\ \alpha = \sqrt{2}\end{array}\right\}\text{BPSK}$$

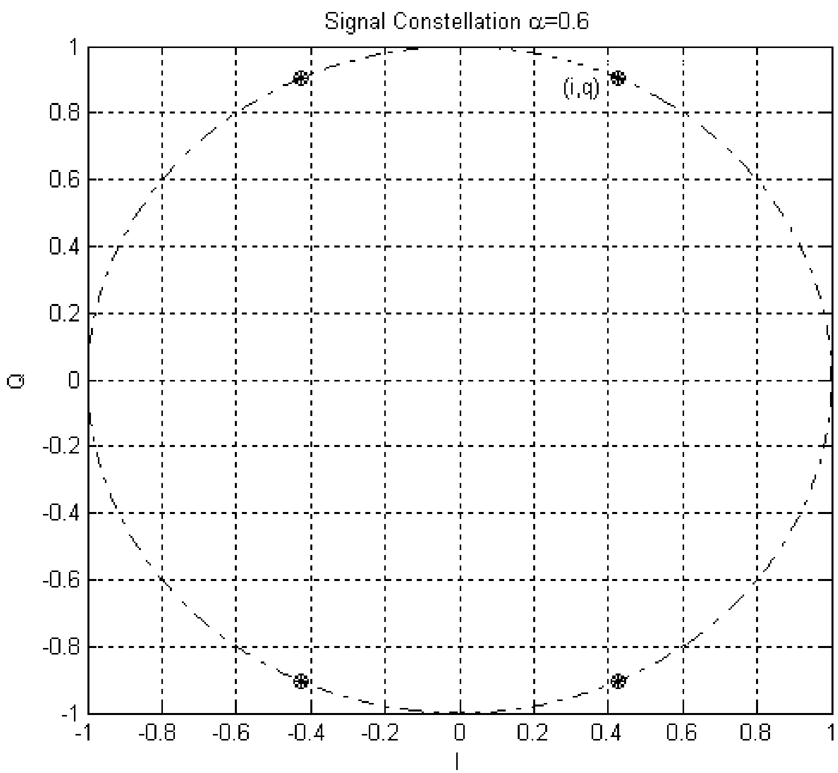
$$\alpha = 1 \rightarrow \text{QPSK}$$

$$-\alpha\sqrt{\frac{1}{2}} - j\sqrt{2-\alpha^2}\sqrt{\frac{1}{2}}$$

$$-\alpha\sqrt{\frac{1}{2}} + j\sqrt{2-\alpha^2}\sqrt{\frac{1}{2}}$$

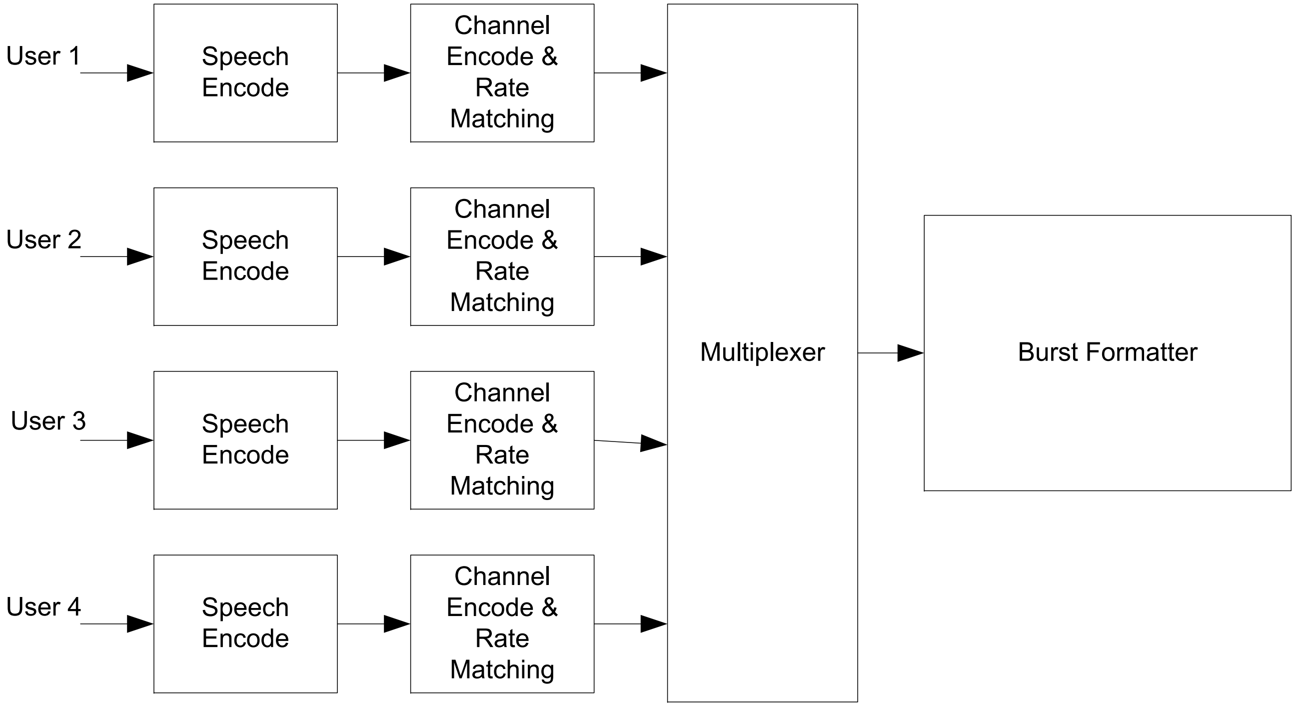
$$\alpha\sqrt{\frac{1}{2}} - j\sqrt{2-\alpha^2}\sqrt{\frac{1}{2}}$$

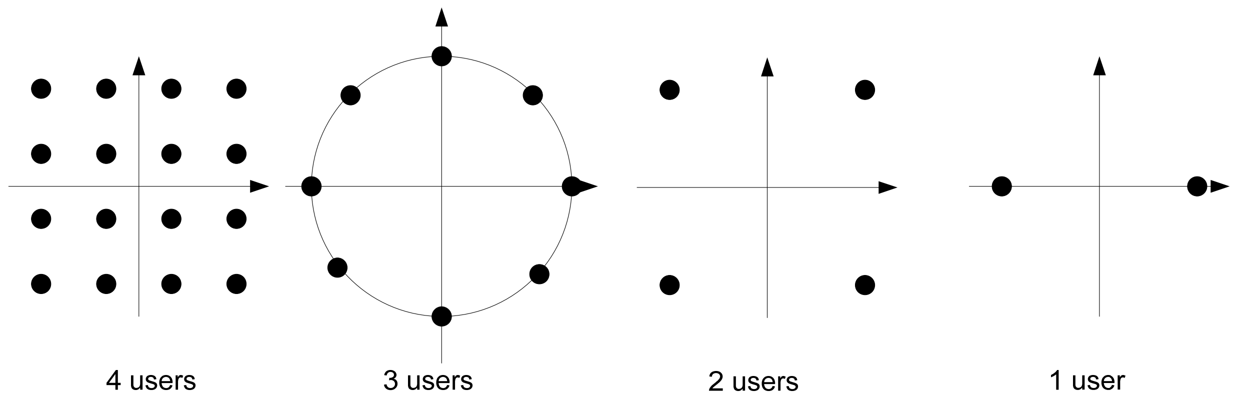
$$\alpha\sqrt{\frac{1}{2}} + j\sqrt{2-\alpha^2}\sqrt{\frac{1}{2}}$$



- α selection adaptive in time

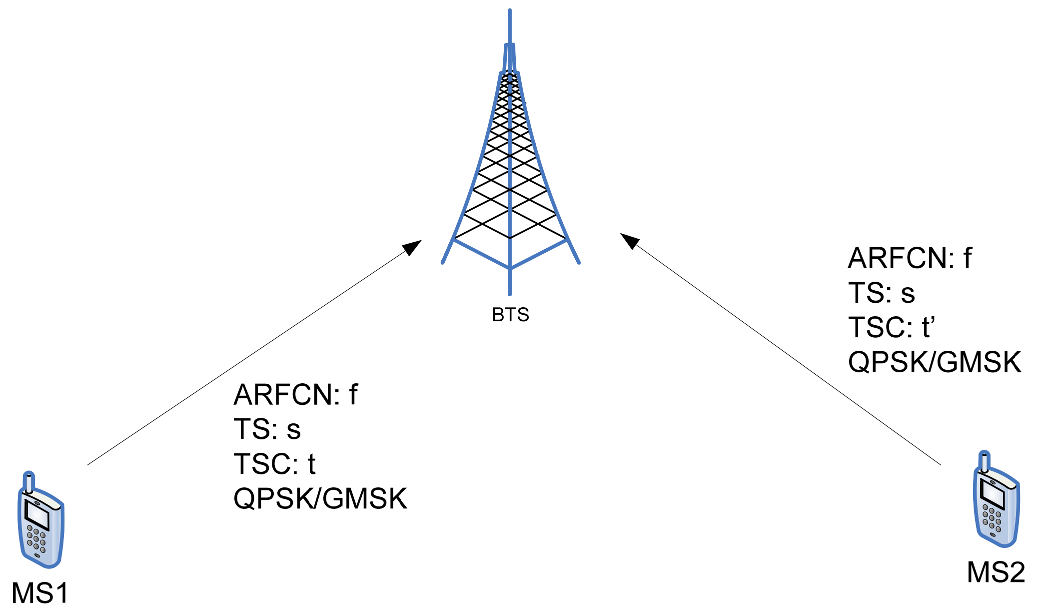
Higher Order Modulations



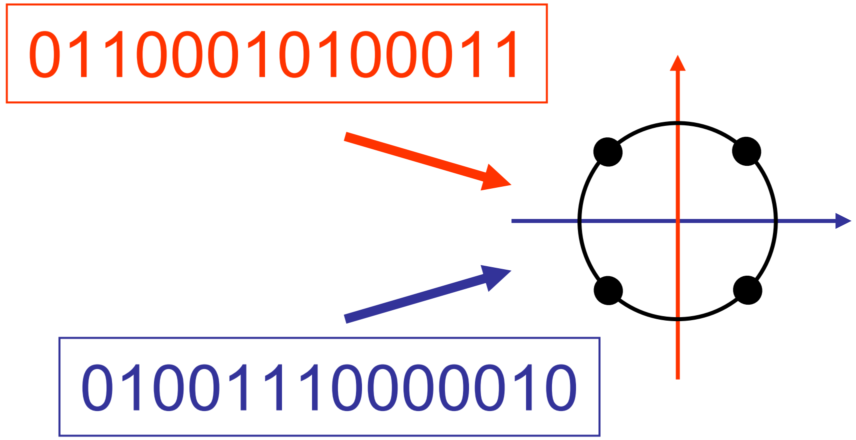


Higher Order Modulations

- UL as DARP, OSC, ASC



VAMOS – phase 1



Downlink:

- Two data streams to the timeslot
- New modulation: QPSK
  - Modulate both streams together
  - Equal power to each MS
  - Up to 3,3 dB PAR (same as EDGE = power back-off)
- Two MS sharing power
  - 3dB less power for each MS
- Each MS uses SAIC to filter out its signal

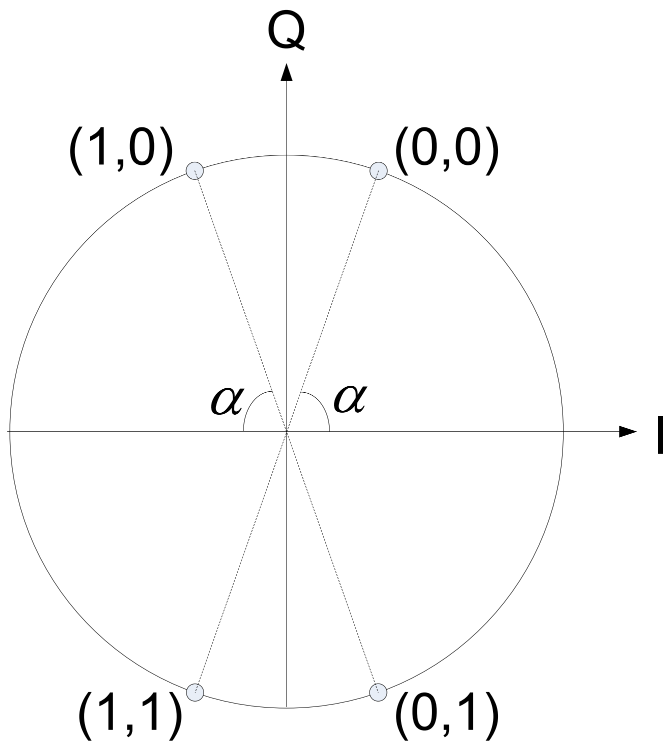
Uplink:

- Each MS sends uplink GMSK bursts exactly as normal
- BTS uses IRC to sort each signal

AQPSK

- similar to Adaptive Symbol Constellation

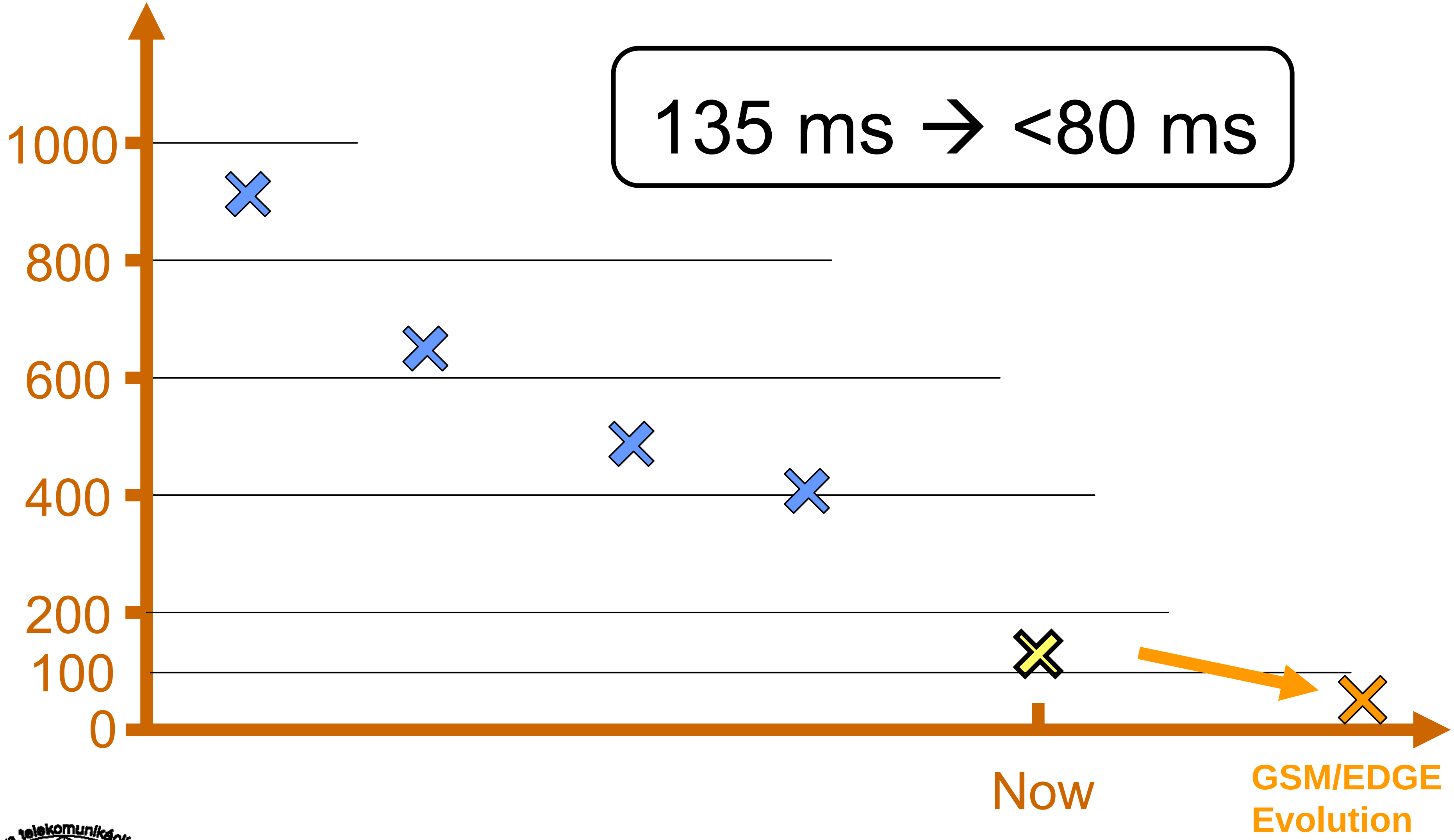
Modulating bits for a_i, b_i	AQPSK symbol in polar notation s_i
0, 0	$e^{j\alpha}$
0, 1	$e^{-j\alpha}$
1, 0	$-e^{-j\alpha}$
1, 1	$-e^{j\alpha}$



EDGE Evolution

Reaching 1 Mbps

EDGE Evolution – Latency

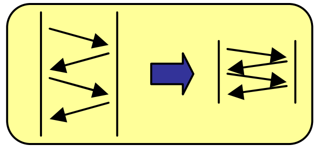


What is EDGE Evolution?

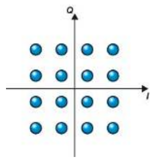
Benefit

Dual-antenna terminals 

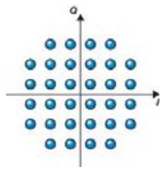
3 – 8 dB improved link

10 ms TTI
& Fast ACK 

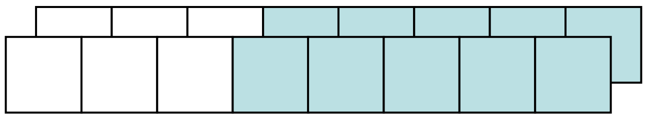
80 ms e2e latency

16 QAM & turbo codes UL/DL  & 

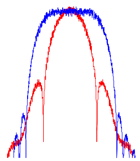
80 kbps per timeslot

32 QAM & turbo codes UL/DL  & 

100 kbps per timeslot

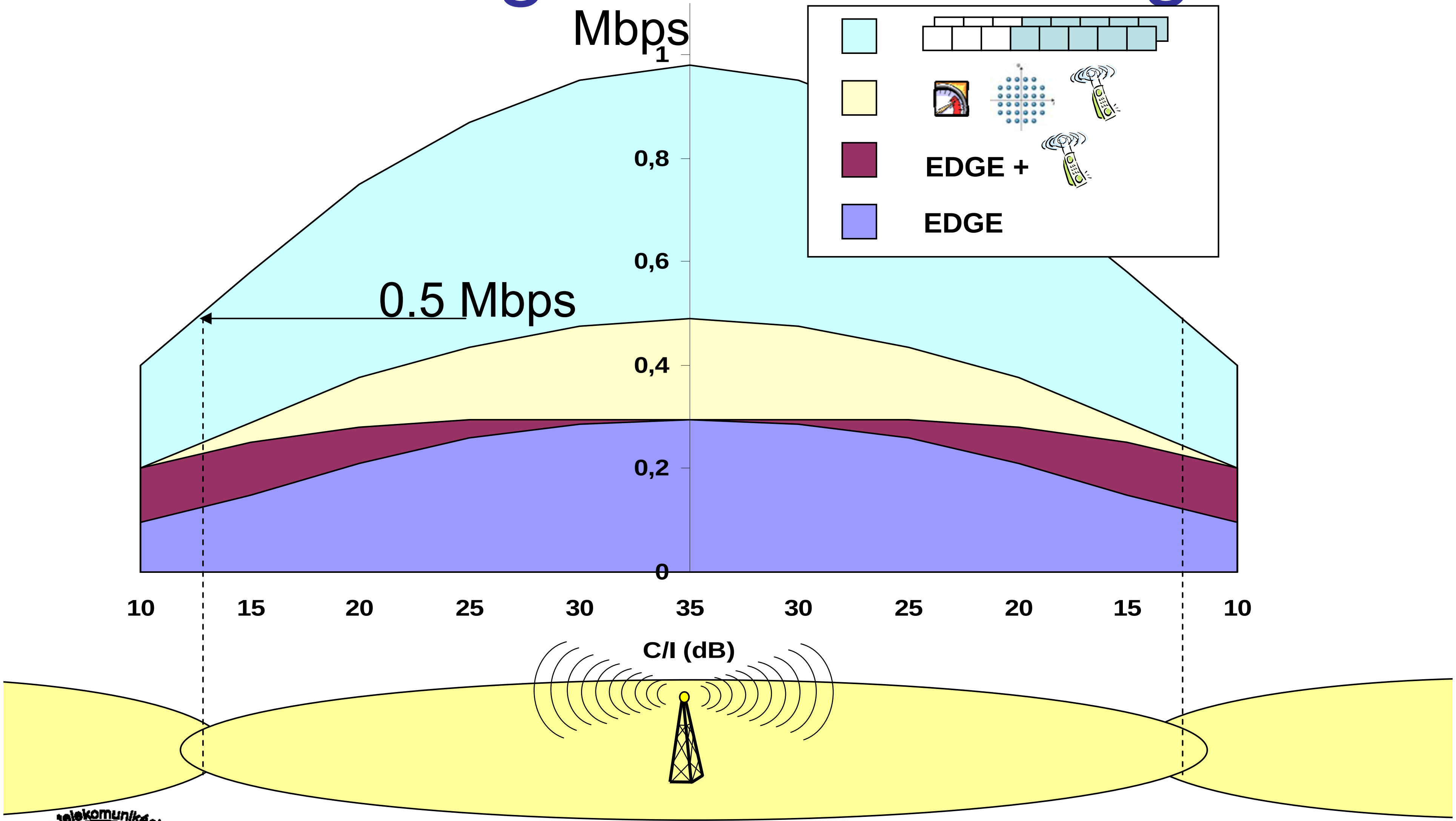
Dual carrier DL 

1.0 Mbps
with 32QAM & 10 TS

1.2x symbol rate UL/DL 

+20% bitrate per carrier/timeslot

Extending service coverage



Terminal capability levels defined in 3GPP

Downlink (Work item name: ”RED HOT”)

Level A: 16QAM+32QAM+turbo codes

Level B: 16QAM+32QAM+turbo codes+1.2x symbol rate

Uplink (Work item name: ”HUGE”)

Level A: 16QAM

Level B: 16QAM+1.2x symbol rate

Level C: 16QAM+32QAM (+turbo codes)+1.2x symbol rate

Technical proposals

1. Dual antenna terminals (MSRD)
2. Higher order modulations, turbo codes and higher symbol rates (EGPRS2)
3. Downlink Dual-Carrier (DLDC)
4. Reduced Transmission Time Interval
5. Faster feedback

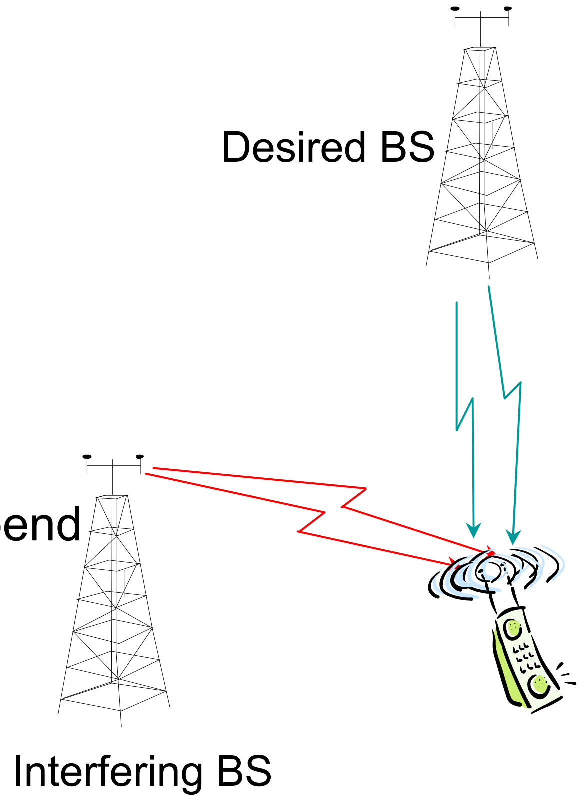
Dual antenna terminals

Introduction

- Downlink performance limited by interference
  - Difficult to cancel interference with single antenna
    - Single Antenna Interference Cancellation (SAIC) performs well but only with GMSK modulated carrier and GMSK modulated interference
  - Two antennas enable introduction of interference cancellation for all modulations
- Downlink performance limited by coverage
  - Two antennas improve coverage by
    - Array gain against thermal noise
    - Diversity against fading
- User benefits
  - Higher data rates in most part of the cell
  - Improved coverage for a given data rate

Dual antenna terminals
Limitations of mobile terminal

- Antenna correlation
  - Small size typically yields high fading correlation
  - → Diversity advantage against fading depend on correlation
- Antenna gain mismatch
  - One antenna may have to be placed in “bad” location, causing gain mismatch
  - → Array gain advantage against thermal noise depend on the gain mismatch



Dual antenna terminals
Conclusion

- Benefits
  - Improve both speech and data performance
  - 8 dB improved downlink performance in interference limited scenarios
  - 2-6 dB improved downlink sensitivity in noise limited scenario (coverage)
- Easy introduction
  - No impact on network HW or SW
  - New terminals with dual-antenna will experience higher throughput and increased coverage

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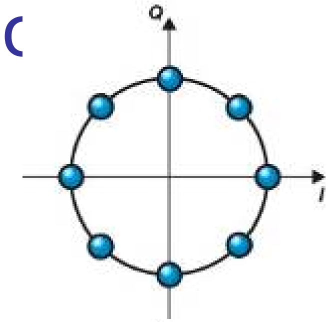
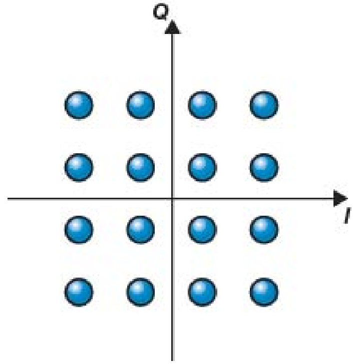
Higher order modulations, higher symbol rates and turbo codes

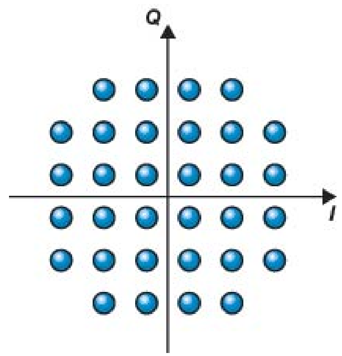
Introduction – higher order modulatic



- With EDGE, 8-PSK modulation was introduced
  → Threefold increase in peak bit rate and significant increase in mean bit rate compared to GMSK



- Highest EDGE modulation/coding schemes used extensively in live networks
  → Good radio conditions and potential for further improvements



- The extra bits given by HOM can be used for
  - more channel coding → increased robustness
  - more user data → increased peak rates

- 16QAM and 32QAM are part of 3GPP for both uplink and downlink

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Higher order modulations, higher symbol rates and turbo codes

Introduction – turbo codes

- Turbo codes outperform convolutional codes
- Gains increase with larger data blocks → synergy with higher order modulations
- Decoding complexity is high but hardware accelerators can be used
  - Downlink: By using the same turbo codes as in WCDMA, MS hardware can be reused and the extra cost is minor (especially in a dual-mode MS)
- Turbo codes are part of 3GPP Rel-7 for downlink

Higher order modulations, higher symbol rates and turbo codes

Introduction – higher symbol rates

- Higher symbol rate has a similar effect as a higher order modulation
  - Increased number of bits can be used for robustness and/or peak rates
- Higher symbol rate also increases the inter-symbol interference (ISI)
  - → Wider Tx filter may be necessary to reduce ISI
  - → Adjacent channel interference increases
- 20% higher symbol rate (325 kBd) is part of 3GPP both for uplink and downlink

Technical proposals

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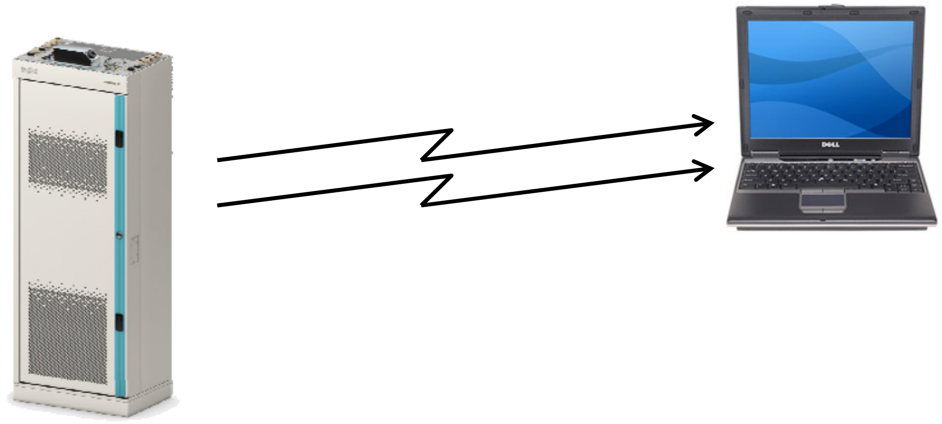
EDGE Evolution – Dual Carrier

Benefit

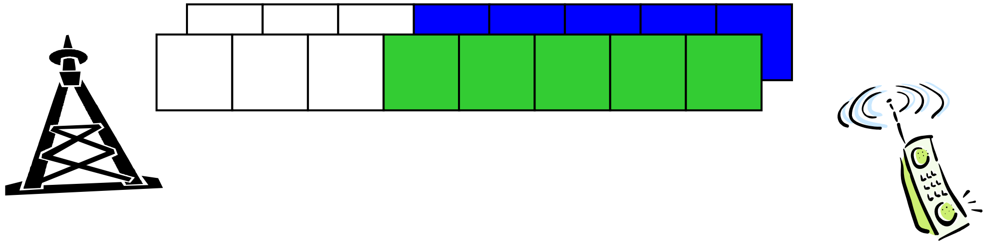
Up to 0,6 Mbps bitrate per user on any EDGE capable RBS



- Dual Carrier doubles end-user bitrates in the downlink
- Fast and cost efficient roll out of mobile broadband services, software upgrade only
- Better experience for users who fall out of TD-SCDMA, WCDMA or LTE coverage to GSM

EDGE Evolution – Dual Carrier
Description

- Dual Carrier
  - Enables downlink allocation of two carriers simultaneously to a single terminal
  - Timeslot allocation not changed, all timeslots can still be on-demand in order to not impact voice capacity
  - Any two carriers in the same band can be used, no impact on frequency planning or frequency hopping



- Other benefits
  - Increased trunking gain (better to let two users share 10 timeslots, than having 2 users with 5 timeslots each)

Downlink dual-carrier

Gains & Conclusion

- Peak and mean throughput will (at least) increase proportionally to number of carriers
- Flexibility of channel assignment and scheduling will increase

→ Trunking efficiency will increase (both uplink and downlink)

=> End-user bitrates are doubled

Number of carriers	Peak throughput with EDGE (5 TS/carrier)
1	300 kbps
2	600 kbps

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Reduced TTI*

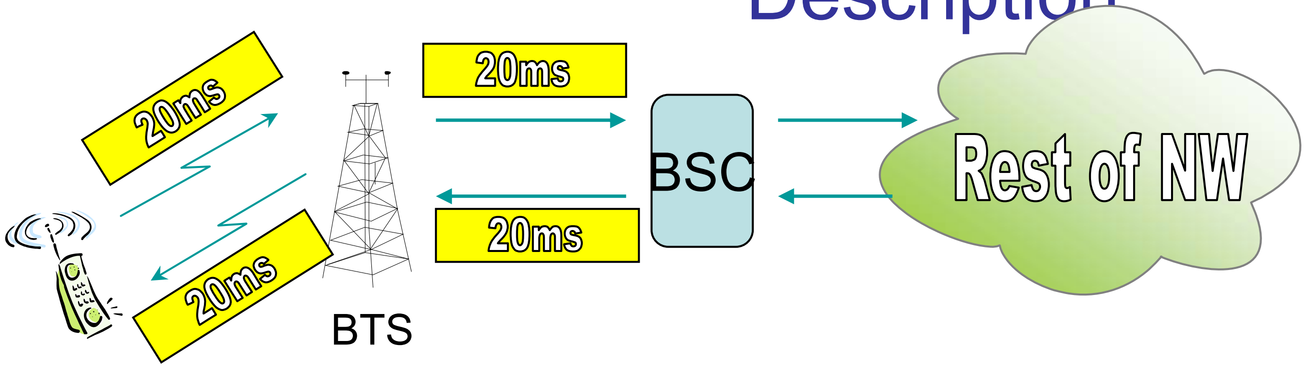
Introduction

- Low latency is crucial
  - for TCP/IP to utilize high bandwidth
  - for services with a lot of interaction
  - for real-time services like VoIP
- Ericsson's state-of-the-art BSS latency is 135 ms
  - Latency defined by a 32-byte PING from Terminal -> Server -> Terminal, i.e. e2e round-trip-time.
- RAN sets the latency
  - Of 135 ms e2e latency, ~90 ms is in the radio access network

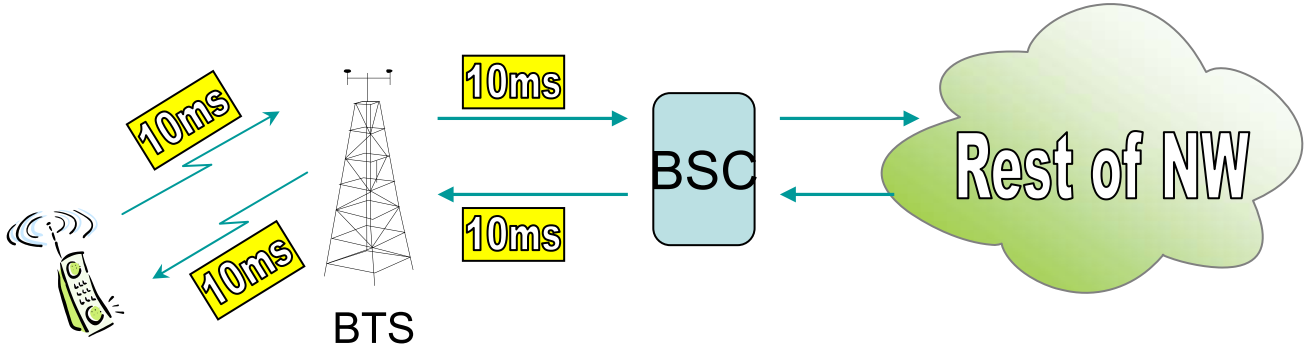
* Transmission time interval – the time interval to send radio blocks

Reduced TTI

Description



Today: 135 ms e2e latency and 20 ms long radio blocks



Shorter TTI save transport time on radio and Abis. Lead to ~80 ms e2e latency

Method of reducing TTI:

Transmit the four burst over two timeslots/carriers instead of one

Reduced TTI

Conclusions

- Transmission time interval impacts latency
  - Today's TTI of 20 ms contribute to transmission delay on radio interface and Abis interface, total 80 ms
  - Reduced TTI down to 10 ms saves 40 ms in round-trip-time just on transmission.

⇒ End-to-end latency below 80 ms is enabled

- Benefits end-user applications on existing EDGE bitrates
  - For example:
    - 25-30% improved e-mail service
    - 20% improved web download
  - Enabler of latency demanding applications such as Gaming and VoIP

Technical proposals

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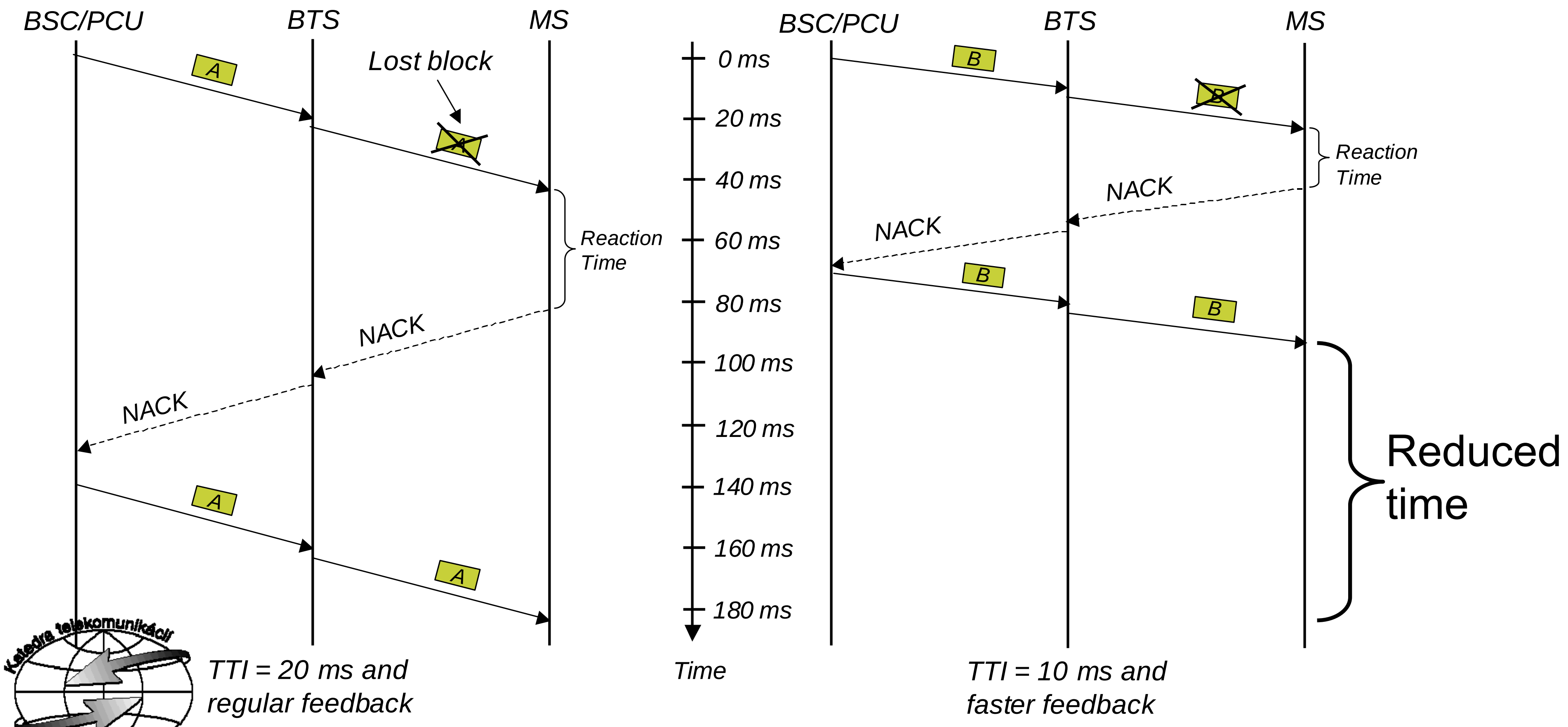
Faster Feedback
Introduction

- Loss of radio blocks increase latency
  - Incorrectly received radio blocks are normal in radio transmission
  - 10-30% retransmission rate is common
  - Incorrectly received blocks are retransmitted, complete IP packets are not delivered to application until all radio blocks are correctly received
- Faster feedback
  - Introduction of a Fast ACK/NACK reporting mechanism to reduce time for network to realize that a block is lost
  - Combined with shorter TTI, total time to retransmit lost radio blocks is significantly reduced
- Benefit
  - Retransmissions of radio blocks can be done for delay sensitive applications such as VoIP
  - This enables larger capacity and robustness for VoIP

Faster Feedback

Description

- Faster feedback & Reduced TTI
  - Faster RLC/MAC feedback in combination with reduced TTI improves time for retransmissions significantly.



Naming convention
Coding schemes uplink

Name in work item	Feature name in specs	Abbreviation	Modulation and coding scheme name
HUGE level A	EGPRS-2A in the uplink	**UAS-x**	Uplink Level A modulation and coding Scheme
HUGE level B	EGPRS-2B in the uplink	**UBS-x**	Uplink Level B modulation and coding Scheme
RED HOT level A	EGPRS-2A in the downlink	**DAS-x**	Downlink Level A modulation and coding Scheme
RED HOT level B	EGPRS-2B in the downlink	**DBS-x**	Downlink Level B modulation and coding Scheme

Uplink Level A

MCS	Modulation	Bitrate (kbps)	Symbol Rate
UAS-11	16QAM	76.8	
UAS-10	16QAM	67.2	
UAS-9	16QAM	59.2	
UAS-8	16QAM	51.2	
UAS-7	16QAM	44.8	
MCS-6	8PSK	29.6	NSR
MCS-5	8PSK	22.4	
MCS-4	GMSK	17.6	
MCS-3	GMSK	14.8	
MCS-2	GMSK	11.2	
MCS-1	GMSK	8.8	

Uplink Level B

MCS	Modulation	Bitrate (kbps)	Symbol Rate
UBS-12	32QAM	118.4	
UBS-11	32QAM	108.8	
UBS-10	32QAM	88.8	
UBS-9	16QAM	67.2	HSR
UBS-8	16QAM	59.2	
UBS-7	16QAM	44.8	
UBS-6	QPSK	29.6	
UBS-5	QPSK	22.4	
MCS-4	GMSK	17.6	
MCS-3	GMSK	14.8	NSR
MCS-2	GMSK	11.2	
MCS-1	GMSK	8.8	

Coding schemes downlink

- All new coding schemes use turbo codes (DxS-)
- MCS-1 to 4 identical with today's EDGE
- Level A has normal symbol rate, while Level B use higher symbol rate (above MCS-4)

Downlink Level A

MCS	Modulation	Bitrate (kbps)	Symbol Rate
DAS-12	32QAM	98.4	NSR
DAS-11	32QAM	81.6	
DAS-10	32QAM	65.6	
DAS-9	16QAM	54.4	
DAS-8	16QAM	44.8	
DAS-7	8PSK	32.8	
DAS-6	8PSK	27.2	
DAS-5	8PSK	22.4	
MCS-4	GMSK	17.6	
MCS-3	GMSK	14.8	
MCS-2	GMSK	11.2	
MCS-1	GMSK	8.8	

Downlink Level B

MCS	Modulation	Bitrate (kbps)	Symbol Rate
DBS-12	32QAM	118.4	HSR
DBS-11	32QAM	108.8	
DBS-10	32QAM	88.8	
DBS-9	16QAM	67.2	
DBS-8	16QAM	59.2	
DBS-7	16QAM	44.8	
DBS-6	QPSK	29.6	
DBS-5	QPSK	22.4	
MCS-4	GMSK	17.6	NSR
MCS-3	GMSK	14.8	
MCS-2	GMSK	11.2	
MCS-1	GMSK	8.8	