HOGESCHOOL VOOR WETENSCHAP & KUNST | DE NAYER INSTITUUT
SINT-KATELIJNE-WAVER

ASSOCIATIE K.U.LEUVEN

Datacommunicatie keuzevak

Bachelor in de Industriële Wetenschappen: elektronica-ICT
3e jaar, 6e semester

3Ba E / SP E

EmSD
Embedded System Design

ir. J. Meel
april 2008

HOGESCHOOL VOOR WETENSCHAP & KUNST **DE NAYER INSTITUUT**
SINT-KATELIJNE-WAVER

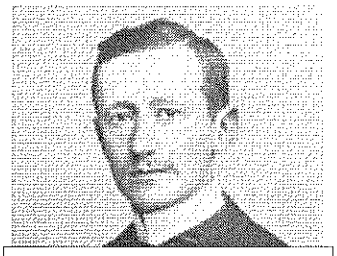
Datacommunicatie
Mobile Communication

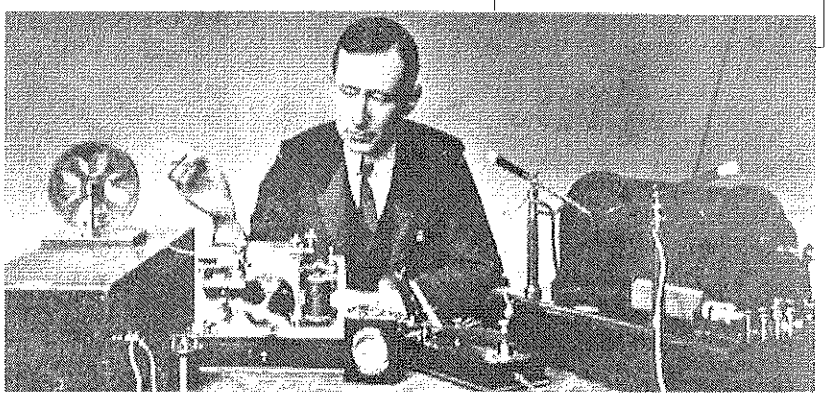
EmSD
Embedded System Design

ir. J. Meel
april 2008

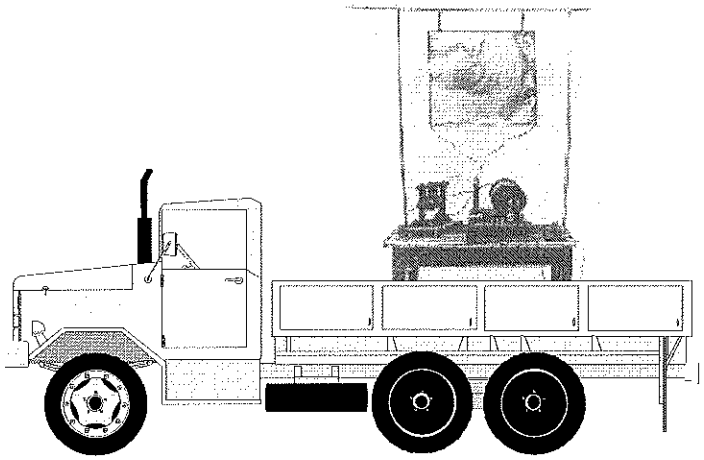
Marconi

1895

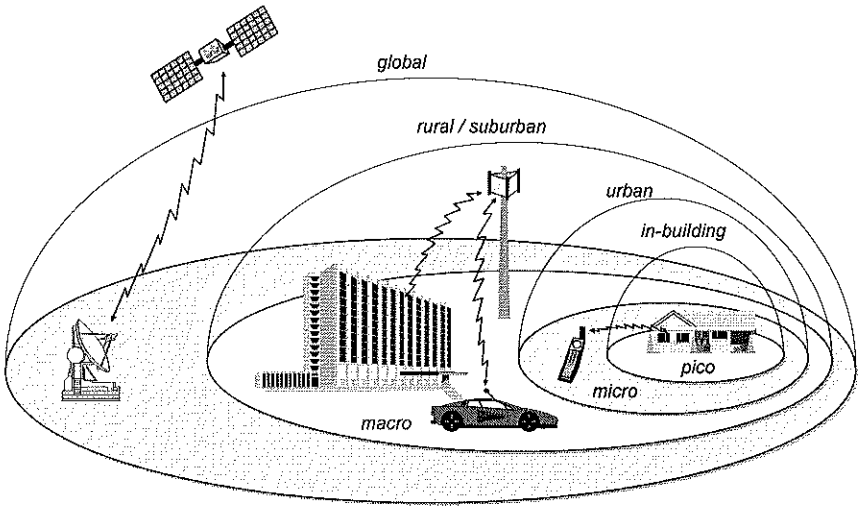


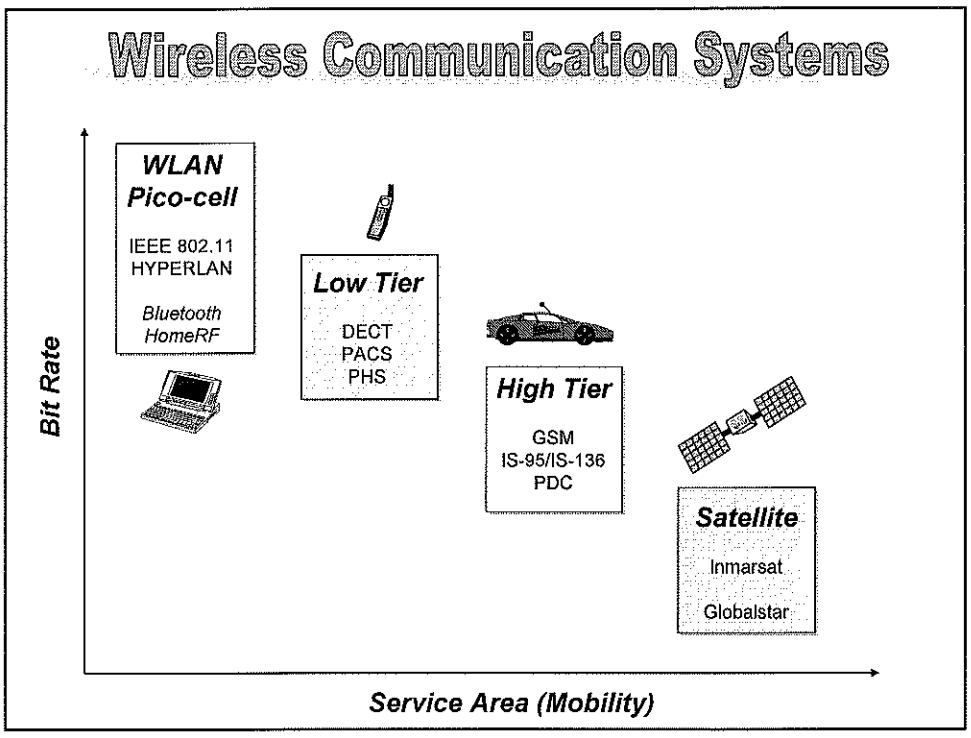


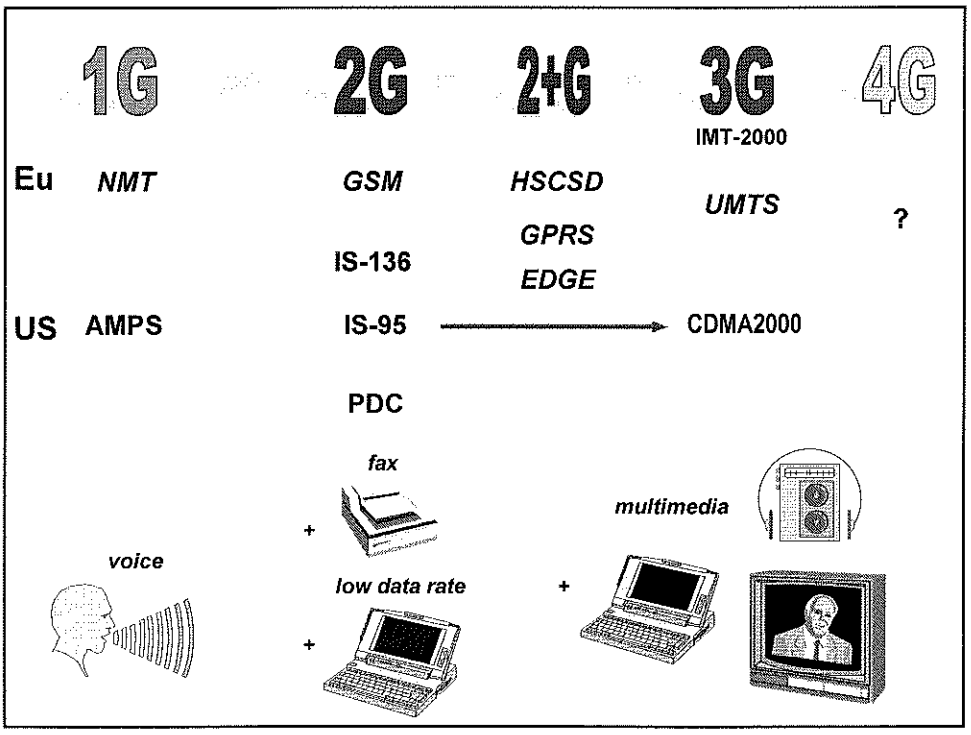
Mobile Wireless Communications

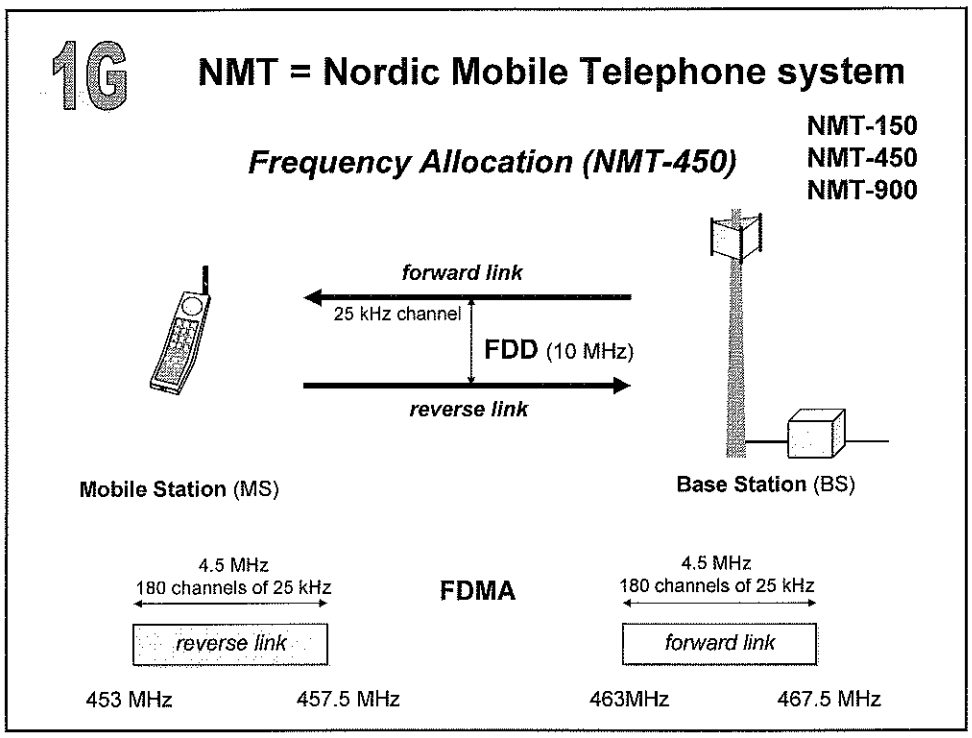


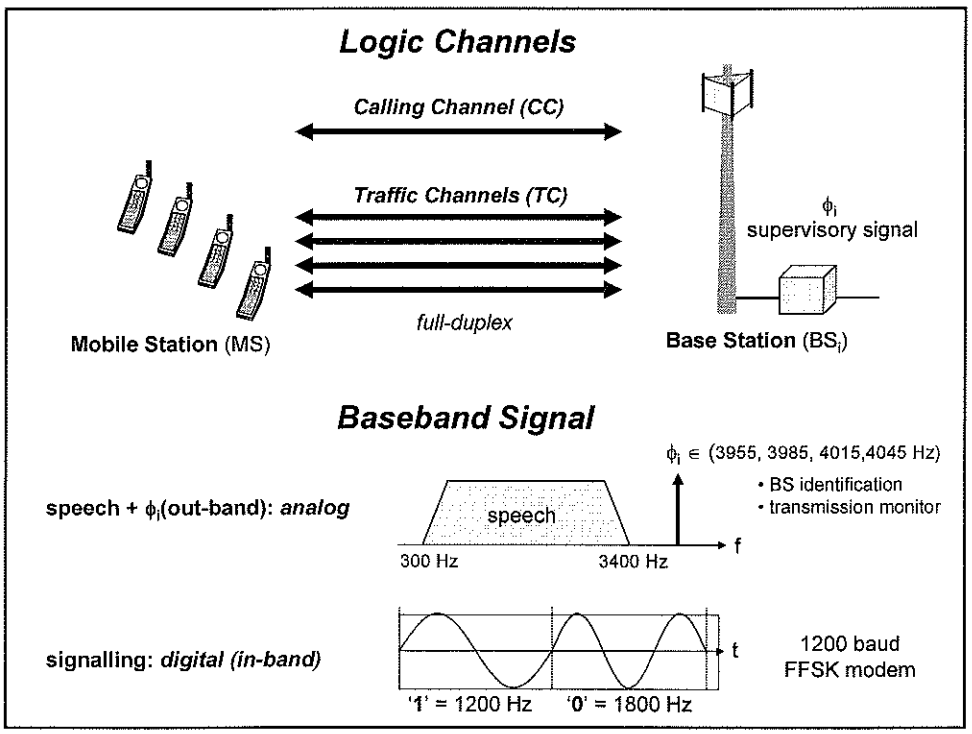
Wireless Communication Systems



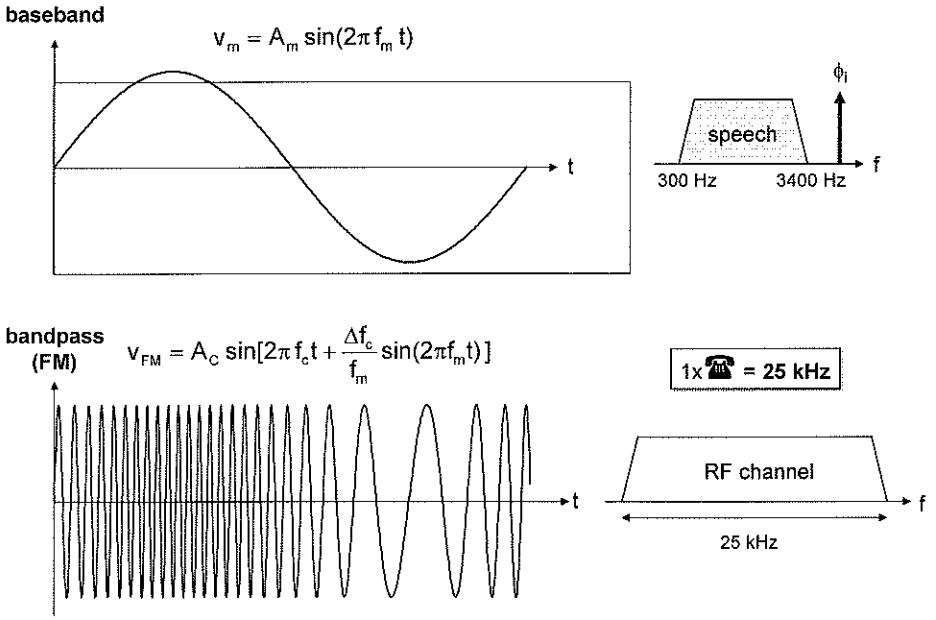

Wireless Communication Systems
WLAN
Pico-cell
IEEE 802.11
HYPERLAN
Bluetooth
HomeRF
Low Tier
DECT
PACS
PHS
High Tier
GSM
IS-95/IS-136
PDC
Satellite
Inmarsat
Globalstar
Bit Rate
Service Area (Mobility)


1G
2G
2+G
3G
4G
IMT-2000
Eu
NMT
GSM
HSCSD
GPRS
EDGE
UMTS
?
IS-136
US
AMPS
IS-95
CDMA2000
PDC
fax
multimedia
voice
low data rate

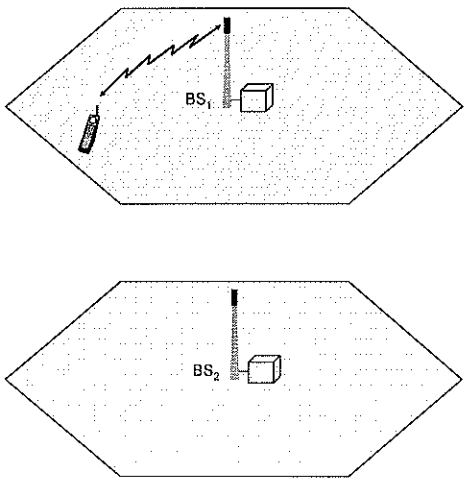

1G
NMT = Nordic Mobile Telephone system
NMT-150
NMT-450
NMT-900
Frequency Allocation (NMT-450)
forward link
25 kHz channel
FDD (10 MHz)
reverse link
Mobile Station (MS)
Base Station (BS)
4.5 MHz
180 channels of 25 kHz
reverse link
FDMA
4.5 MHz
180 channels of 25 kHz
forward link
453 MHz
457.5 MHz
463MHz
467.5 MHz


Logic Channels
Calling Channel (CC)
Traffic Channels (TC)
full-duplex
Mobile Station (MS)
Base Station (BSi)
φi
supervisory signal
Baseband Signal
φi ∈ (3955, 3985, 4015,4045 Hz)
• BS identification
• transmission monitor
speech + φi(out-band): analog
speech
300 Hz
3400 Hz
f
signalling: digital (in-band)
t
1200 baud
FFSK modem
'1' = 1200 Hz
'0' = 1800 Hz

FM modulation

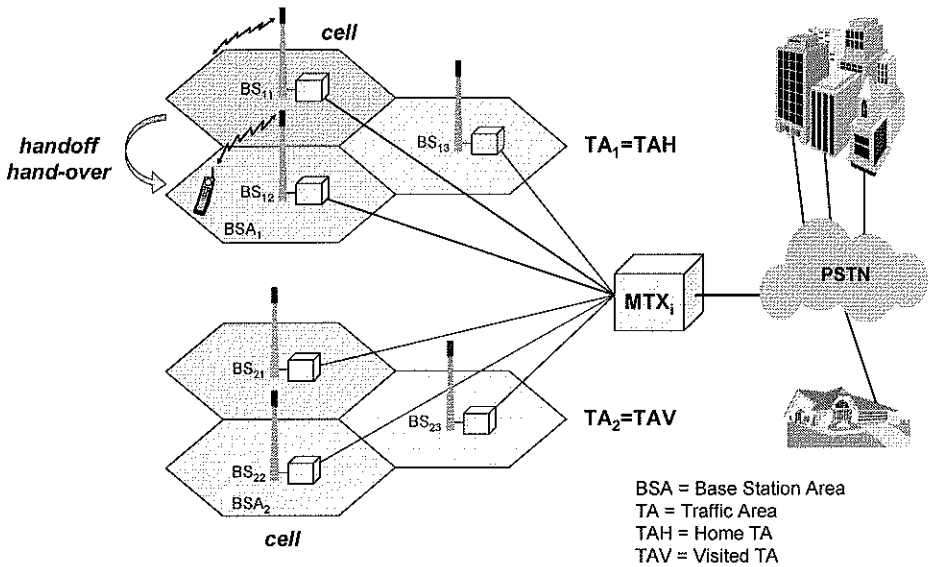


NMT Network Architecture: NMT-150



- *large area*
- *large power*
- *low capacity*

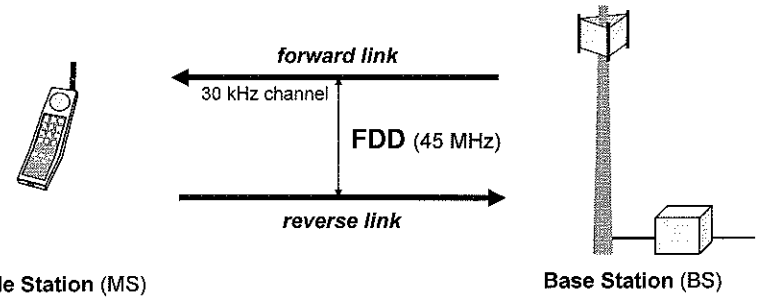
NMT Network Architecture: cellular



BSA = Base Station Area
TA = Traffic Area
TAH = Home TA
TAV = Visited TA
MTA = MTX Area
MTX = Mobile Telephone eXchange

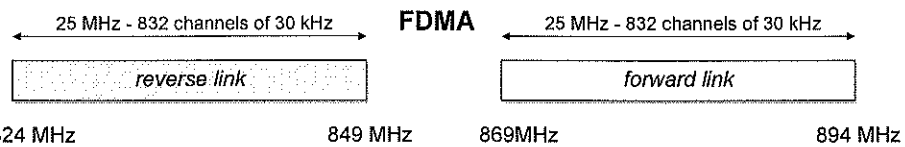
1G AMPS = Advanced Mobile Phone Service

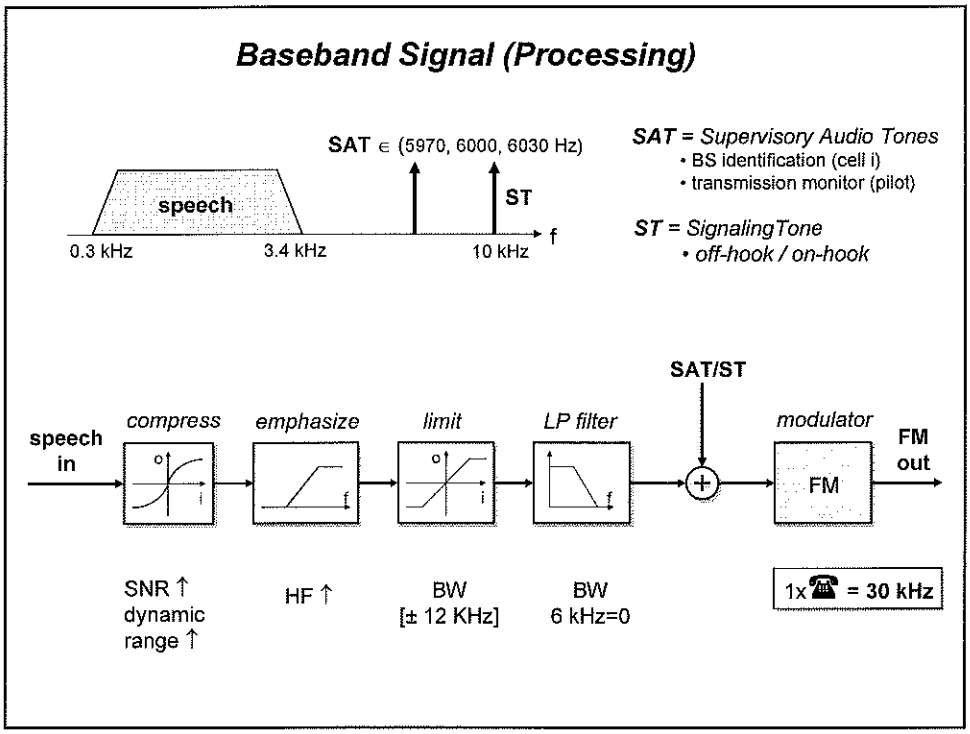
Frequency Allocation

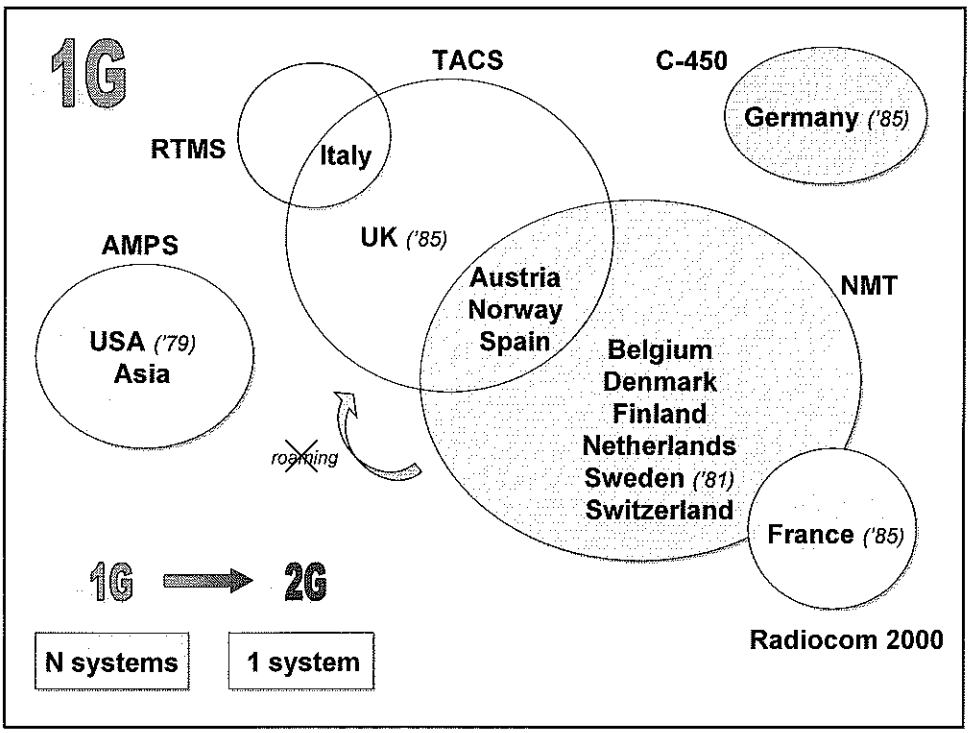


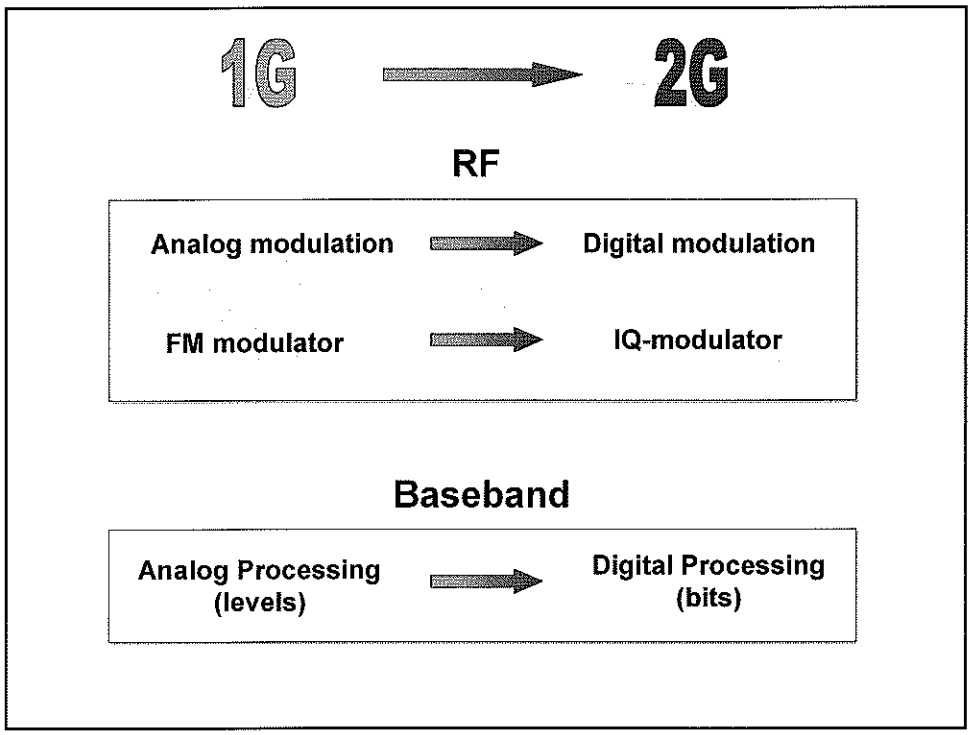
Mobile Station (MS)

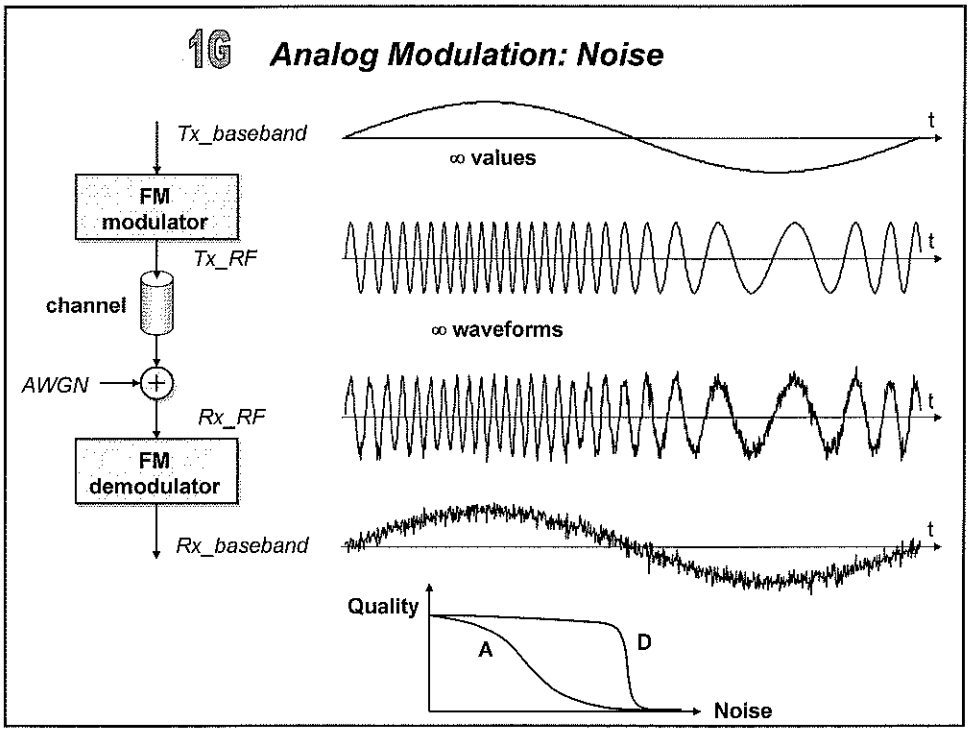
Base Station (BS)

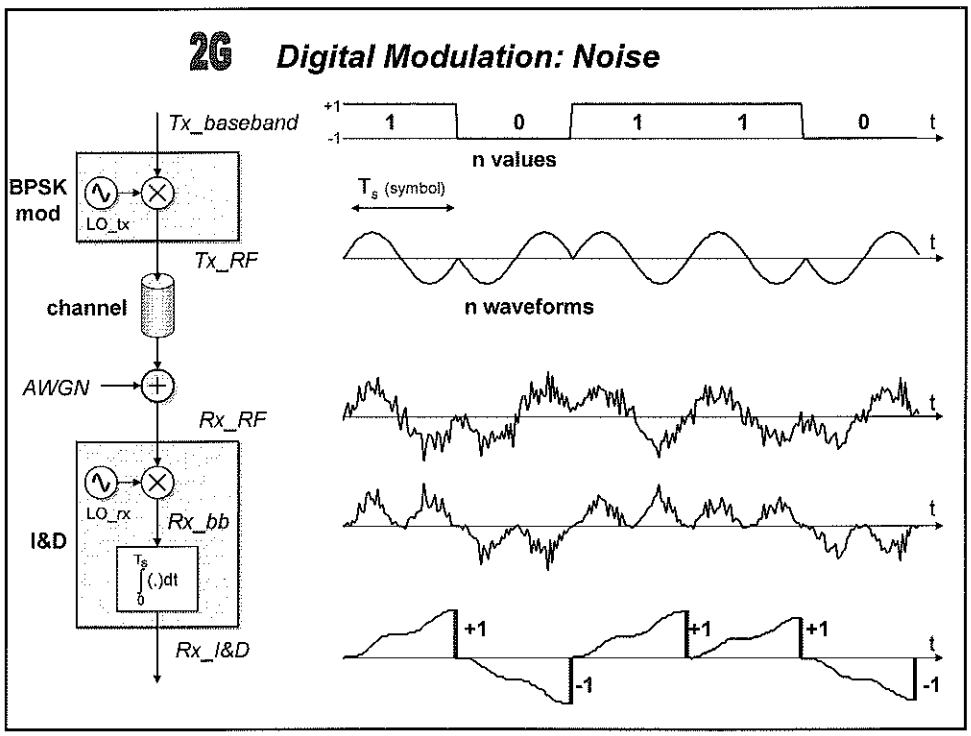


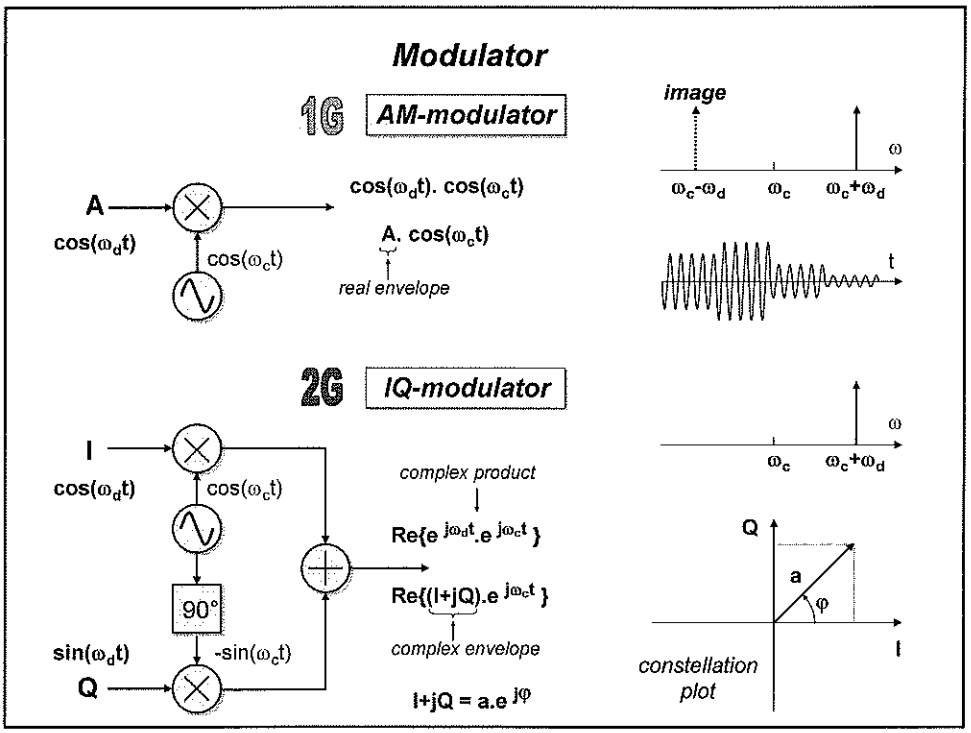

Baseband Signal (Processing)
SAT ∈ (5970, 6000, 6030 Hz)
ST
speech
0.3 kHz
3.4 kHz
10 kHz
f
SAT = Supervisory Audio Tones
• BS identification (cell i)
• transmission monitor (pilot)
ST = SignalingTone
• off-hook / on-hook
SAT/ST
speech in
compress
emphasize
limit
LP filter
modulator
FM
FM out
SNR ↑ dynamic range ↑
HF ↑
BW [± 12 KHz]
BW 6 kHz=0
1x☎ = 30 kHz

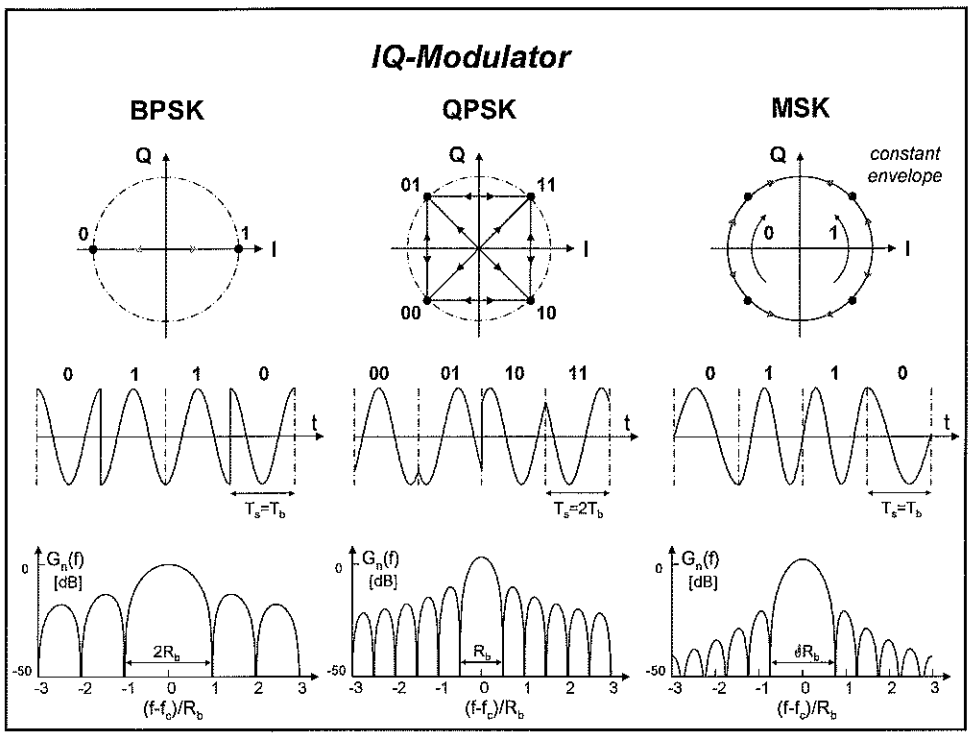

1G
TACS
C-450
Germany ('85)
RTMS
Italy
UK ('85)
AMPS
Austria
Norway
Spain
NMT
USA ('79)
Asia
Belgium
Denmark
Finland
Netherlands
Sweden ('81)
Switzerland
roaming
France ('85)
1G → 2G
Radiocom 2000
N systems
1 system

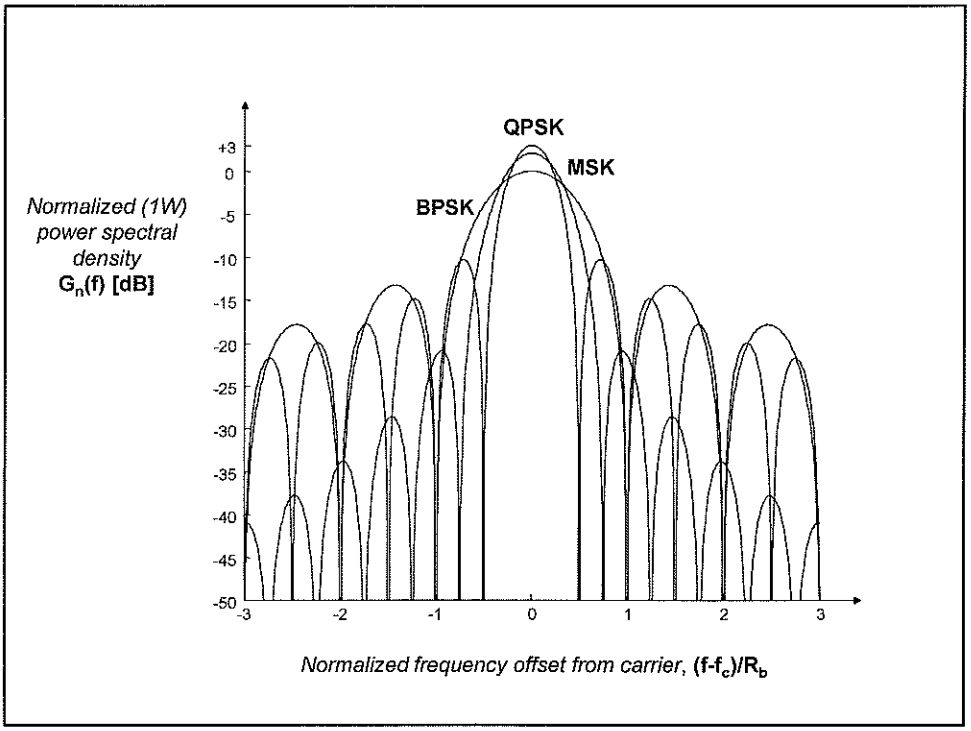

1G
2G
RF
Analog modulation
Digital modulation
FM modulator
IQ-modulator
Baseband
Analog Processing (levels)
Digital Processing (bits)

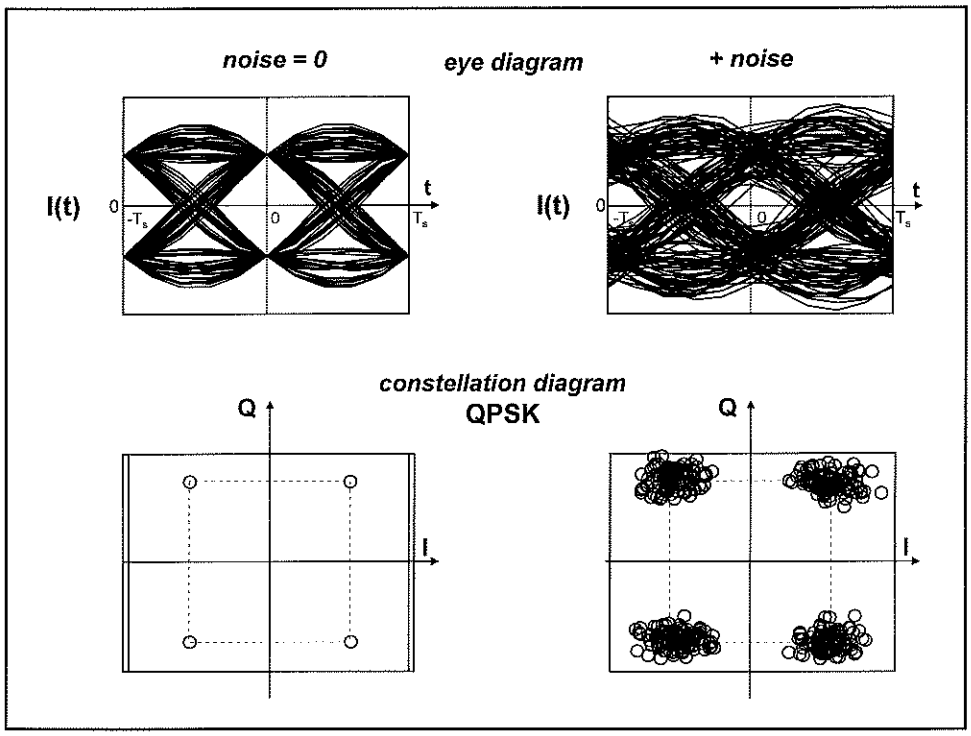

1G Analog Modulation: Noise
Tx_baseband
FM modulator
Tx_RF
channel
AWGN
Rx_RF
FM demodulator
Rx_baseband
∞ values
∞ waveforms
t
Quality
A
D
Noise


2G
Digital Modulation: Noise
Tx_baseband
BPSK mod
LO_tx
Tx_RF
channel
AWGN
Rx_RF
LO_rx
Rx_bb
I&D
Ts ∫ (.)dt 0
Rx_I&D
+1
-1
1 0 1 1 0 t
n values
Ts (symbol)
t
n waveforms
+1 +1 +1
-1 -1

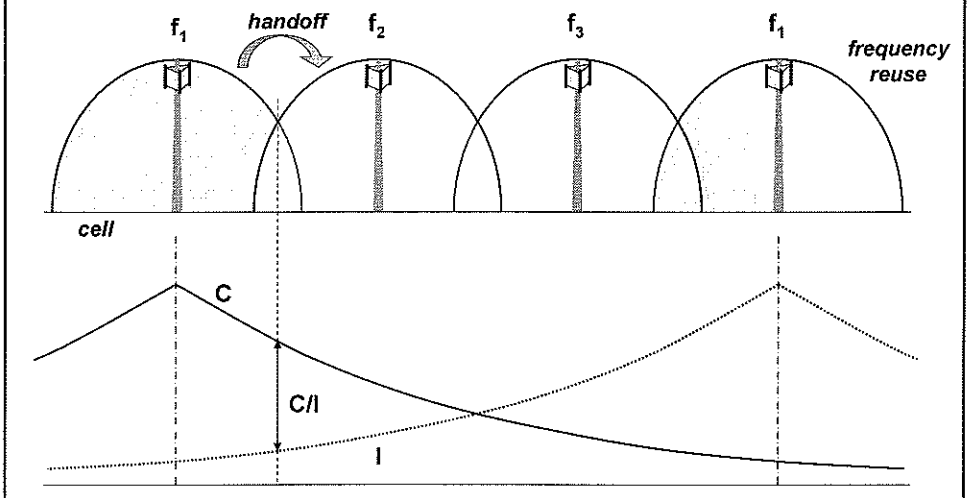

Modulator
1G
AM-modulator
A
cos(ωdt)
cos(ωct)
cos(ωdt). cos(ωct)
A. cos(ωct)
real envelope
image
ωc-ωd
ωc
ωc+ωd
ω
t
2G
IQ-modulator
I
cos(ωdt)
cos(ωct)
90°
sin(ωdt)
-sin(ωct)
Q
complex product
Re{e jωdt.e jωct }
Re{(I+jQ).e jωct }
complex envelope
I+jQ = a.e jφ
constellation plot
a
φ


IQ-Modulator
BPSK
QPSK
MSK
Q
I
0
1
01
11
00
10
constant
envelope
0 1 1 0
00 01 10 11
t
$T_s=T_b$
$T_s=2T_b$
$G_n(f)$
[dB]
$2R_b$
R_b
$\frac{3}{2}R_b$
$(f-f_c)/R_b$


Normalized (1W)
power spectral
density
$G_n(f)$ [dB]
QPSK
MSK
BPSK
+3
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-3 -2 -1 0 1 2 3
Normalized frequency offset from carrier, $(f-f_c)/R_b$

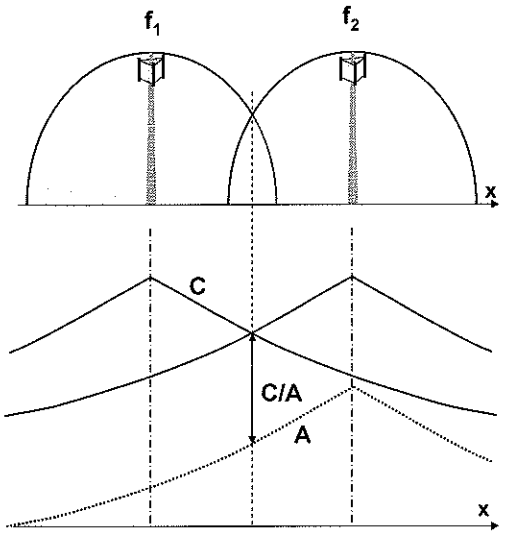


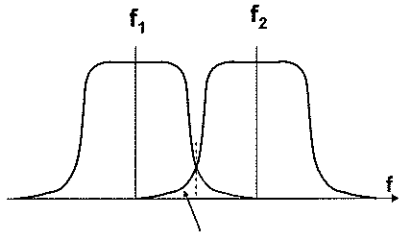
Cellular Network: Co-channel Interference



C = Carrier level
I = Interference from a nearby cell on the same radio carrier frequency
(↓ ≠busy hour, PC=power control, DTX=Discontinuous Transmission, FH = Freq. Hopping)
C/I : a technology (analog/digital) with a smaller ratio for the same transmission quality can reuse the same carrier frequency more often, thus increasing the system capacity

Cellular Network: Adjacent Channel Interference



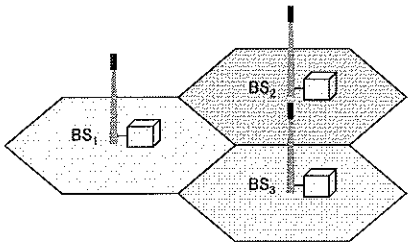


A = ***Adjacent Channel Power (ACP)***

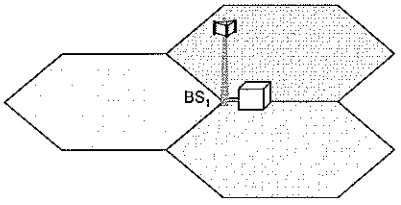
ACP is power generated outside the channel bandwidth interfering with adjacent channels.

Radio channels in a single cell are not spaced adjacent to each other.

Cellular Network: Sites



Omni Site
- BS in the centre, serves 1 cell
- omnidirectional (horizontal) antenna



Sectorized Site
- BS serves 3 cells
- directive antenna (120° sector)

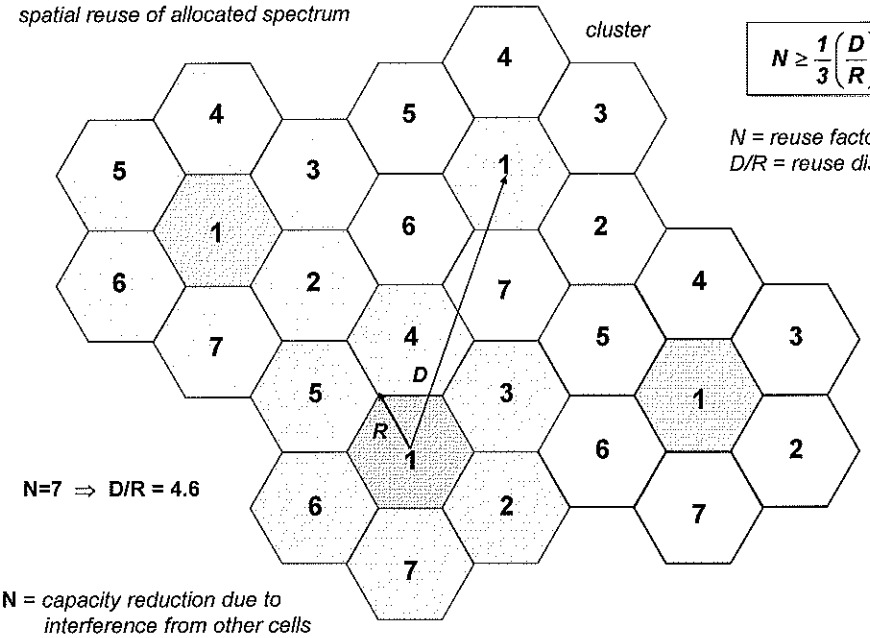
Cell Frequency Plan: Reuse Factor N

spatial reuse of allocated spectrum

cluster

$$N \geq \frac{1}{3}\left(\frac{D}{R}\right)^2$$

N = reuse factor
D/R = reuse distance

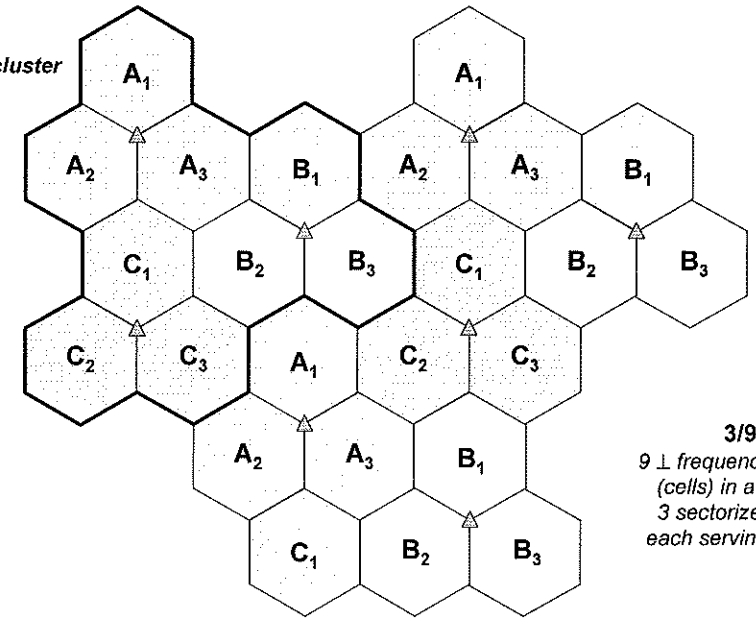


N=7 ⇒ D/R = 4.6

N = *capacity reduction due to interference from other cells*

Cell Frequency Plan: Reuse Factor N

cluster

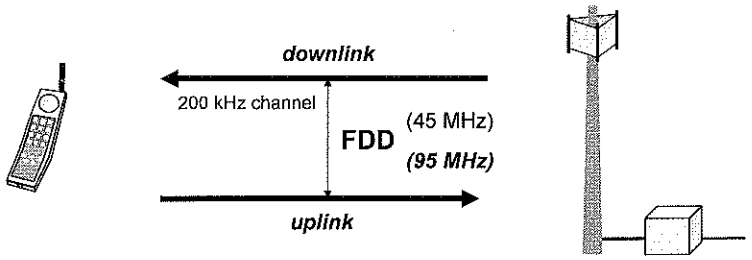


3/9
9 ⊥ frequency groups (cells) in a cluster
3 sectorized sites each serving 3 cells

2G

GSM
Global System for Mobile communication

Frequency Allocation

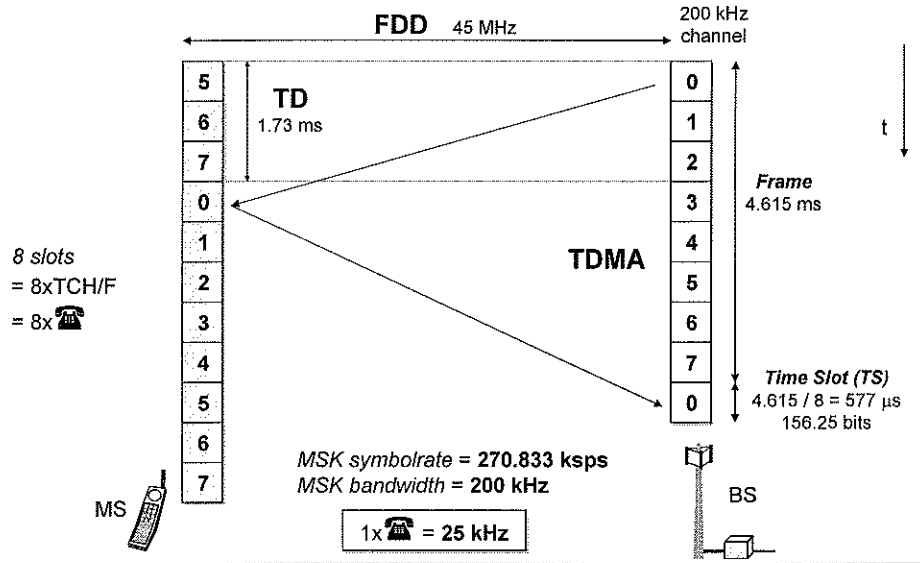


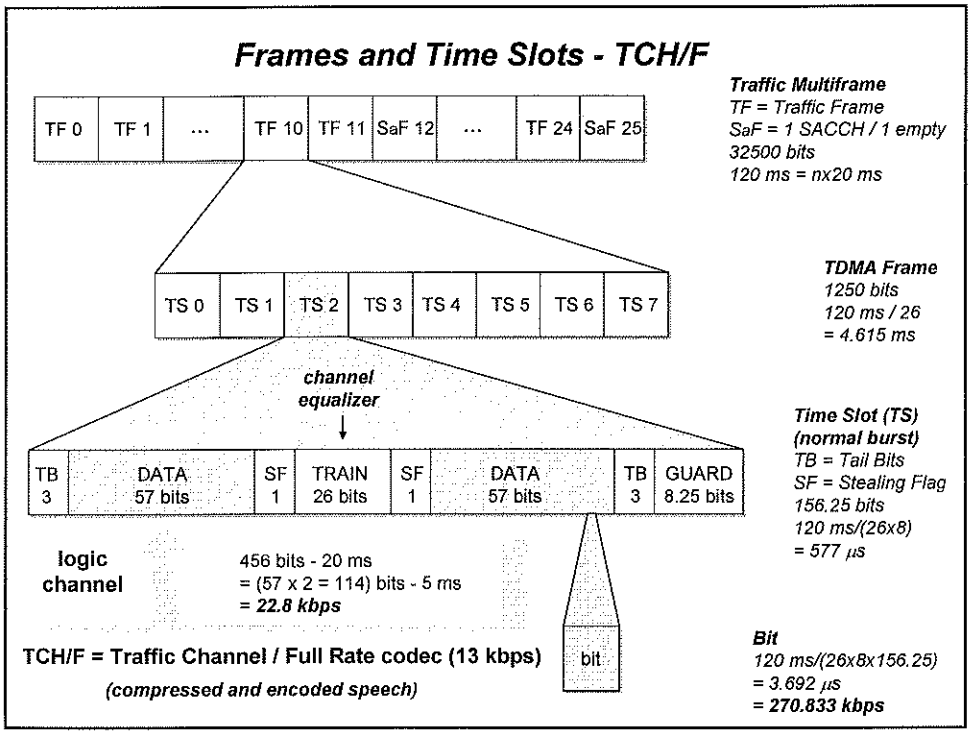
Mobile Station (MS) **Base Station** (BS)

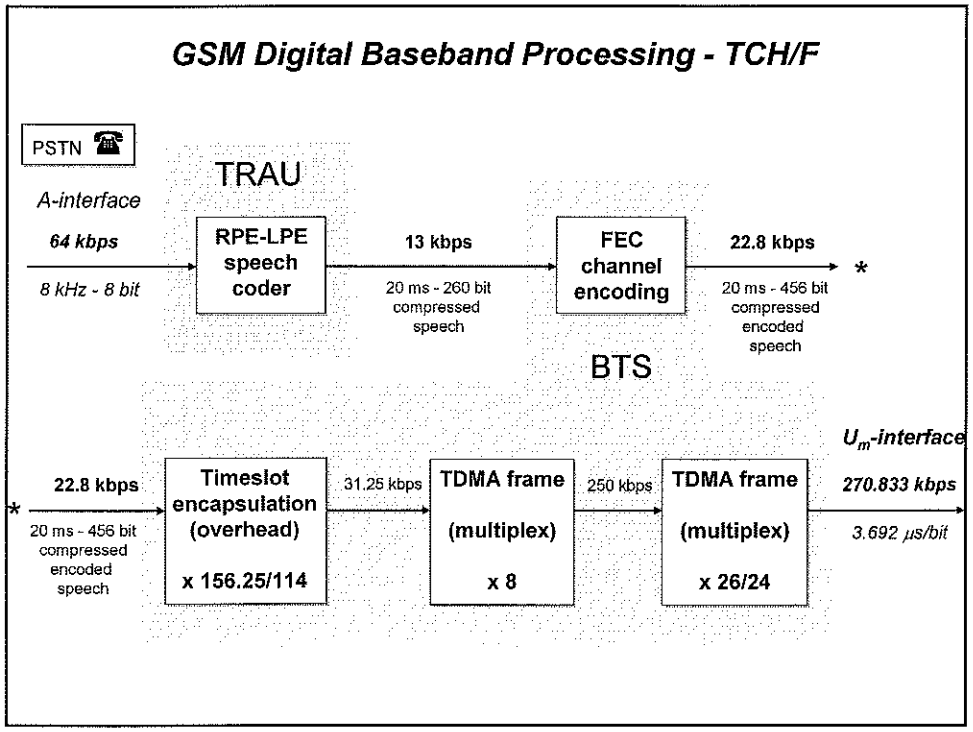
25 MHz - 124 channels of 200 kHz			FDMA	25 MHz - 124 channels of 200 kHz	
uplink				*downlink*	
890 MHz	124	915 MHz	GSM	935MHz	960 MHz
1710 MHz	***374***	***1785 MHz***	***DCS***	***1805 MHz***	***1880 MHz***
1850 MHz	***299***	***1910 MHz***	***PCS***	***1930 MHz***	***1990 MHz***

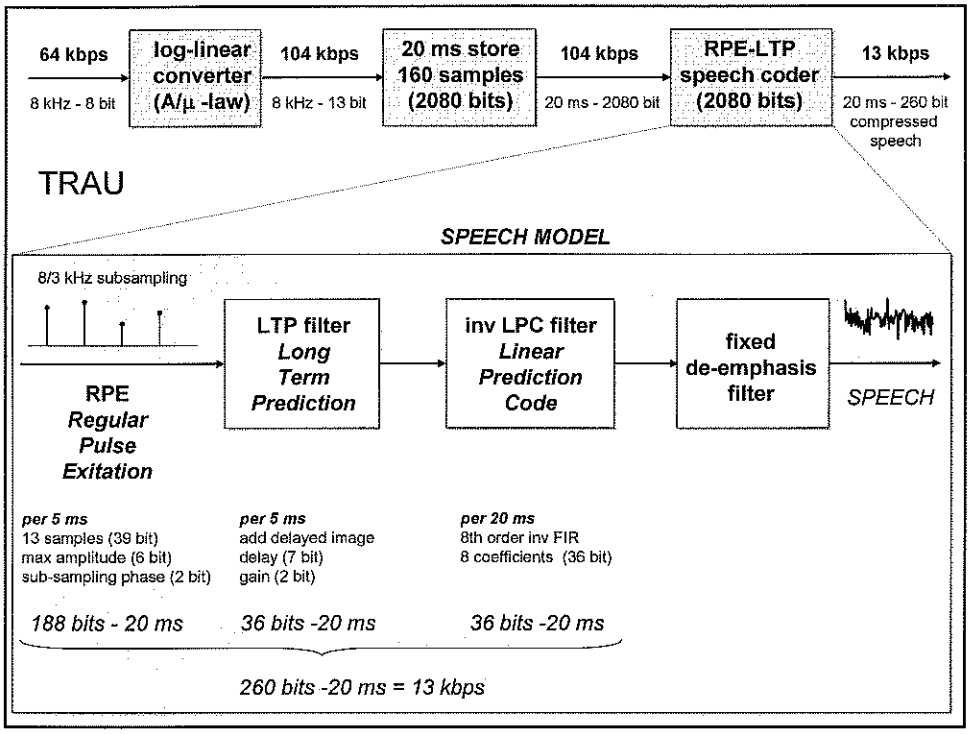
Frames and Time Slots

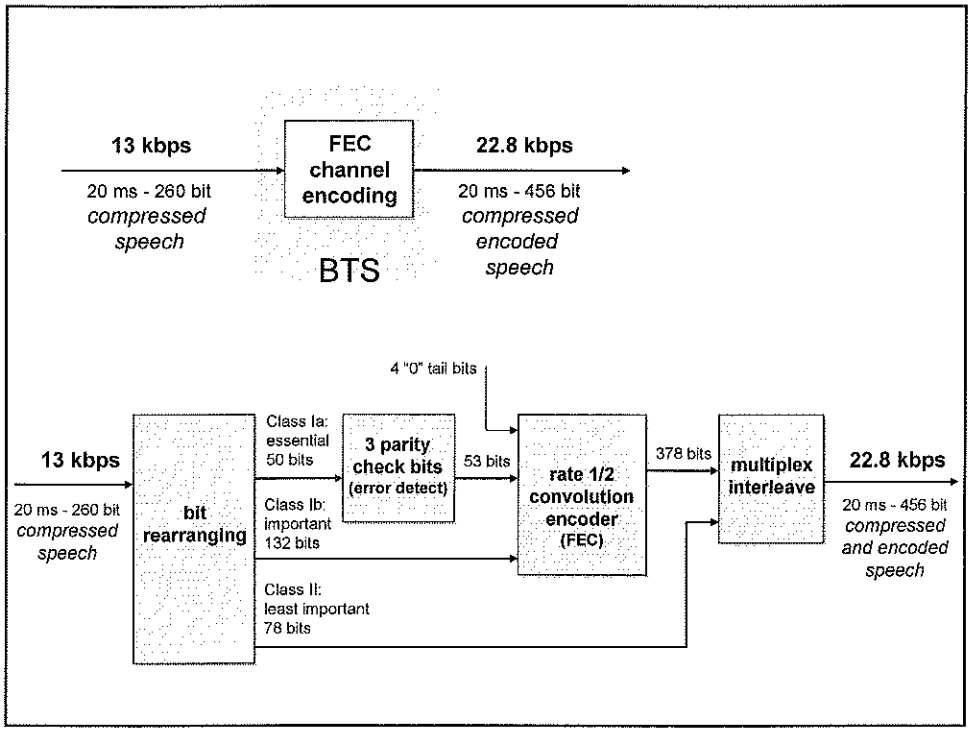
uplink (MS → BS) **FDMA** *downlink (BS → MS)*

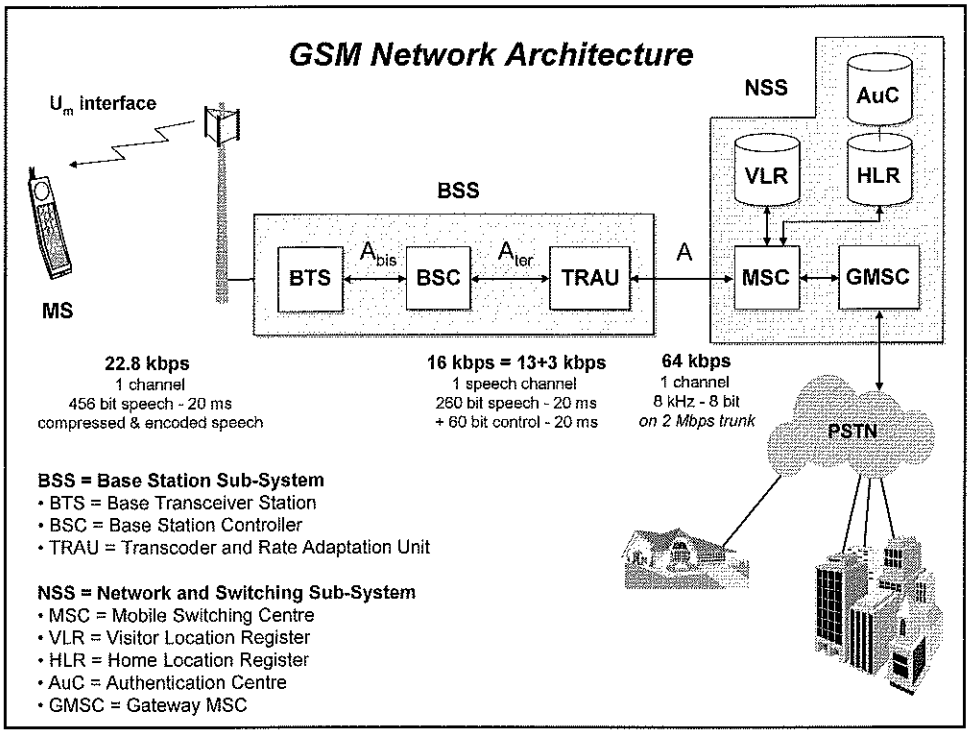


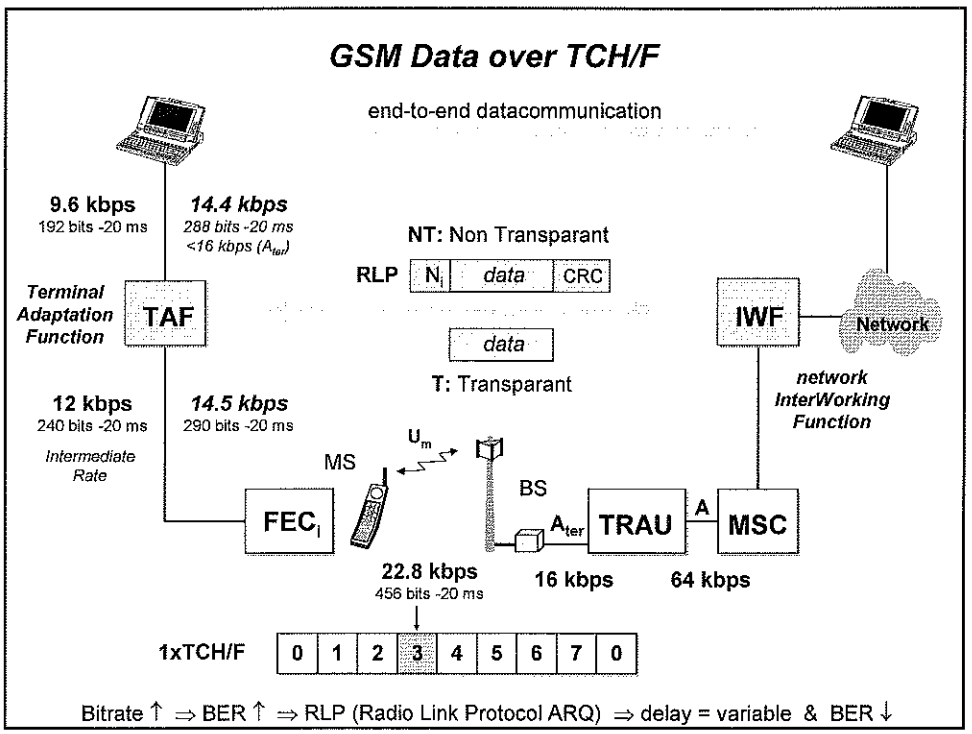

Frames and Time Slots - TCH/F
TF 0
TF 1
...
TF 10
TF 11
SaF 12
...
TF 24
SaF 25
Traffic Multiframe
TF = Traffic Frame
SaF = 1 SACCH / 1 empty
32500 bits
120 ms = nx20 ms
TS 0
TS 1
TS 2
TS 3
TS 4
TS 5
TS 6
TS 7
TDMA Frame
1250 bits
120 ms / 26
= 4.615 ms
channel equalizer
TB 3
DATA 57 bits
SF 1
TRAIN 26 bits
SF 1
DATA 57 bits
TB 3
GUARD 8.25 bits
Time Slot (TS) (normal burst)
TB = Tail Bits
SF = Stealing Flag
156.25 bits
120 ms/(26x8)
= 577 µs
logic channel
456 bits - 20 ms
= (57 x 2 = 114) bits - 5 ms
= 22.8 kbps
TCH/F = Traffic Channel / Full Rate codec (13 kbps)
(compressed and encoded speech)
bit
Bit
120 ms/(26x8x156.25)
= 3.692 µs
= 270.833 kbps

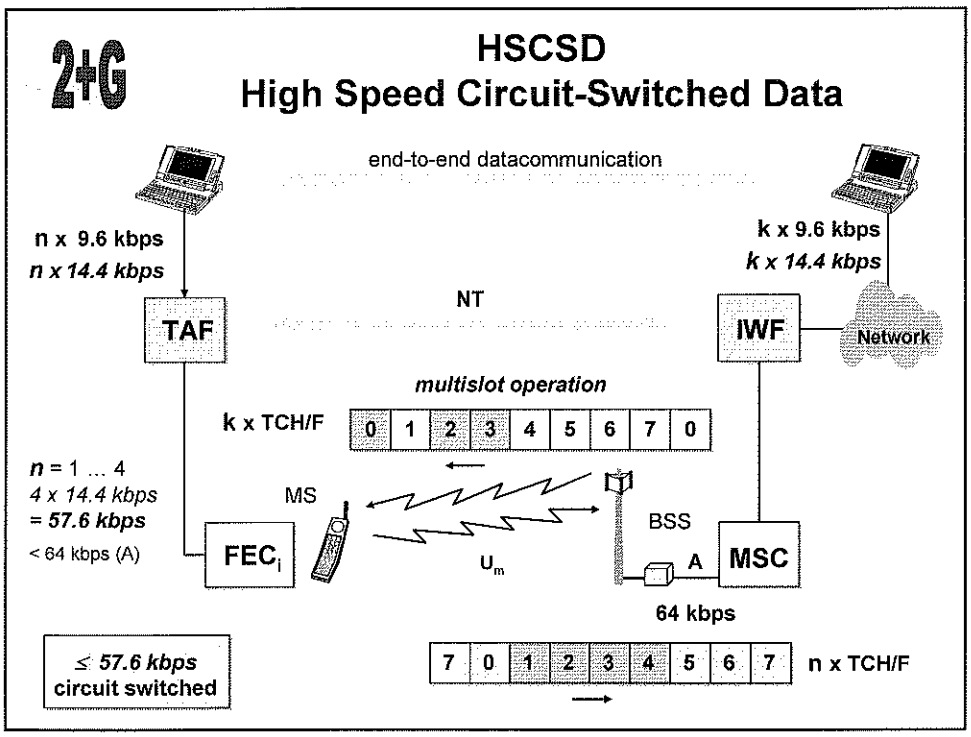

GSM Digital Baseband Processing - TCH/F
PSTN
A-interface
64 kbps
8 kHz - 8 bit
TRAU
RPE-LPE speech coder
13 kbps
20 ms - 260 bit compressed speech
FEC channel encoding
22.8 kbps
20 ms - 456 bit compressed encoded speech
*
BTS
Um-interface
270.833 kbps
3.692 µs/bit
22.8 kbps
20 ms - 456 bit compressed encoded speech
Timeslot encapsulation (overhead)
x 156.25/114
31.25 kbps
TDMA frame (multiplex)
x 8
250 kbps
TDMA frame (multiplex)
x 26/24

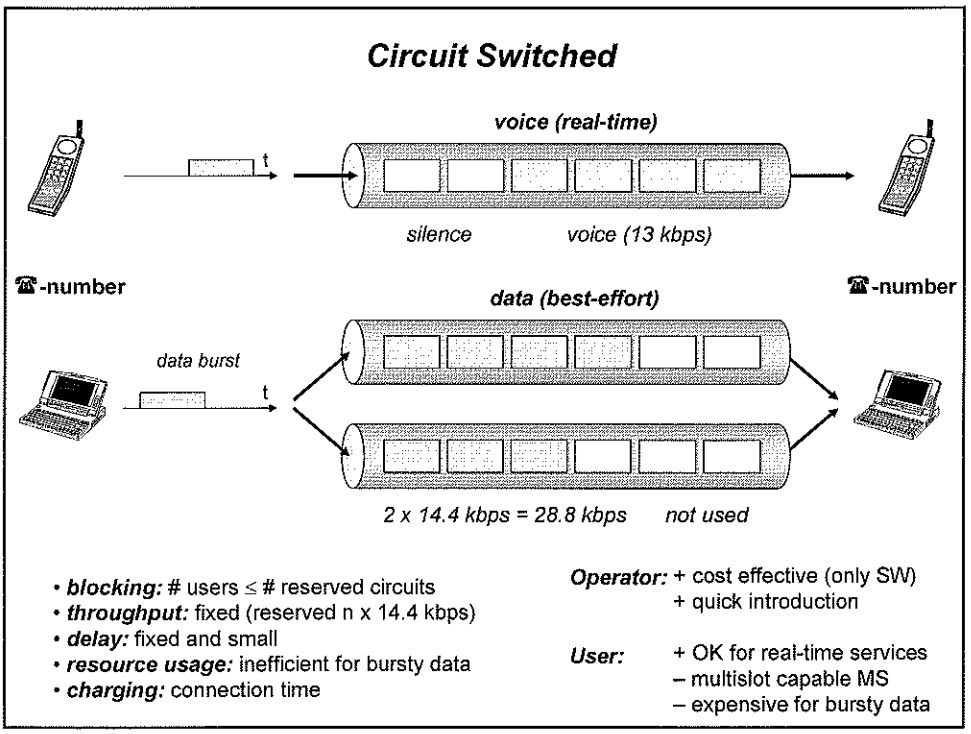

64 kbps
8 kHz - 8 bit
log-linear converter (A/μ -law)
104 kbps
8 kHz - 13 bit
20 ms store 160 samples (2080 bits)
104 kbps
20 ms - 2080 bit
RPE-LTP speech coder (2080 bits)
13 kbps
20 ms - 260 bit compressed speech
TRAU
SPEECH MODEL
8/3 kHz subsampling
RPE Regular Pulse Exitation
LTP filter Long Term Prediction
inv LPC filter Linear Prediction Code
fixed de-emphasis filter
SPEECH
per 5 ms
13 samples (39 bit)
max amplitude (6 bit)
sub-sampling phase (2 bit)
per 5 ms
add delayed image
delay (7 bit)
gain (2 bit)
per 20 ms
8th order inv FIR
8 coefficients (36 bit)
188 bits - 20 ms
36 bits -20 ms
36 bits -20 ms
260 bits -20 ms = 13 kbps

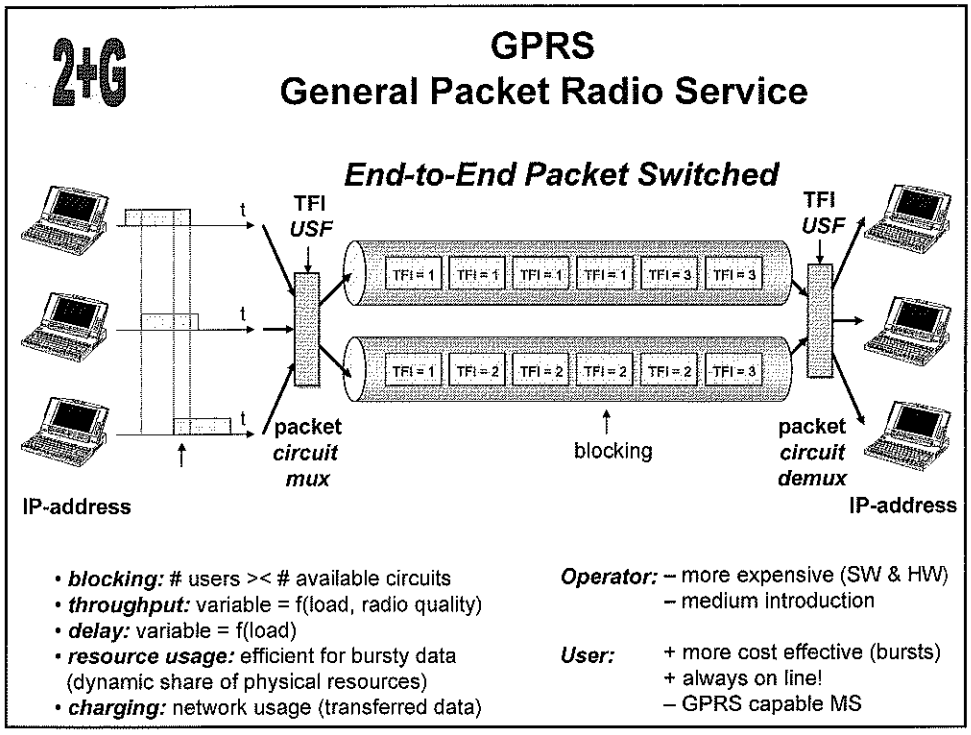

13 kbps
20 ms - 260 bit compressed speech
FEC channel encoding
22.8 kbps
20 ms - 456 bit compressed encoded speech
BTS
4 "0" tail bits
13 kbps
20 ms - 260 bit compressed speech
bit rearranging
Class Ia: essential 50 bits
Class Ib: important 132 bits
Class II: least important 78 bits
3 parity check bits (error detect)
53 bits
rate 1/2 convolution encoder (FEC)
378 bits
multiplex interleave
22.8 kbps
20 ms - 456 bit compressed and encoded speech

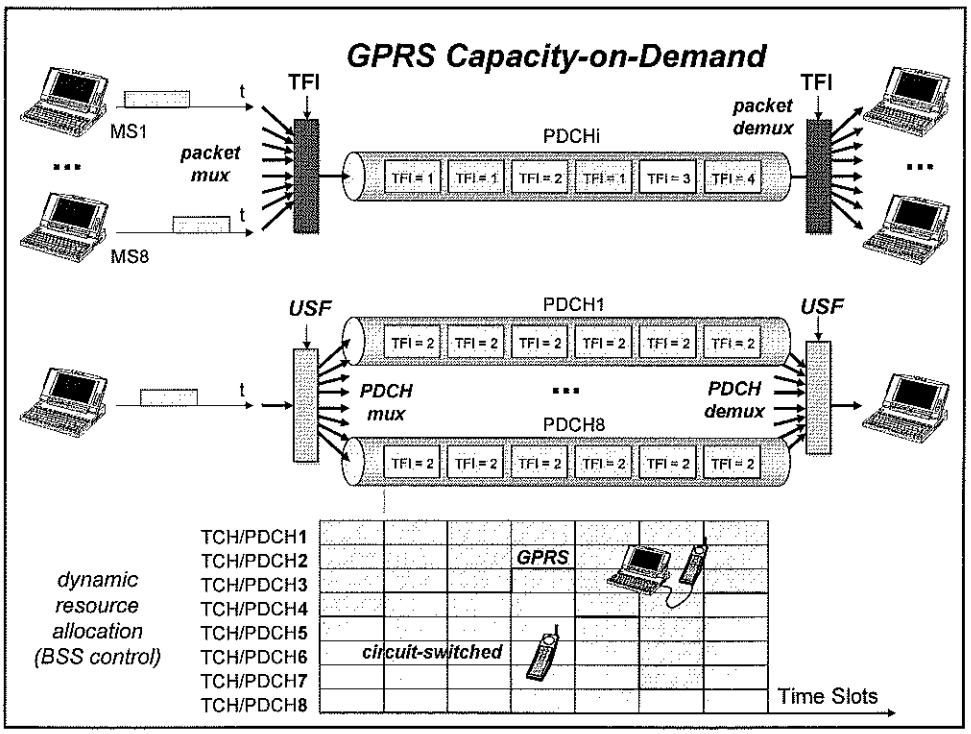

GSM Network Architecture
U_m interface
MS
BSS
BTS
A_bis
BSC
A_ter
TRAU
A
NSS
AuC
VLR
HLR
MSC
GMSC
PSTN
22.8 kbps
1 channel
456 bit speech - 20 ms
compressed & encoded speech
16 kbps = 13+3 kbps
1 speech channel
260 bit speech - 20 ms
+ 60 bit control - 20 ms
64 kbps
1 channel
8 kHz - 8 bit
on 2 Mbps trunk
BSS = Base Station Sub-System
• BTS = Base Transceiver Station
• BSC = Base Station Controller
• TRAU = Transcoder and Rate Adaptation Unit
NSS = Network and Switching Sub-System
• MSC = Mobile Switching Centre
• VLR = Visitor Location Register
• HLR = Home Location Register
• AuC = Authentication Centre
• GMSC = Gateway MSC


GSM Data over TCH/F
end-to-end datacommunication
9.6 kbps
192 bits -20 ms
14.4 kbps
288 bits -20 ms
<16 kbps (A_ter)
NT: Non Transparant
RLP
N_i
data
CRC
Terminal Adaptation Function
TAF
data
T: Transparant
IWF
Network
network InterWorking Function
12 kbps
240 bits -20 ms
Intermediate Rate
14.5 kbps
290 bits -20 ms
U_m
MS
BS
FEC_i
A_ter
TRAU
A
MSC
22.8 kbps
456 bits -20 ms
16 kbps
64 kbps
1xTCH/F
0 1 2 3 4 5 6 7 0
Bitrate ↑ ⇒ BER ↑ ⇒ RLP (Radio Link Protocol ARQ) ⇒ delay = variable & BER ↓

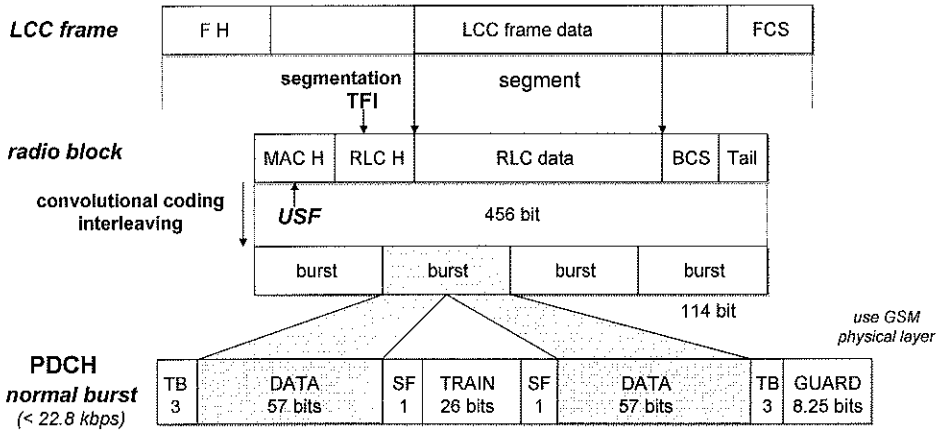

2+G
HSCSD
High Speed Circuit-Switched Data
end-to-end datacommunication
n x 9.6 kbps
n x 14.4 kbps
k x 9.6 kbps
k x 14.4 kbps
NT
TAF
IWF
Network
multislot operation
k x TCH/F
0 1 2 3 4 5 6 7 0
n = 1 ... 4
4 x 14.4 kbps
= 57.6 kbps
< 64 kbps (A)
MS
BSS
FEC
U
A
MSC
64 kbps
≤ 57.6 kbps
circuit switched
7 0 1 2 3 4 5 6 7
n x TCH/F


Circuit Switched
voice (real-time)
t
silence
voice (13 kbps)
-number
-number
data (best-effort)
data burst
t
2 x 14.4 kbps = 28.8 kbps
not used
• blocking: # users ≤ # reserved circuits
• throughput: fixed (reserved n x 14.4 kbps)
• delay: fixed and small
• resource usage: inefficient for bursty data
• charging: connection time
Operator: + cost effective (only SW)
+ quick introduction
User: + OK for real-time services
– multislot capable MS
– expensive for bursty data


2+G
GPRS
General Packet Radio Service
End-to-End Packet Switched
TFI
USF
t
TFI = 1
TFI = 2
TFI = 3
packet
circuit
mux
blocking
packet
circuit
demux
IP-address
IP-address
• blocking: # users >< # available circuits
• throughput: variable = f(load, radio quality)
• delay: variable = f(load)
• resource usage: efficient for bursty data
(dynamic share of physical resources)
• charging: network usage (transferred data)
Operator: – more expensive (SW & HW)
– medium introduction
User: + more cost effective (bursts)
+ always on line!
– GPRS capable MS


GPRS Capacity-on-Demand
TFI
MS1
MS8
packet
mux
PDCHi
packet
demux
TFI = 1
TFI = 2
TFI = 3
TFI = 4
USF
PDCH1
PDCH8
PDCH
mux
PDCH
demux
dynamic
resource
allocation
(BSS control)
TCH/PDCH1
TCH/PDCH2
TCH/PDCH3
TCH/PDCH4
TCH/PDCH5
TCH/PDCH6
TCH/PDCH7
TCH/PDCH8
GPRS
circuit-switched
Time Slots

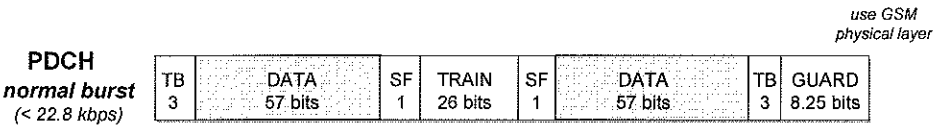
GPRS Air Interface Protocol



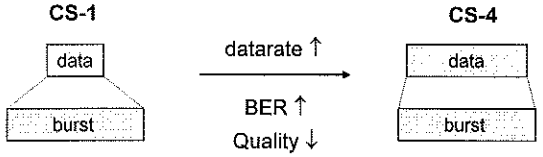
Code Scheme	Code Rate	Payload (from 456 bits)	USF	BCS	Tail Bits	Data Rate (kbps)	Max. Rate (kbps)
CS-1	1/2	181	3	40	4	9.05	72.4
CS-2	≈2/3	268	6	16	4	13.4	107.2
CS-3	≈3/4	312	6	16	4	15.6	124.8
CS-4	1	428	16	16	4	21.4	171.2

channel quality ↑
⇓
protection ↓
datarate↑

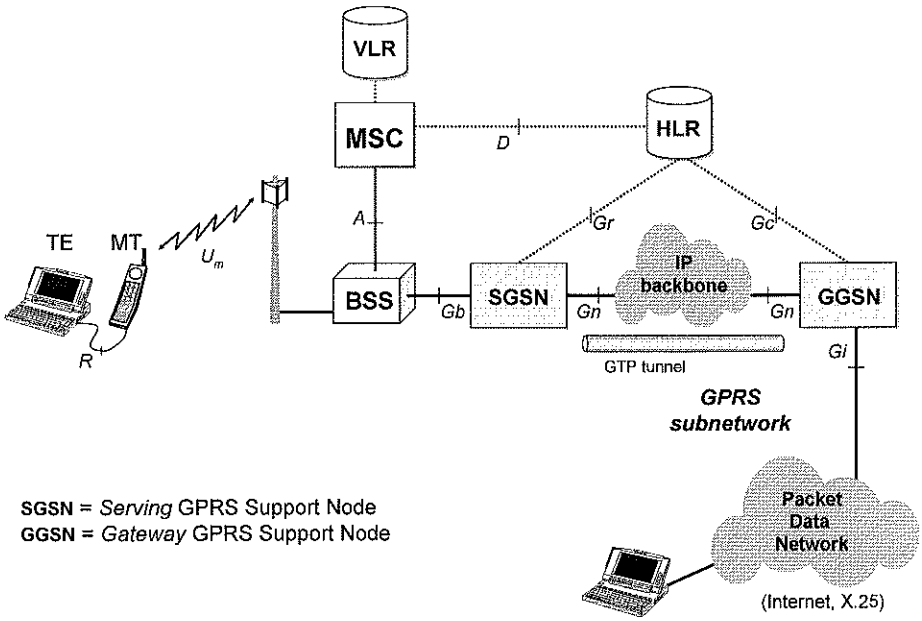
GPRS Air Interface Protocol



						1 TS	8 TS
Code Scheme	*Code Rate*	*Payload (from 456 bits)*	*USF*	*BCS*	*Tail Bits*	***Data Rate (kbps)***	***Max. Rate (kbps)***
CS-1	1/2	181	3	40	4	9.05	72.4
CS-2	≈2/3	268	6	16	4	13.4	107.2
CS-3	≈3/4	312	6	16	4	15.6	124.8
CS-4	1	428	16	16	4	21.4	171.2



GPRS Architecture

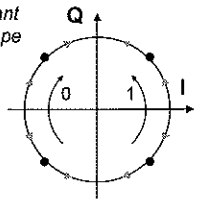


SGSN = *Serving* GPRS Support Node
GGSN = *Gateway* GPRS Support Node

2+G EDGE
Enhanced Data rates for GSM Evolution

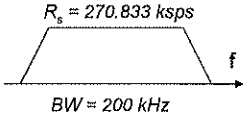
GMSK

constant envelope

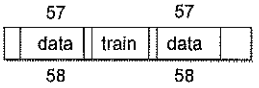


*114 bit / 5ms = **22.8 kbps***
8.TS = 182.4 kbps

R_s = 270.833 ksps

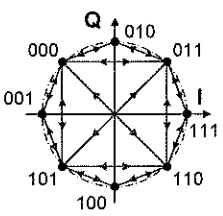


BW = 200 kHz



gross bit rate

8-PSK

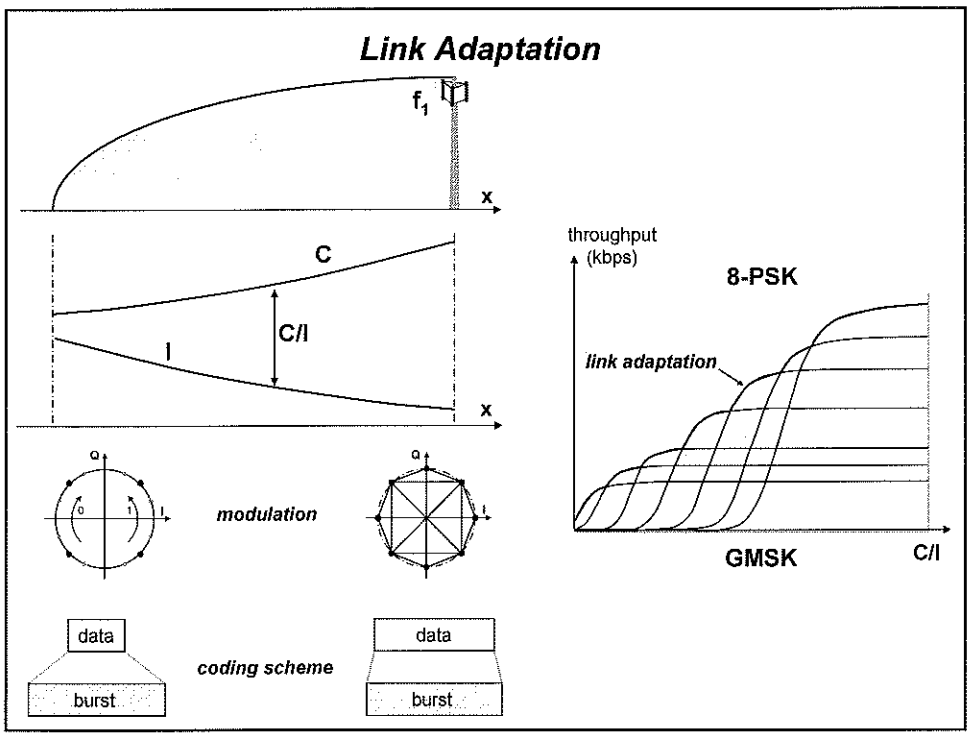


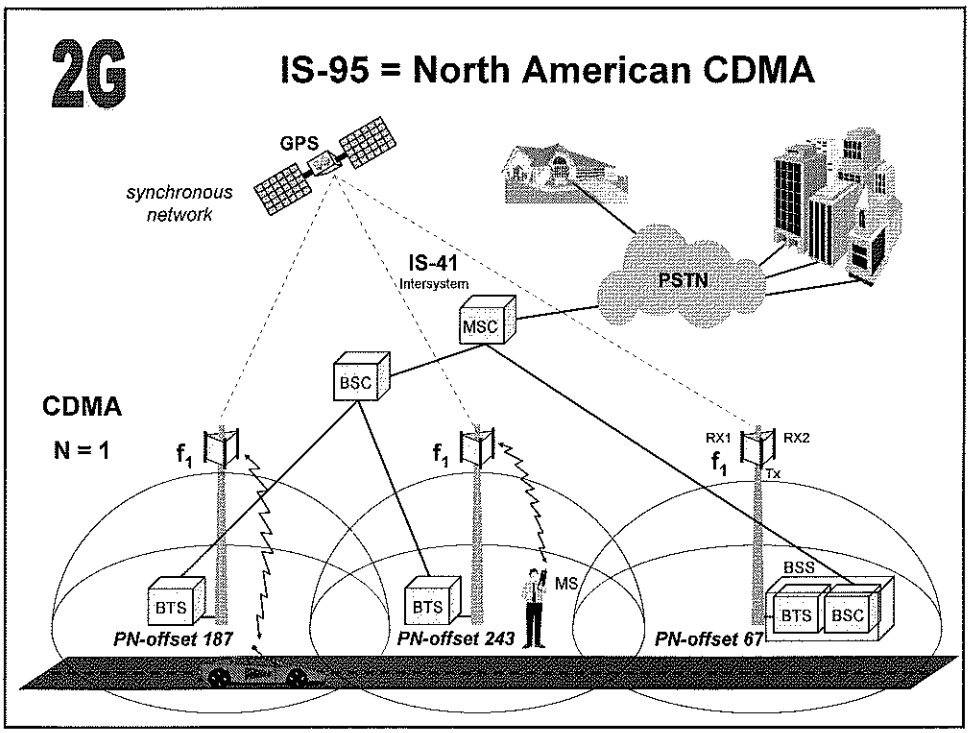
more noise sensitive

3x** 116 bit / 5ms = **69.6 kbps
8.TS = 556.8 kbps

HSCSD	NT: 57.6 kbps / 4TS	***circuit-switched***	NT: 57.6 kbps / 2TS	**ECSD**
GPRS	≤ 21.4 kbps / TS 8.TS = 171.2 kbps	***packet-switched***	≤ 59.2 kbps / TS 8 TS = 473.6 kbps	**EGPRS**

Standardization: ETSI - GSM Phase 2+ and TIA TR45.3 (IS-136)


Link Adaptation
f1
x
C
C/I
I
x
throughput
(kbps)
8-PSK
link adaptation
GMSK
C/I
Q
I
0
1
modulation
data
burst
coding scheme
data
burst


2G
IS-95 = North American CDMA
GPS
synchronous
network
IS-41
Intersystem
PSTN
MSC
BSC
CDMA
N = 1
f1
f1
f1
RX1
RX2
TX
BTS
BTS
MS
BSS
BTS
BSC
PN-offset 187
PN-offset 243
PN-offset 67

HOBU-fonds IWT97109 - DE NAYER instituut

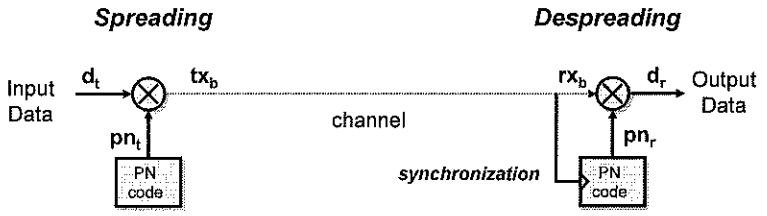
Spread Spectrum

DS-CDMA demonstrator at 2.4 GHz (ISM band)

Measurement aspects
for wireless communication systems

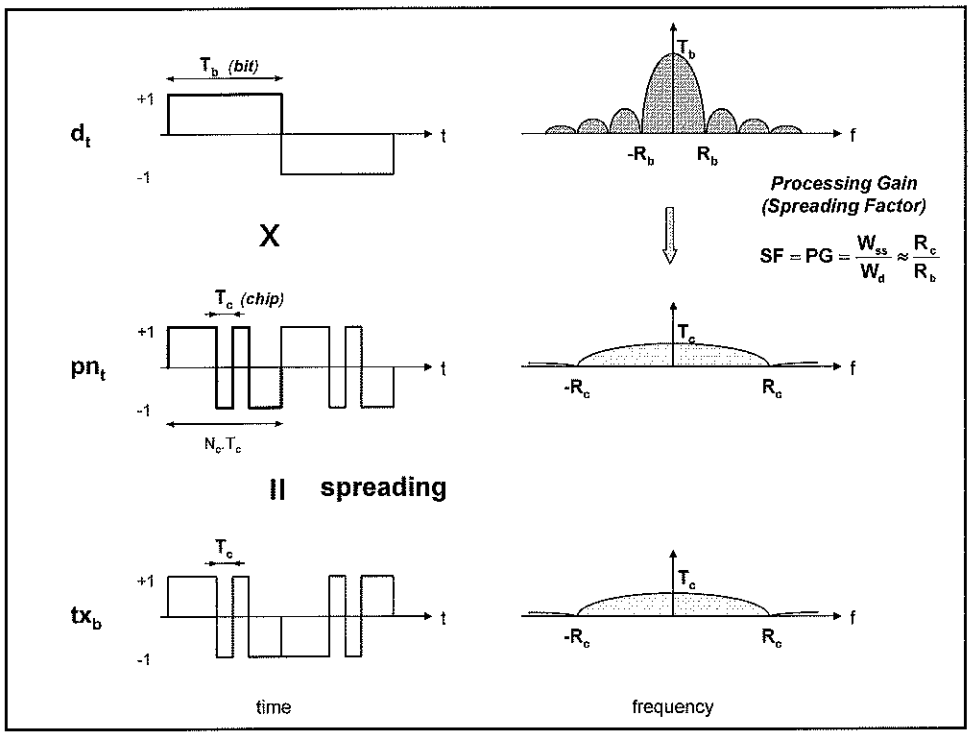
Measurement infrastructure (VSA, IQ-mod, BERT)

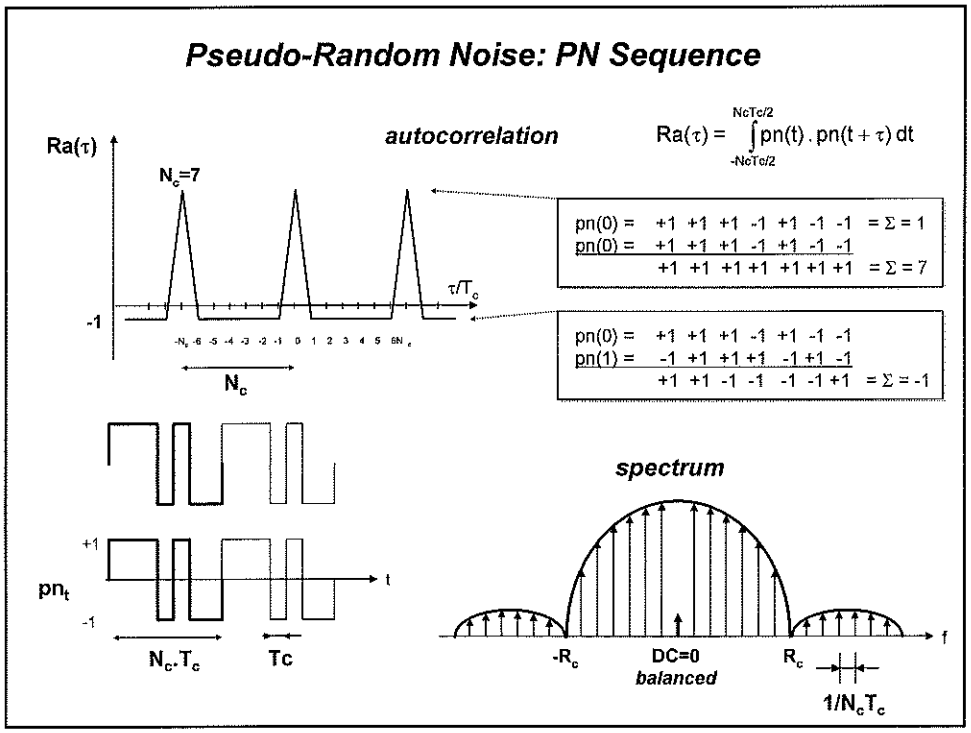
DSSS = Direct Sequence Spread Spectrum



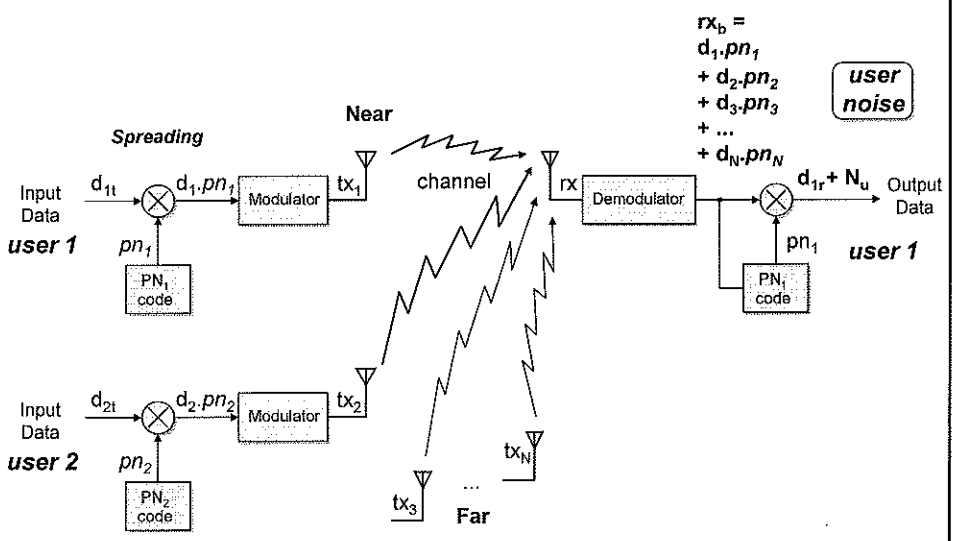
$tx_b = d_t \cdot pn_t$

$d_t = rx_b \cdot pn_r$


T_b (bit)
+1
-1
d_t
t
X
T_c (chip)
pn_t
$N_c.T_c$
II spreading
tx_b
time
T_b
$-R_b$ R_b
f
Processing Gain
(Spreading Factor)
$SF = PG = \frac{W_{ss}}{W_d} \approx \frac{R_c}{R_b}$
T_c
$-R_c$ R_c
frequency


Pseudo-Random Noise: PN Sequence
autocorrelation
$Ra(\tau) = \int_{-NcTc/2}^{NcTc/2} pn(t).pn(t+\tau)\,dt$
Ra(τ)
N_c=7
τ/T_c
-1
N_c
pn(0) = +1 +1 +1 -1 +1 -1 -1 = Σ = 1
pn(0) = +1 +1 +1 -1 +1 -1 -1
+1 +1 +1 +1 +1 +1 +1 = Σ = 7
pn(0) = +1 +1 +1 -1 +1 -1 -1
pn(1) = -1 +1 +1 +1 -1 +1 -1
+1 +1 -1 -1 -1 -1 +1 = Σ = -1
spectrum
pn_t
+1
-1
t
$N_c.T_c$
Tc
$-R_c$
DC=0
balanced
R_c
f
$1/N_cT_c$

CDMA = Code Division Multiple Access



Hadamard-Walsh Code set

$$H_N = \begin{bmatrix} H_{N/2} & H_{N/2} \\ H_{N/2} & -H_{N/2} \end{bmatrix} \quad \text{with} \quad H_0 = [1]$$

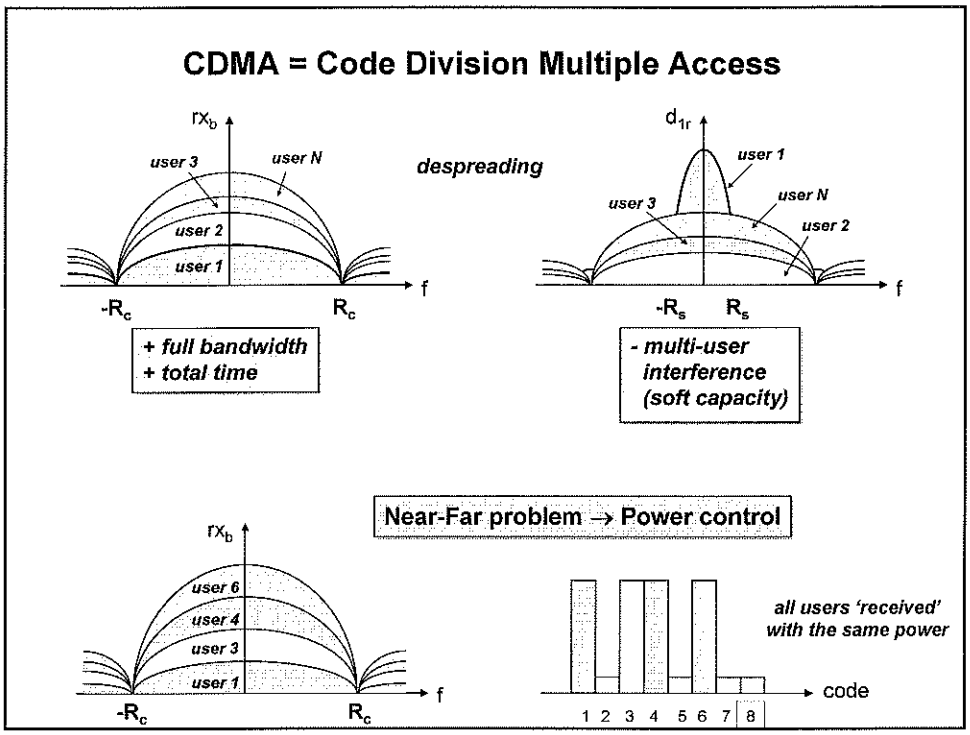
$$H_2 = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \qquad H_4 = \left[\begin{array}{cc:cc} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ \hdashline 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{array}\right]$$

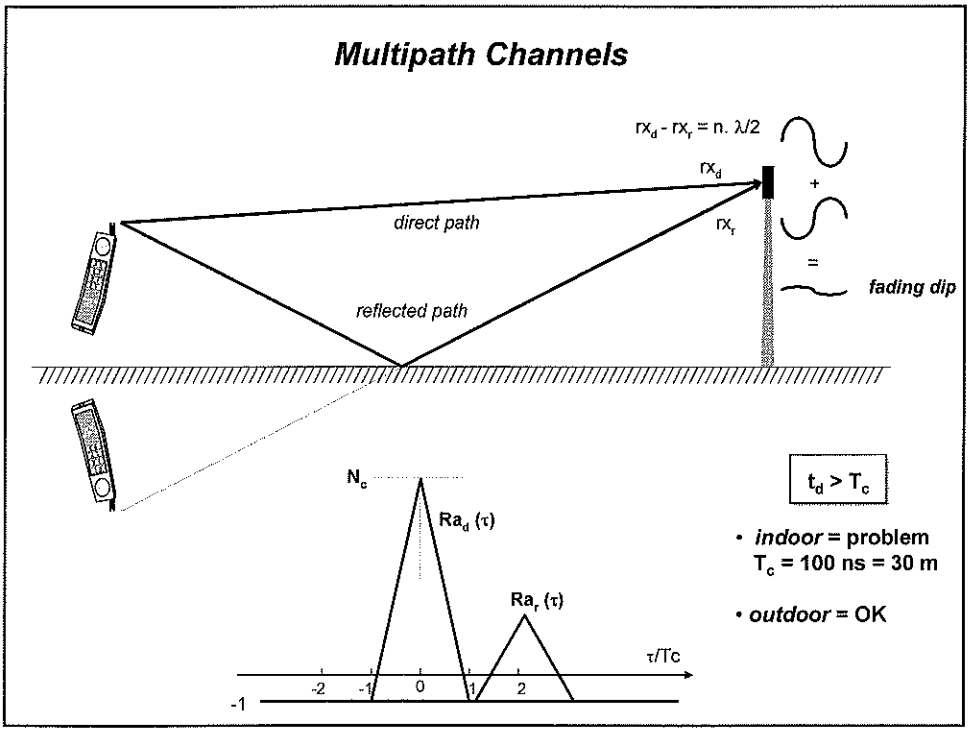
+ *large set*
+ *orthogonal*
- *bad synchronisation*

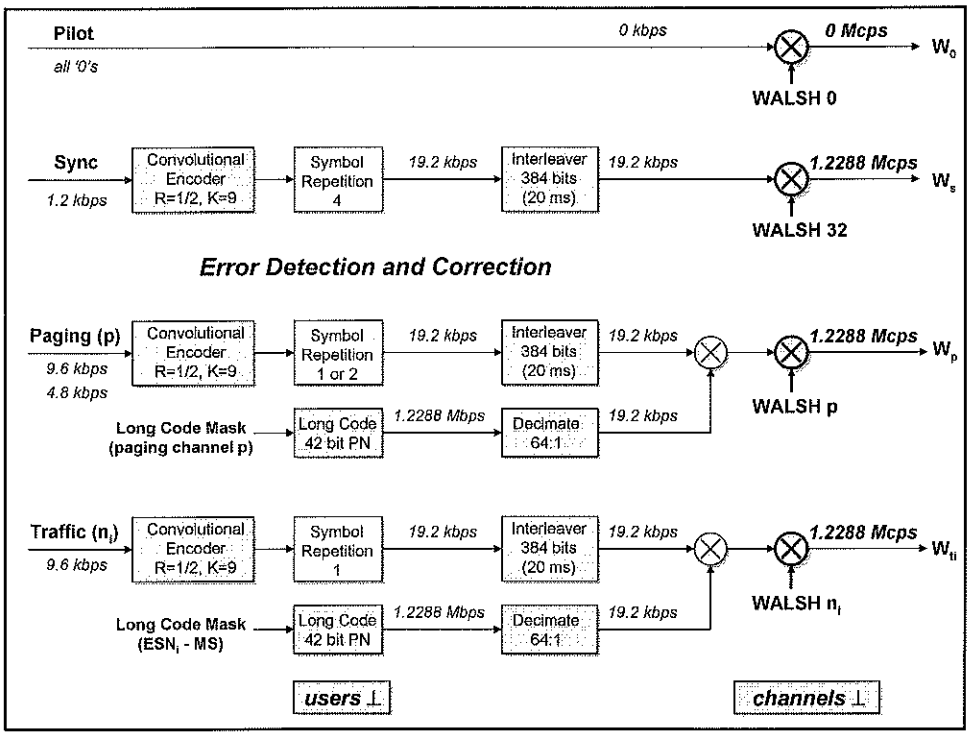
→ *synchronous CDMA*

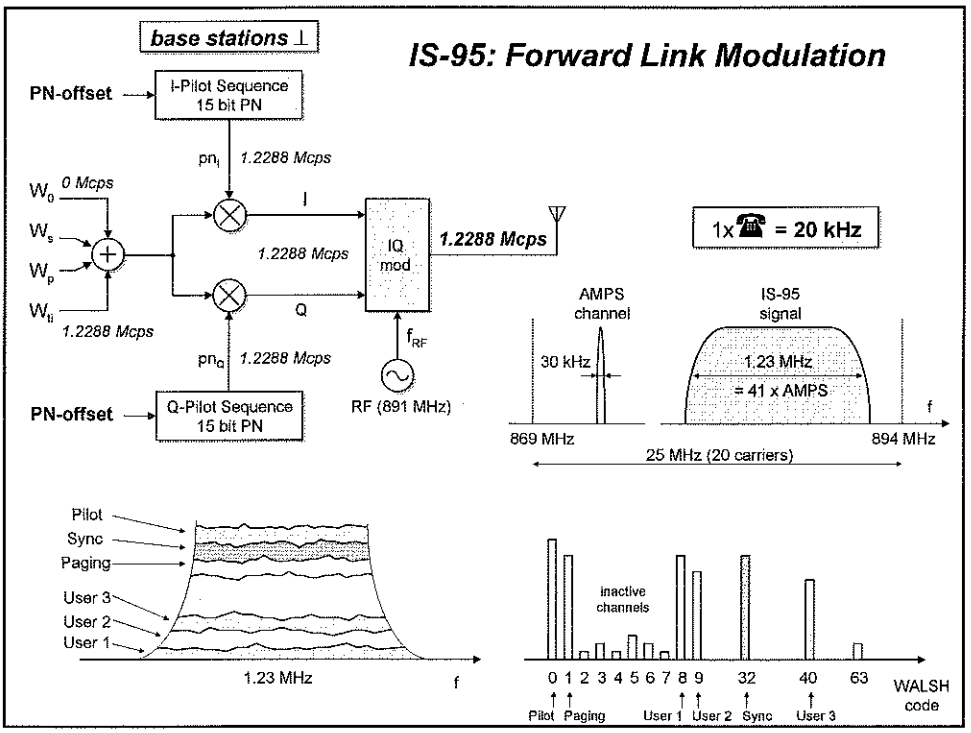
$$H_8 = \left[\begin{array}{cccccccc} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \end{array}\right]$$

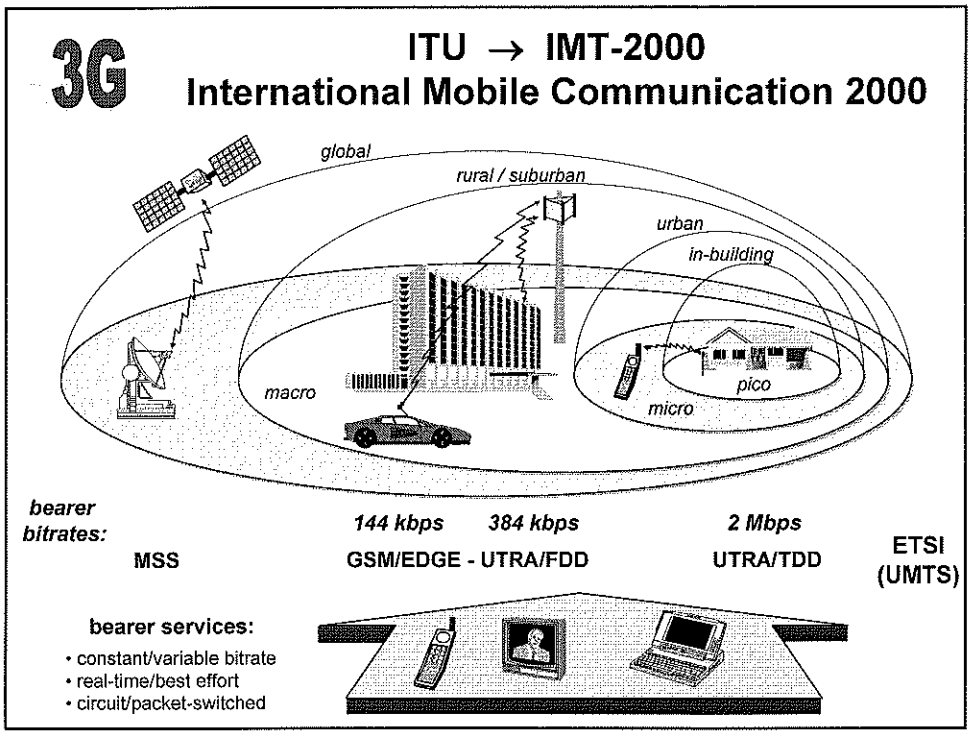
← all 1s
← Σ = 0
← 4 1s & 4 0s
orthogonal

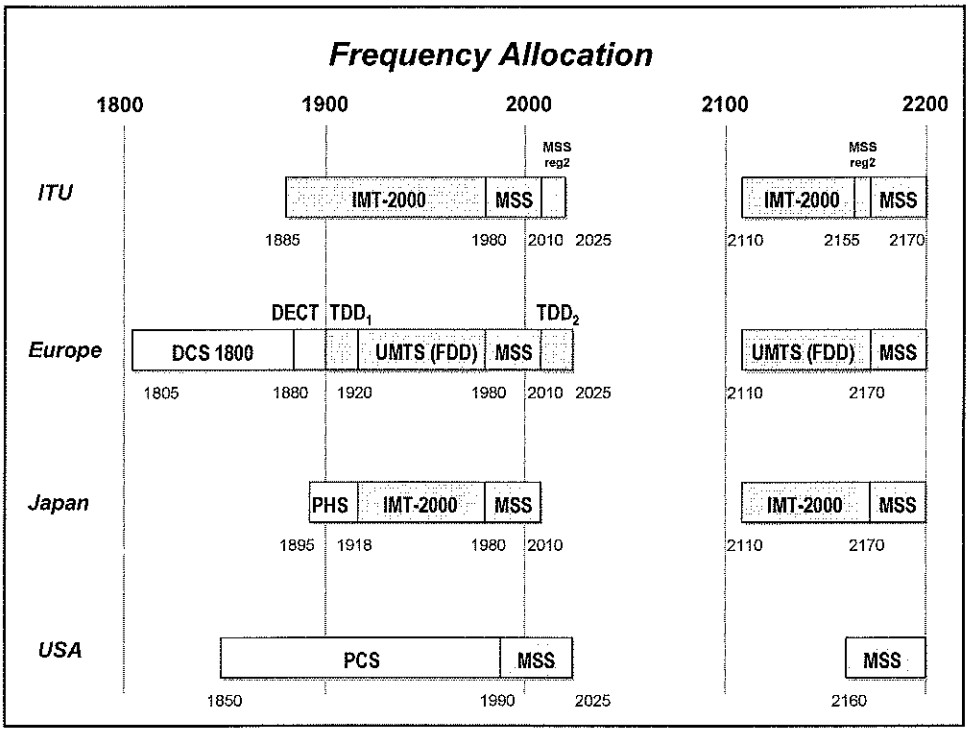

CDMA = Code Division Multiple Access
rx_b
user 3
user N
user 2
user 1
-R_c
R_c
f
despreading
d_1r
user 1
user N
user 3
user 2
-R_s
R_s
f
+ full bandwidth
+ total time
- multi-user interference (soft capacity)
Near-Far problem → Power control
rx_b
user 6
user 4
user 3
user 1
-R_c
R_c
f
all users 'received' with the same power
code
1 2 3 4 5 6 7 8

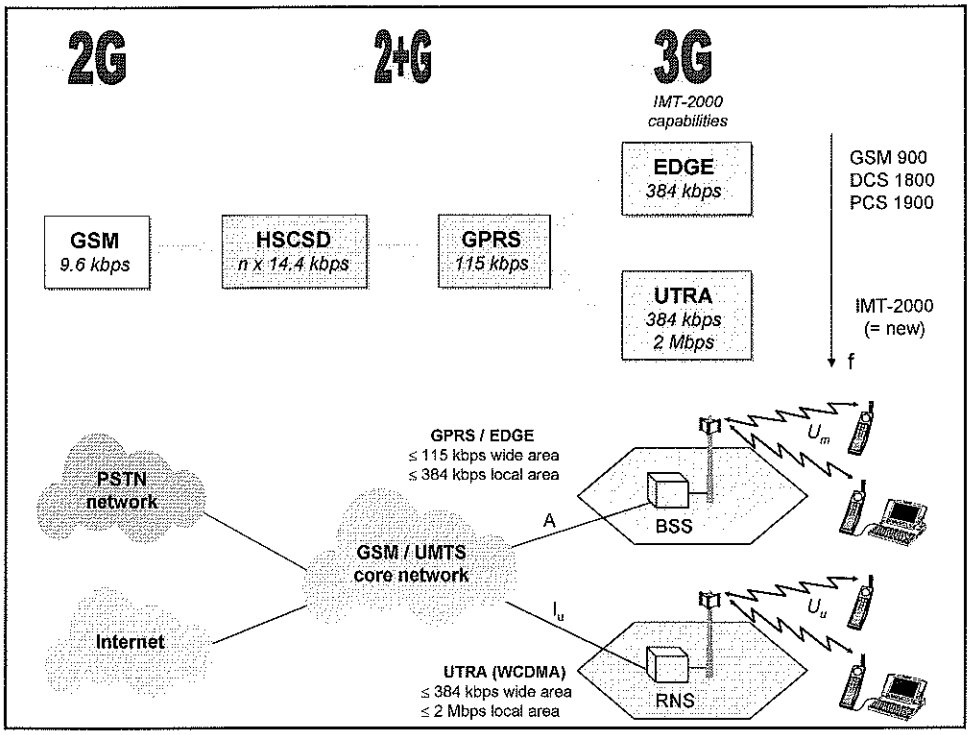

Multipath Channels
rx_d - rx_r = n. λ/2
rx_d
direct path
rx_r
reflected path
+
=
fading dip
N_c
Ra_d (τ)
Ra_r (τ)
τ/Tc
-2
-1
0
1
2
-1
t_d > T_c
• indoor = problem
T_c = 100 ns = 30 m
• outdoor = OK

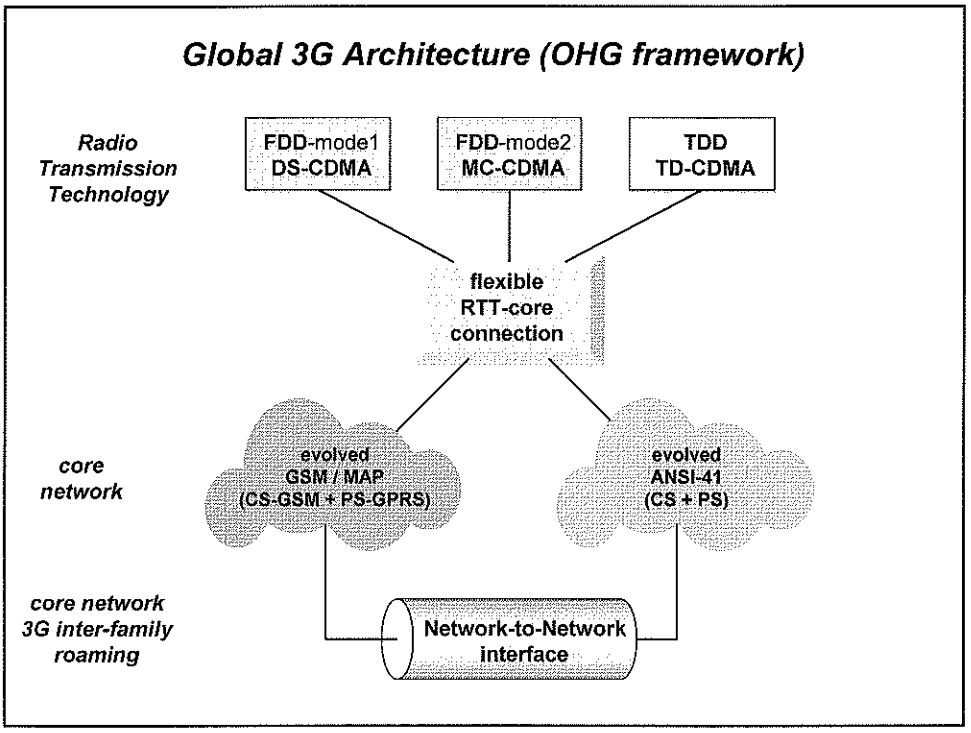

Pilot
all '0's
0 kbps
0 Mcps
W_0
WALSH 0
Sync
1.2 kbps
Convolutional Encoder R=1/2, K=9
Symbol Repetition 4
19.2 kbps
Interleaver 384 bits (20 ms)
19.2 kbps
1.2288 Mcps
W_s
WALSH 32
Error Detection and Correction
Paging (p)
9.6 kbps
4.8 kbps
Convolutional Encoder R=1/2, K=9
Symbol Repetition 1 or 2
19.2 kbps
Interleaver 384 bits (20 ms)
19.2 kbps
1.2288 Mcps
W_p
WALSH p
Long Code Mask (paging channel p)
Long Code 42 bit PN
1.2288 Mbps
Decimate 64:1
19.2 kbps
Traffic (n_i)
9.6 kbps
Convolutional Encoder R=1/2, K=9
Symbol Repetition 1
19.2 kbps
Interleaver 384 bits (20 ms)
19.2 kbps
1.2288 Mcps
W_{ti}
WALSH n_i
Long Code Mask (ESN_i - MS)
Long Code 42 bit PN
1.2288 Mbps
Decimate 64:1
19.2 kbps
users ⊥
channels ⊥


base stations ⊥
IS-95: Forward Link Modulation
PN-offset
I-Pilot Sequence 15 bit PN
pn_I 1.2288 Mcps
W_0 0 Mcps
W_s
W_p
W_{ti}
1.2288 Mcps
I
Q
1.2288 Mcps
IQ mod
1.2288 Mcps
pn_Q 1.2288 Mcps
f_{RF}
RF (891 MHz)
PN-offset
Q-Pilot Sequence 15 bit PN
1x☎ = 20 kHz
AMPS channel
30 kHz
IS-95 signal
1.23 MHz
= 41 x AMPS
f
869 MHz
894 MHz
25 MHz (20 carriers)
Pilot
Sync
Paging
User 3
User 2
User 1
1.23 MHz
f
inactive channels
0 1 2 3 4 5 6 7 8 9 32 40 63
WALSH code
Pilot Paging User 1 User 2 Sync User 3


3G
ITU → IMT-2000
International Mobile Communication 2000
global
rural / suburban
urban
in-building
macro
pico
micro
bearer bitrates:
144 kbps
384 kbps
2 Mbps
MSS
GSM/EDGE - UTRA/FDD
UTRA/TDD
ETSI (UMTS)
bearer services:
• constant/variable bitrate
• real-time/best effort
• circuit/packet-switched

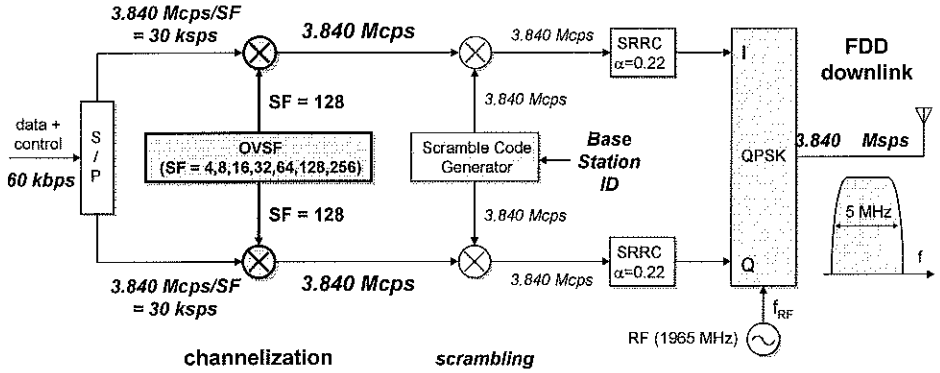

Frequency Allocation
1800
1900
2000
2100
2200
ITU
MSS reg2
IMT-2000
MSS
1885
1980
2010
2025
2110
2155
2170
Europe
DECT
TDD1
TDD2
DCS 1800
UMTS (FDD)
1805
1880
1920
Japan
PHS
1895
1918
USA
PCS
1850
1990
2160


2G
2+G
3G
IMT-2000 capabilities
EDGE
384 kbps
GSM 900
DCS 1800
PCS 1900
GSM
9.6 kbps
HSCSD
n x 14.4 kbps
GPRS
115 kbps
UTRA
384 kbps
2 Mbps
IMT-2000
(= new)
f
GPRS / EDGE
≤ 115 kbps wide area
≤ 384 kbps local area
PSTN network
GSM / UMTS core network
A
BSS
Internet
Iu
UTRA (WCDMA)
≤ 384 kbps wide area
≤ 2 Mbps local area
RNS


Global 3G Architecture (OHG framework)
Radio Transmission Technology
FDD-mode1 DS-CDMA
FDD-mode2 MC-CDMA
TDD TD-CDMA
flexible RTT-core connection
core network
evolved GSM / MAP (CS-GSM + PS-GPRS)
evolved ANSI-41 (CS + PS)
core network 3G inter-family roaming
Network-to-Network interface

W-CDMA
Wideband Code Division Multiple Access

UTRA = UMTS - Terrestrial Radio Access

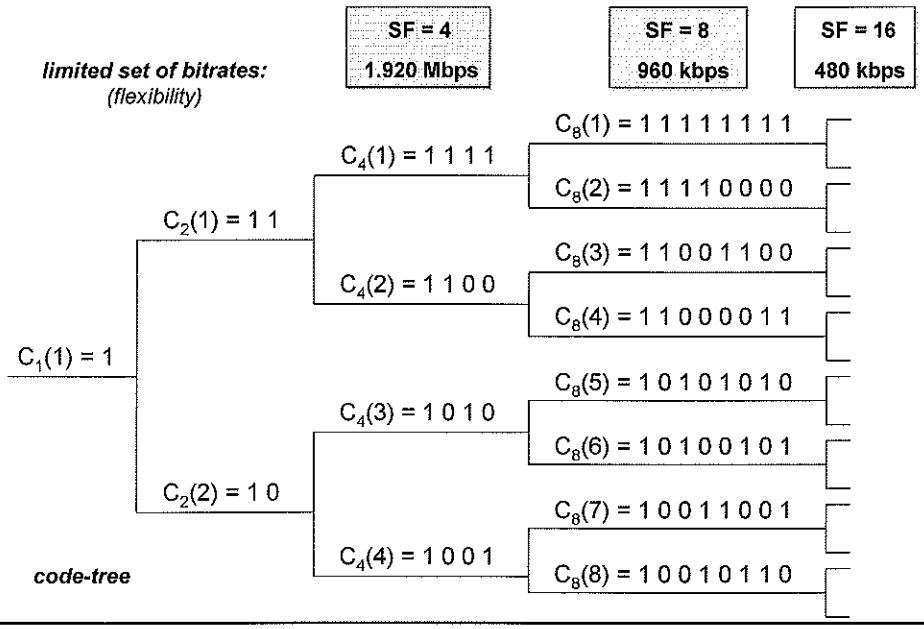


- limited set of bitrates (SFs), needs rate matching
- several channels (codes) in parallel

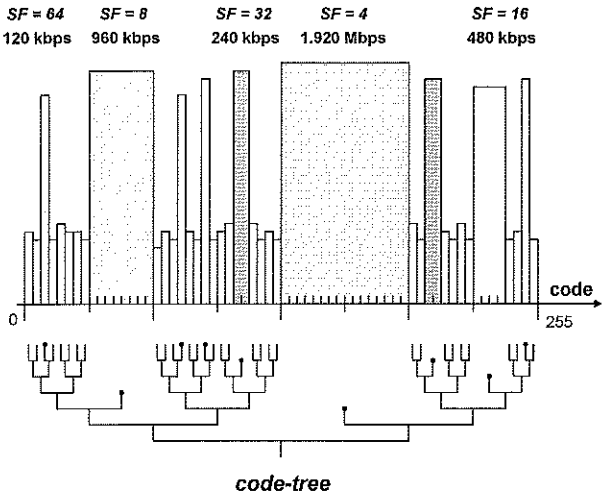
asynchronous base station operation, needs:
- efficient cell search
- inter BS synchronisation for soft handover

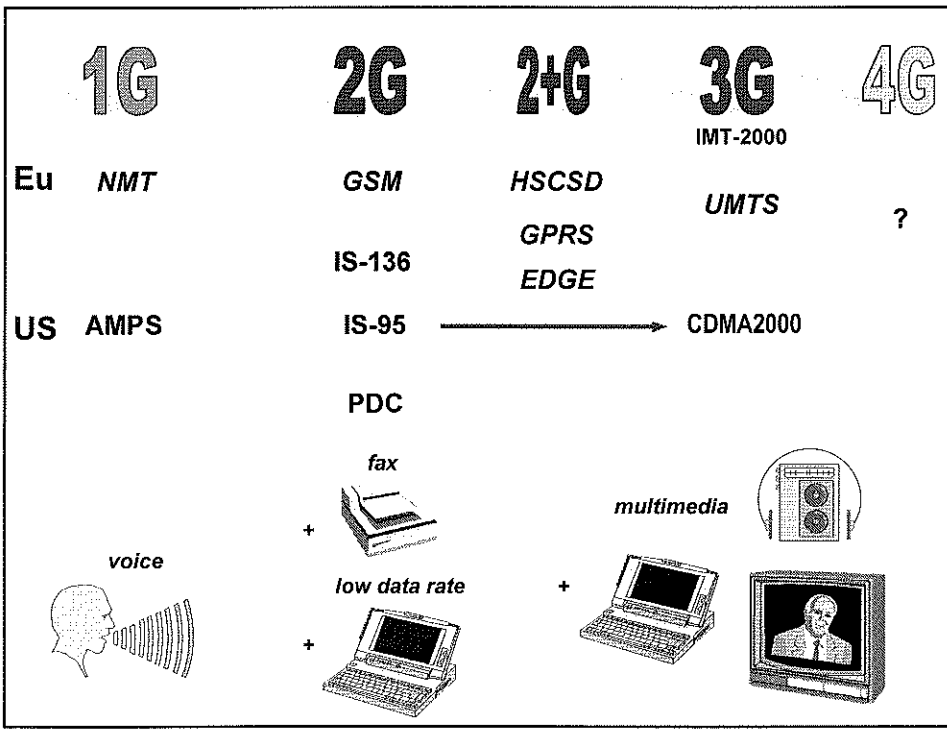
UMTS = Universal Mobile Telecommunication System (ETSI)

W-CDMA: Orthogonal Variable Spreading Factor (OVSF)



W-CDMA: Orthogonal Variable Spreading Factor (OVSF)





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SINT-KATELIJNE-WAVER

In Vehicle Networks
CAN = Controller Area Network

EmSD
Embedded System Design

ir. J. Meel
dec 2009

1. CAN

CAN = Controller Area Network

Extremely robust standardized communication protocol

Developed by **Bosch** (in the 1980s) to create standardization and reduce the cost and weight in vehicle wiring harness

CAN is internationally standardized by
the **International Standardization Organization** (in ISO 11898)
and by other standards organizations (SAE = Society of Automotive Engineers).

Primary uses: automotive and industrial control

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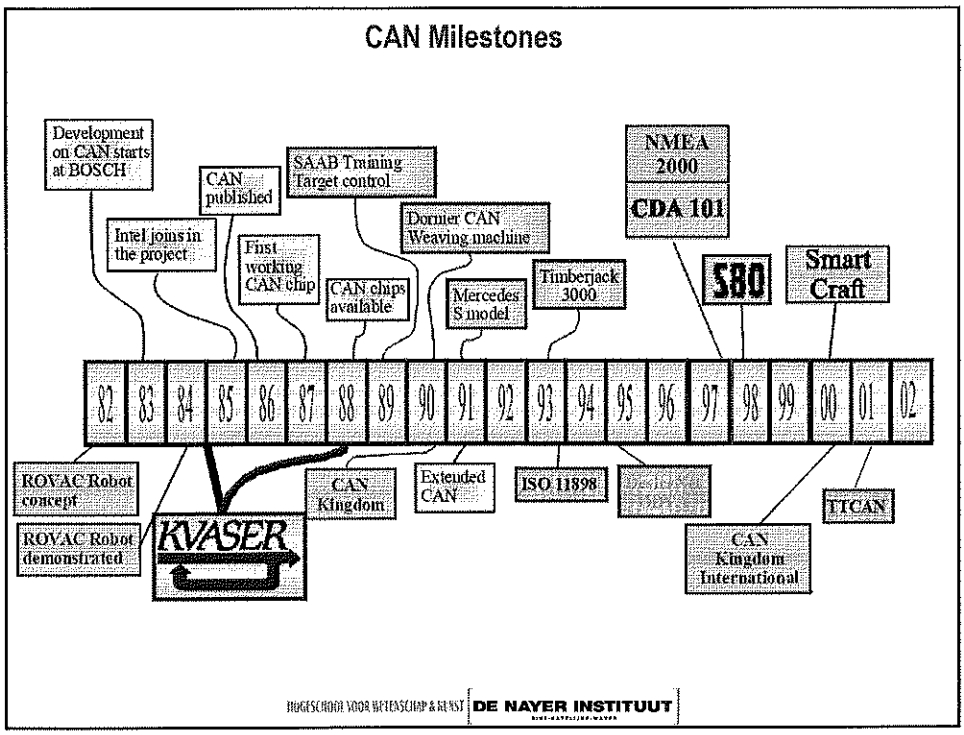
CAN Milestones
Development on CAN starts at BOSCH
CAN published
SAAB Training Target control
Intel joins in the project
First working CAN chip
CAN chips available
Dornier CAN Weaving machine
Mercedes S model
Timberjack 3000
NMEA 2000
CDA 101
S80
Smart Craft
82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02
ROVAC Robot concept
ROVAC Robot demonstrated
KVASER
CAN Kingdom
Extended CAN
ISO 11898
TTCAN
CAN Kingdom International
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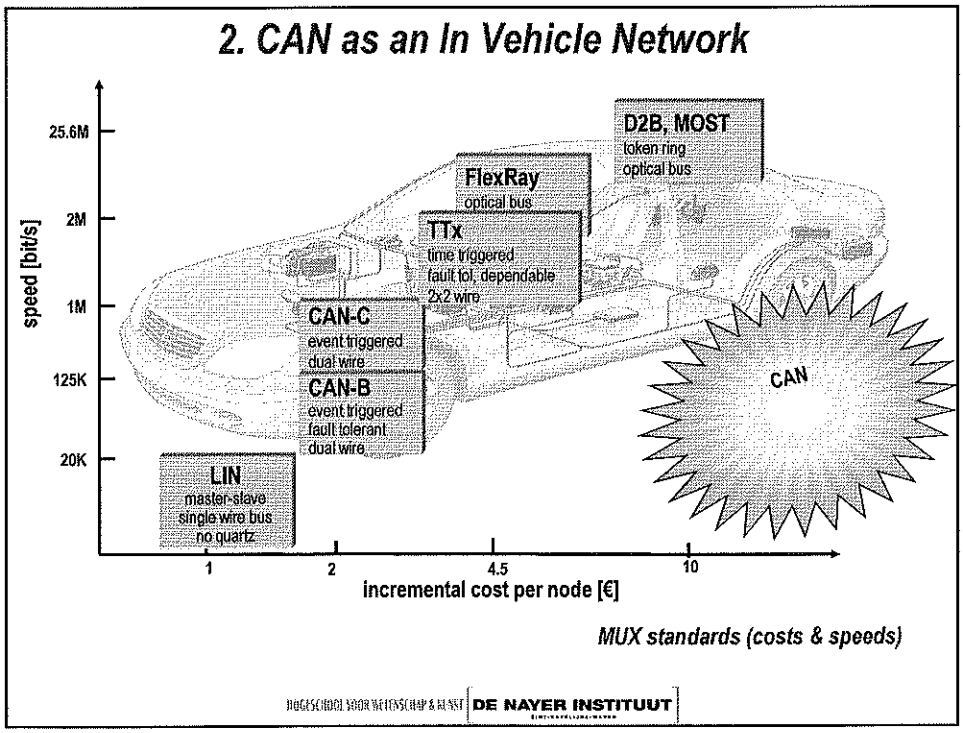
2. CAN as an In Vehicle Network
25.6M
2M
1M
125K
20K
speed [bit/s]
D2B, MOST
token ring
optical bus
FlexRay
optical bus
TTx
time triggered
fault tol. dependable
2x2 wire
CAN-C
event triggered
dual wire
CAN-B
event triggered
fault tolerant
dual wire
LIN
master-slave
single wire bus
no quartz
CAN
1
2
4.5
10
incremental cost per node [€]
MUX standards (costs & speeds)
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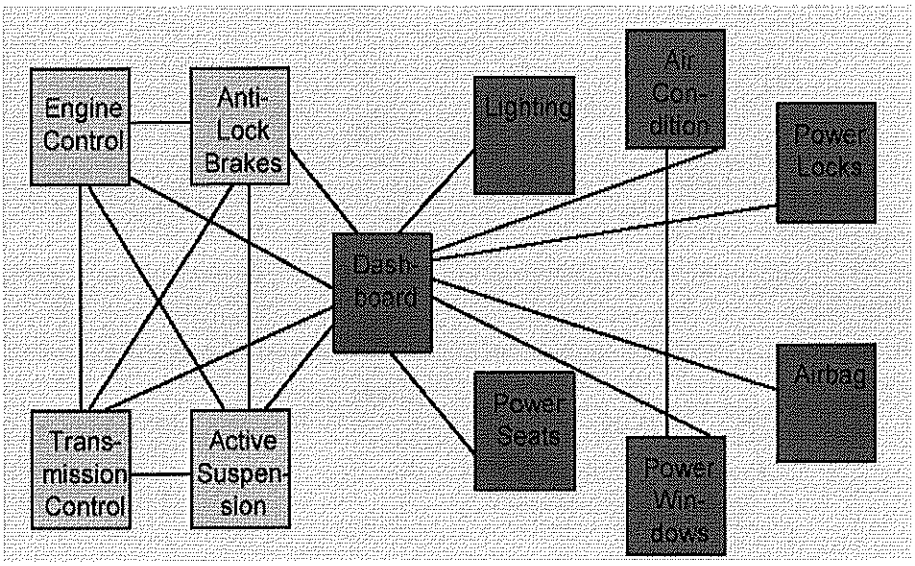
Typical Automobile Wiring



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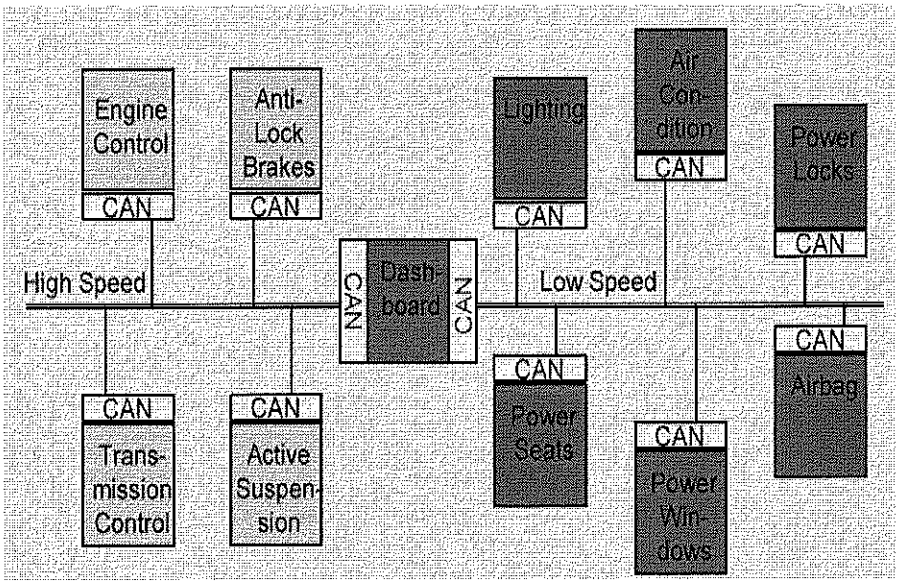
Automobile Wiring with CAN



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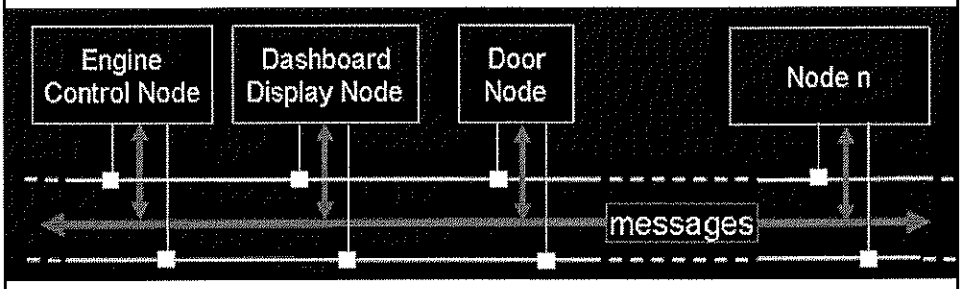
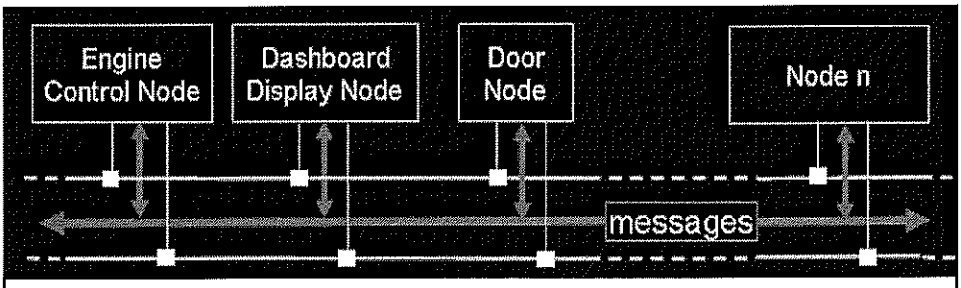
3. CAN Concept

3.1 Network Architecture

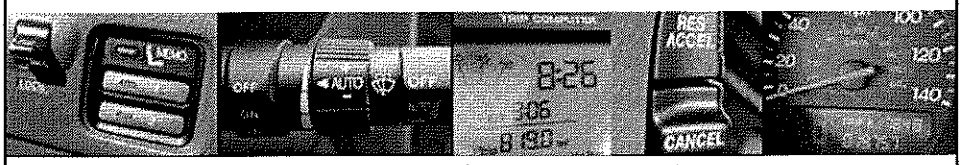
- a CAN network is made up of nodes connected to the bus
- each node can communicate with each other node (flat architecture)
- communication is handled with extremely robust packets called messages
- transmission speeds of up to 1 Mbps are defined



HOGESCHOOL VOOR WETENSCHAP & KUNST DE NAYER INSTITUUT



- A node may *continually send messages*, such as a motor speed control node
- A node may *only transmit a message when a system failure has occurred*, such as a temperature monitoring node
- A node may *only take action when another node instructs it to do so*, such as an electronic valve control



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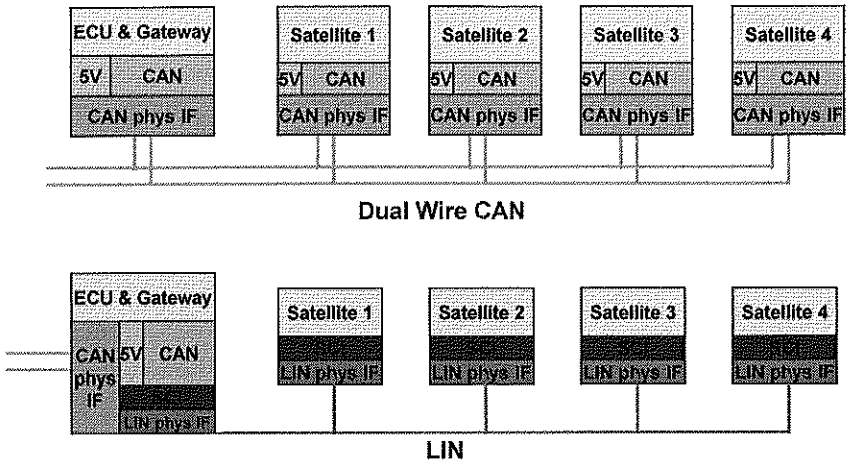
3.2 Sub-Network: LIN vs. CAN



Cost Factors:

- CAN Module
- Crystal
- 2nd Wire / Connector
- Dual Wire Interface
- 5V supply for bus

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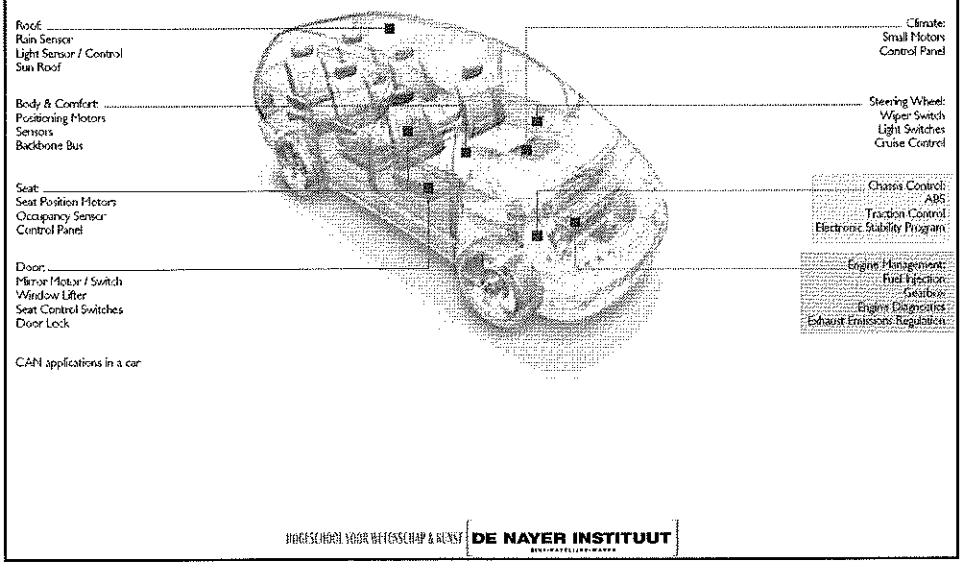
4. CAN Applications



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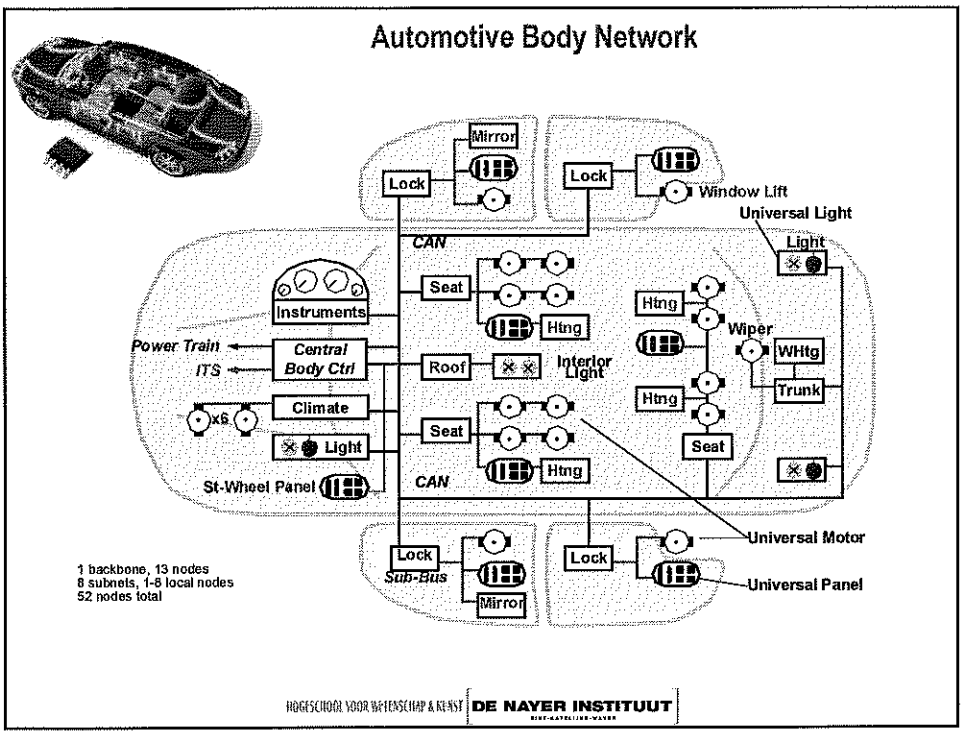
Automotive Body Network
Mirror
Lock
Lock
Window Lift
Universal Light
Light
CAN
Seat
Instruments
Htng
Htng
Wiper
Power Train
ITS
Central Body Ctrl
Roof
Interior Light
WHtg
Trunk
Climate
x6
Seat
Light
Htng
Seat
St-Wheel Panel
CAN
Universal Motor
Lock
Sub-Bus
Lock
Universal Panel
Mirror
1 backbone, 13 nodes
8 subnets, 1-8 local nodes
52 nodes total
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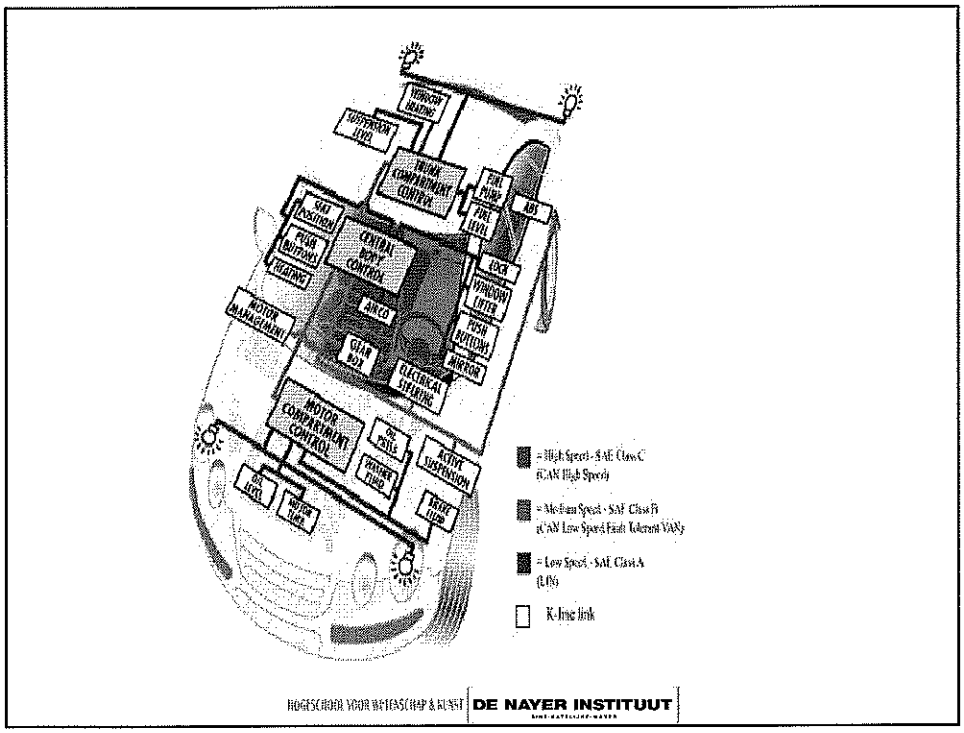
CENTRAL BODY CONTROL
MOTOR COMPARTMENT CONTROL
K-line link
HOGESCHOOL VOOR WETENSCHAP & KUNST
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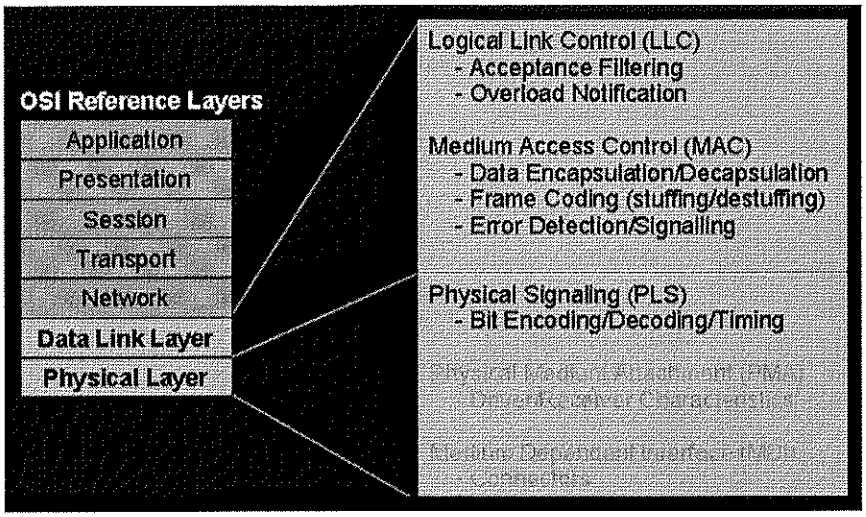
5. CAN Specifications

5.1 Layered Model



CAN only defines portions of the lower 2 layers of the OSI 7-layer reference model

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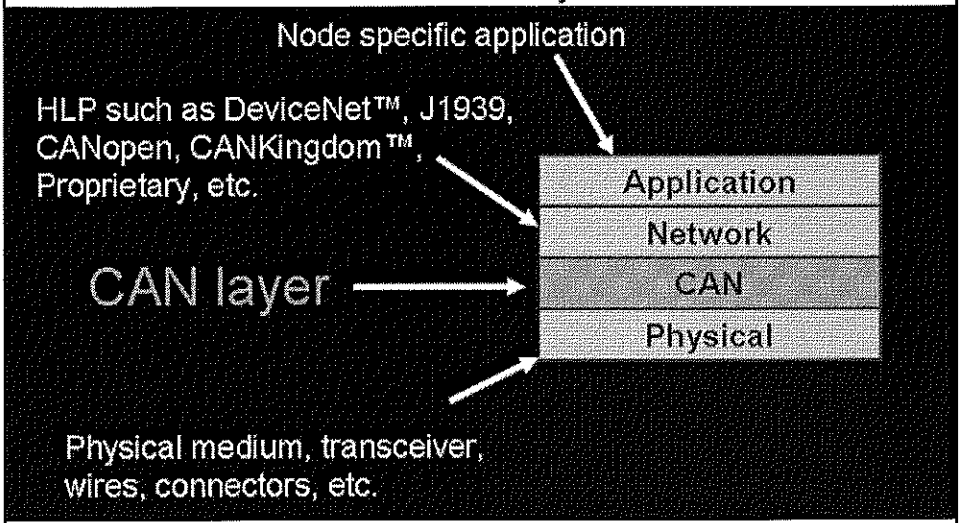
CAN Protocol Layers



NOMENCLATURE	STANDARD	MAX. SIGNALING RATE	IDENTIFIER
Low–Speed CAN	ISO 11898	125 kbps	11-bit
CAN 2.0A	ISO 11898:1993	1 Mbps	11-bit
CAN 2.0B	ISO 11898:1995	1 Mbps	29-bit

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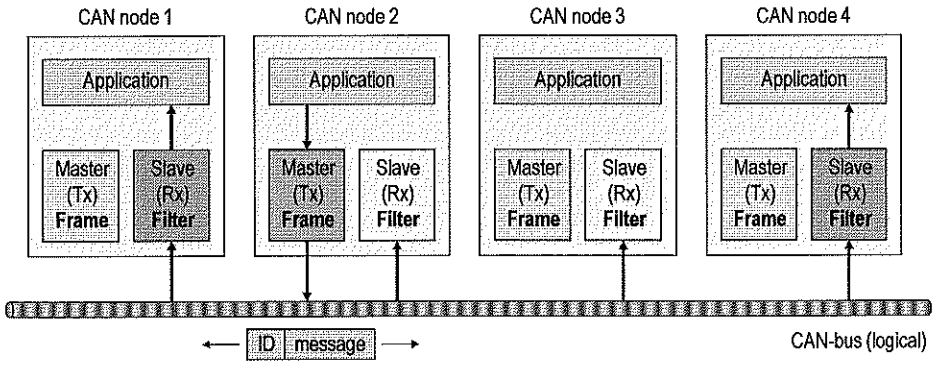
5.1 Concept of Operation

Multi-Master Message Communication



- message identifier (ID) specifies content & priority (no node addressing)
- multimaster – requires busarbitration
- broadcast/multicast capability
- easy connection/disconnection of nodes
- number of nodes not limited by the protocol

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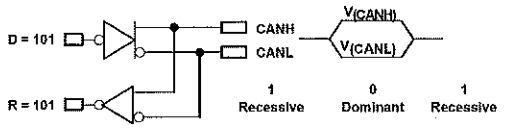
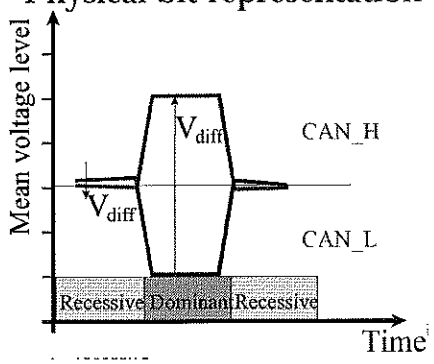
5.2 Physical Interface

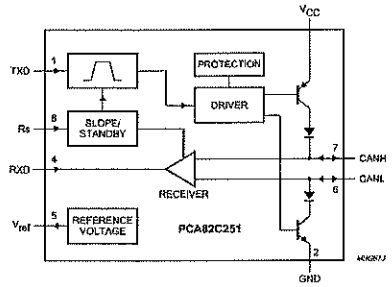
Line driver/receiver



Physical bit representation



CAN Drivers



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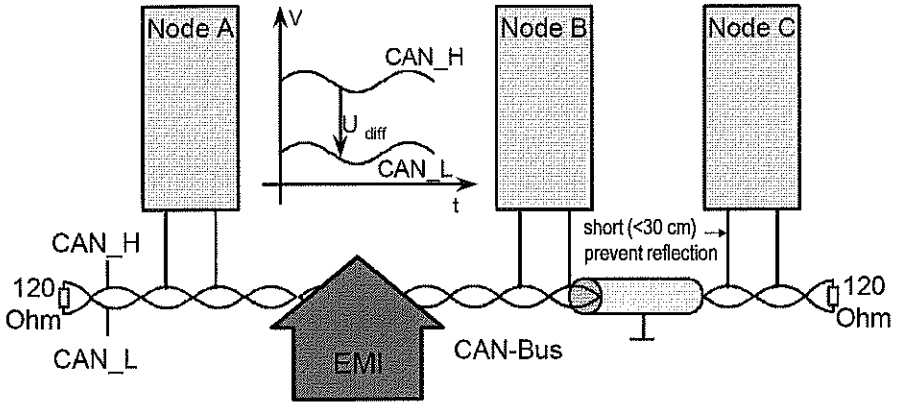
Differential Bus



Differential bus-signaling makes CAN insensitive to EMI (ElectroMagnetic Interference) = common mode

Global resistance between CAN_H and CAN_L: 60Ω

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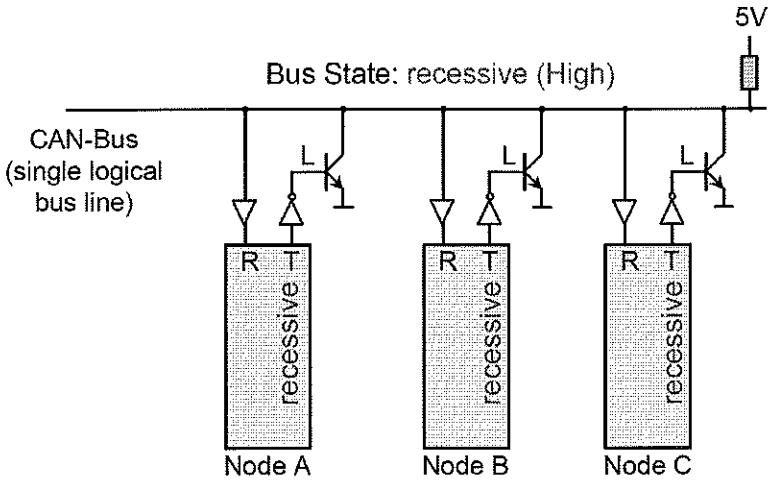
Recessive Bus State



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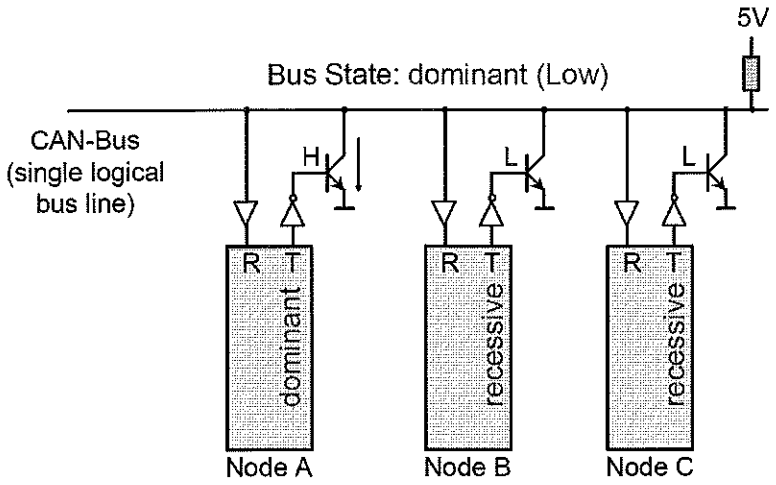
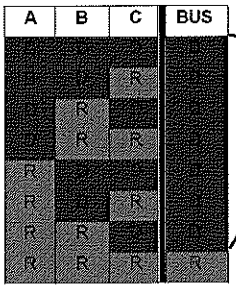
Dominant Bus State



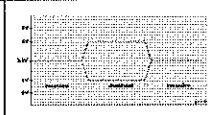
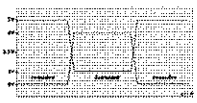
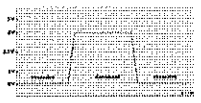
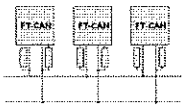
Wired-AND Bus

Two logic states
possible on the bus:
"1" = recessive
"0" = dominant



As soon as one node nodes transmits
a dominant bit (zero)
Bus is in the dominant state.

Only if all nodes transmit
recessive bits (ones)
Bus is in the recessive state.

	High Speed	Fault-Tolerant	Single Wire
Features	HS-CAN	FT-CAN	SW-CAN
Data link layer standard	ISO 11898-1	ISO 11898-1	ISO 11898-1
Physical layer standard	ISO 11898-2	ISO 11898-3	SAE/J2411
Number of bus wires	2 (twisted pair)	2 (twisted pair)	1
Maximum bus speed	1 Mbits/s	125 kbits/s	33/41.6 kbits/s
Bus communication signal			
Bus termination principle			
Bus wire short-circuit and interrupt tolerance	limited short-circuit tolerance	tolerant against any single bus wire short or interrupt	no tolerance
Philips transceiver features [1]	- bus dominant time-out - bus clamping protection - partial networking support - stand-by and sleep modes - node power management - local and remote wake-up - failure diagnosis	- bus dominant time-out - bus clamping protection - partial networking support - stand-by and sleep modes - node power management - local and remote wake-up - failure diagnosis	- loss of ground protection - 100 kbits/s flash mode - partial networking support - selective sleep
Automotive applications	- engine management - backbone bus - body & comfort	- body & comfort	- body & comfort

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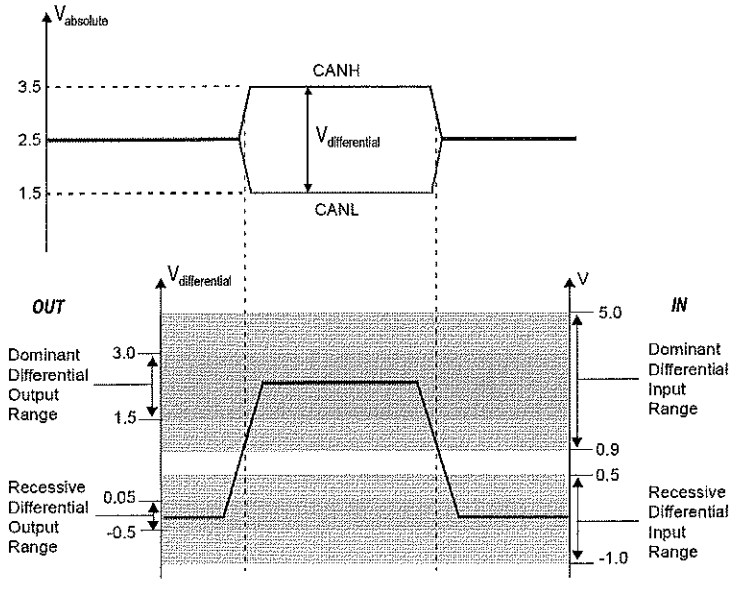
Signal Specification (High Speed CAN, ISO 11898-2)



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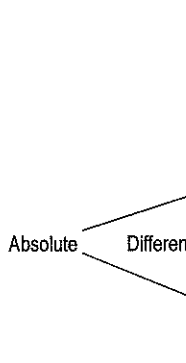

Parameter	ISO-11898-2 min	ISO-11898-2 max	Unit
DC Voltage on CANH and CANL	-3	+32	V
Transient voltage on CANH and CANL	-150	+100	V
Common Mode Bus Voltage	-2.0	+7.0	V
Recessive Output Bus Voltage	+2.0	+3.0	V
Recessive Differential Output Voltage	-500	+50	mV
Differential Internal Resistance	10	100	kΩ
Common Mode Input Resistance	5.0	50	kΩ
Differential Dominant Output Voltage	+1.5	+3.0	V
Dominant Output Voltage (CANH)	+2.75	+4.50	V
Dominant Output Voltage (CANL)	+0.50	+2.25	V
Permanent Dominant Detection (Driver)	Not Required		ms
Power-On Reset and Brown-Out Detection	Not Required		--

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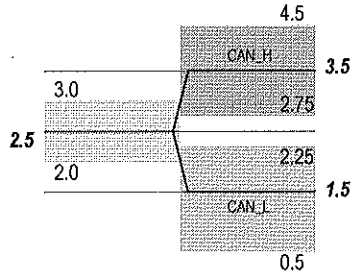
Signal Specification (High Speed CAN vs Low Speed CAN)

High Speed CAN, ISO 11898-2

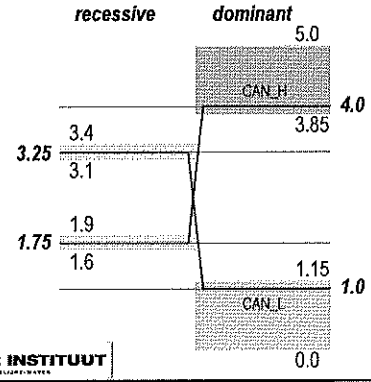
signal	*recessive state*			*dominant state*			
	min	nominal	max	min	nominal	max	
CAN_H	2.0	2.5	3.0	2.75	3.5	4.5	Volt
CAN_L	2.0	2.5	3.0	0.5	1.5	2.25	Volt



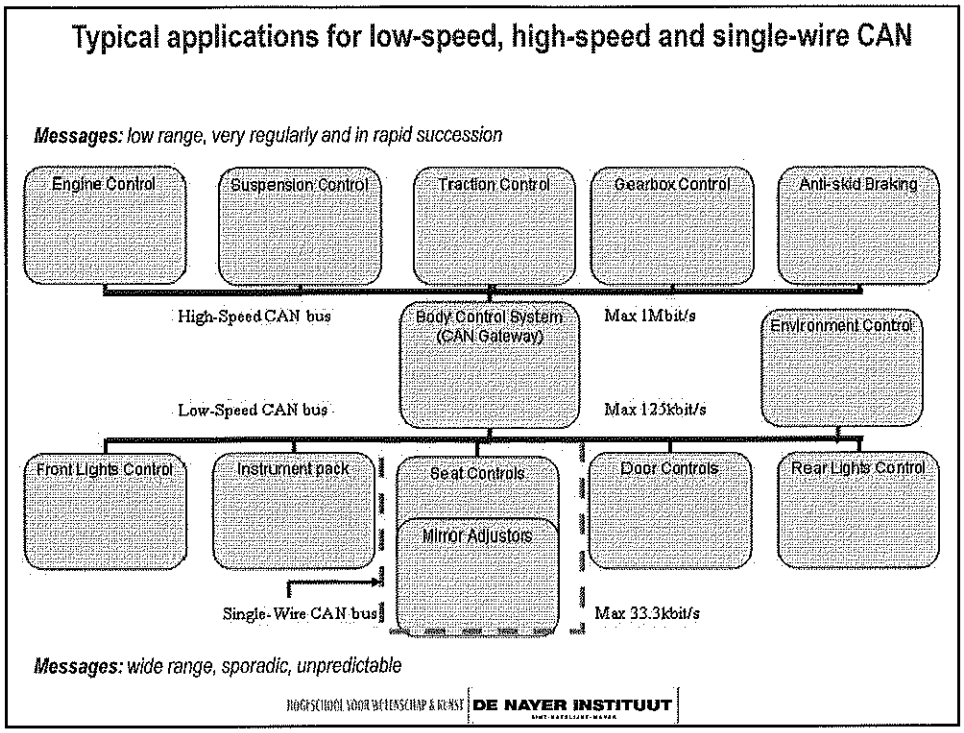
recessive *dominant*

(Low Speed CAN, ISO 11519)

signal	*recessive state*			*dominant state*			
	min	nominal	max	min	nominal	max	
CAN_H	1.6	1.75	1.9	3.85	4.0	5.0	Volt
CAN_L	3.1	3.25	3.4	0	1.0	1.15	Volt



HOGESCHOOL VOOR WETENSCHAP & KUNST DE NAYER INSTITUUT


Typical applications for low-speed, high-speed and single-wire CAN
Messages: low range, very regularly and in rapid succession
Engine Control
Suspension Control
Traction Control
Gearbox Control
Anti-skid Braking
High-Speed CAN bus
Body Control System (CAN Gateway)
Max 1Mbit/s
Environment Control
Low-Speed CAN bus
Max 125kbit/s
Front Lights Control
Instrument pack
Seat Controls
Door Controls
Rear Lights Control
Mirror Adjustors
Single-Wire CAN bus
Max 33.3kbit/s
Messages: wide range, sporadic, unpredictable
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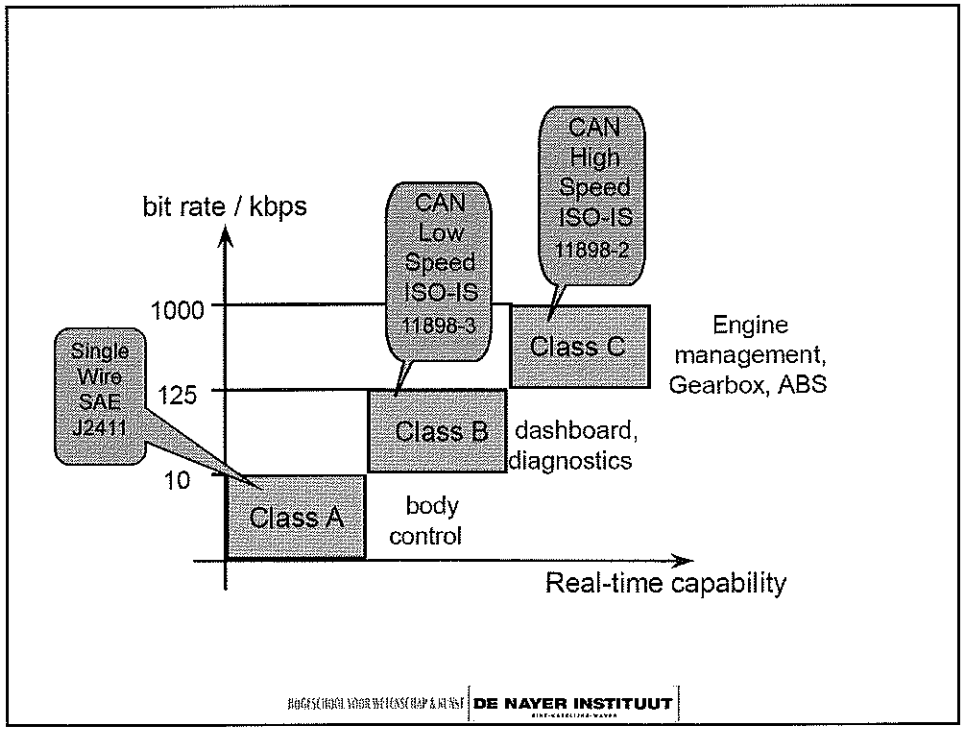
bit rate / kbps
CAN High Speed ISO-IS 11898-2
CAN Low Speed ISO-IS 11898-3
1000
125
10
Single Wire SAE J2411
Class C
Class B
Class A
Engine management, Gearbox, ABS
dashboard, diagnostics
body control
Real-time capability
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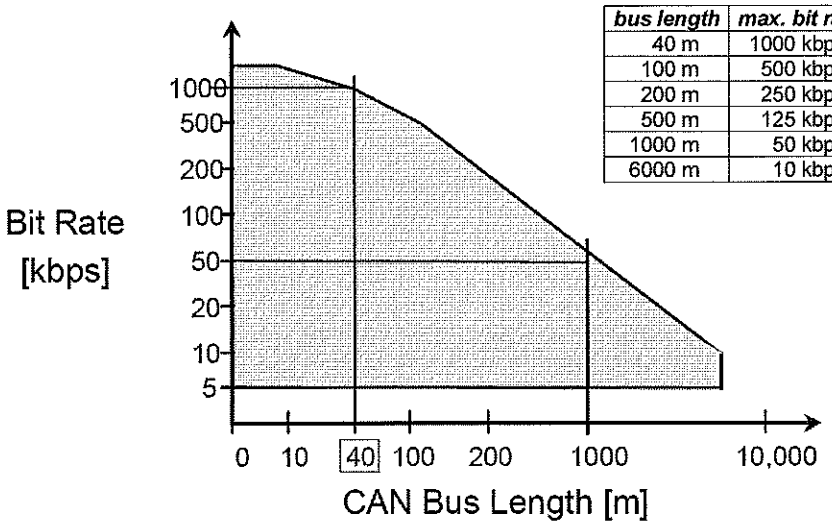
Bit Rate vs Bus Length

bus length	max. bit rate
40 m	1000 kbps
100 m	500 kbps
200 m	250 kbps
500 m	125 kbps
1000 m	50 kbps
6000 m	10 kbps



bus lines assumed to be electrical (e.g. UTP)

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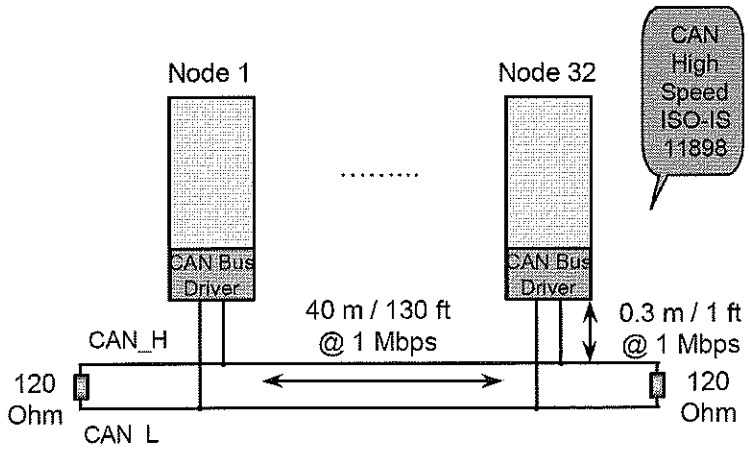

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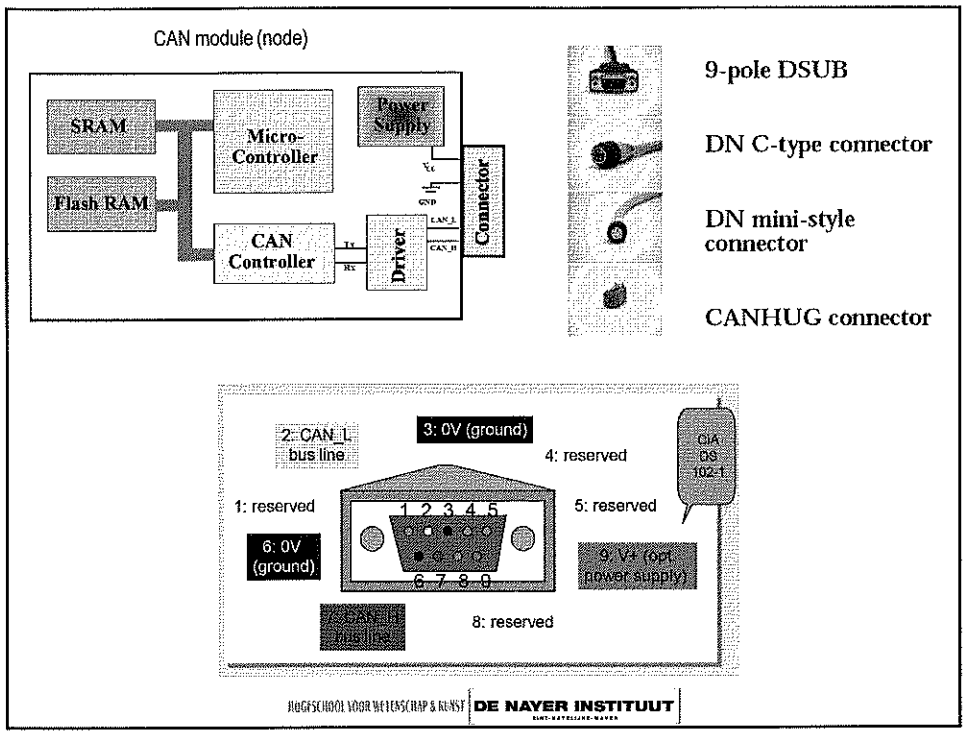
CAN module (node)
SRAM
Flash RAM
Micro-Controller
Power Supply
CAN Controller
Driver
Connector
9-pole DSUB
DN C-type connector
DN mini-style connector
CANHUG connector
2: CAN_L bus line
3: 0V (ground)
4: reserved
1: reserved
5: reserved
6: 0V (ground)
9: V+ (opt. power supply)
7: CAN_H bus line
8: reserved
CiA DS 102-1
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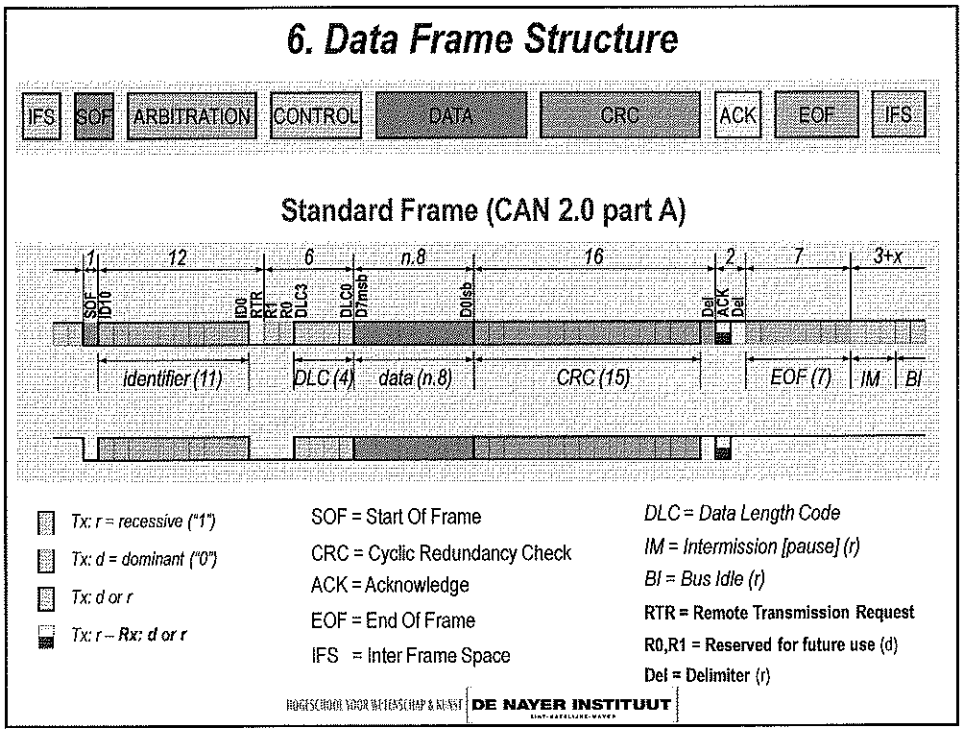
6. Data Frame Structure
IFS
SOF
ARBITRATION
CONTROL
DATA
CRC
ACK
EOF
IFS
Standard Frame (CAN 2.0 part A)
1
12
6
n.8
16
2
7
3+x
SOF
ID10
ID0
RTR
R1
R0
DLC3
DLC0
D7msb
D0lsb
Del
ACK
Del
identifier (11)
DLC (4)
data (n.8)
CRC (15)
EOF (7)
IM
BI
Tx: r = recessive ("1")
Tx: d = dominant ("0")
Tx: d or r
Tx: r – Rx: d or r
SOF = Start Of Frame
CRC = Cyclic Redundancy Check
ACK = Acknowledge
EOF = End Of Frame
IFS = Inter Frame Space
DLC = Data Length Code
IM = Intermission [pause] (r)
BI = Bus Idle (r)
RTR = Remote Transmission Request
R0,R1 = Reserved for future use (d)
Del = Delimiter (r)
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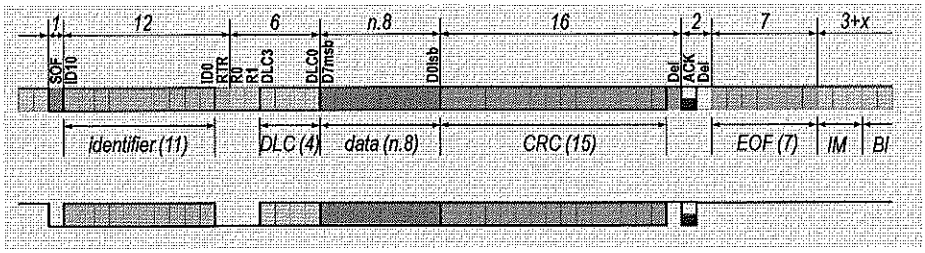
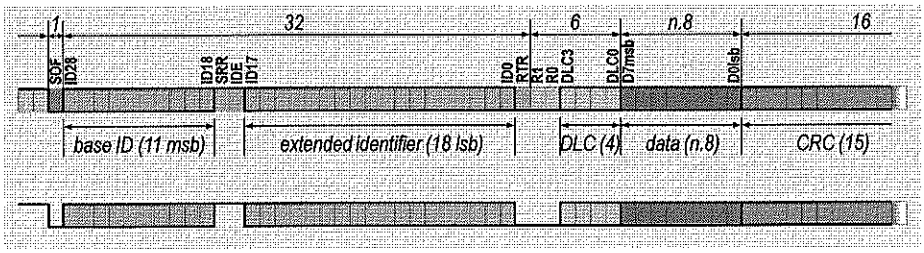
Standard Frame (CAN 2.0 part A)

2^{11} = 2048 ID's



Extended Frame (CAN 2.0 part B)

2^{29} = 536 10^6 ID's



SRR = Substitute Remote Request (SRR) bit IDE = Identifier Extension bit

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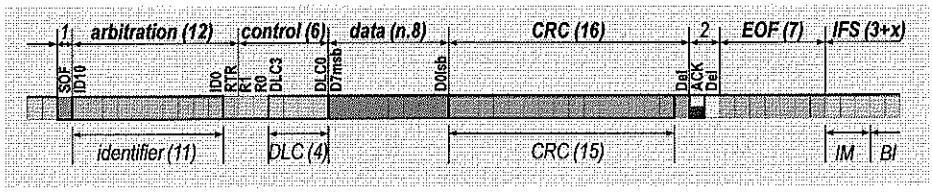
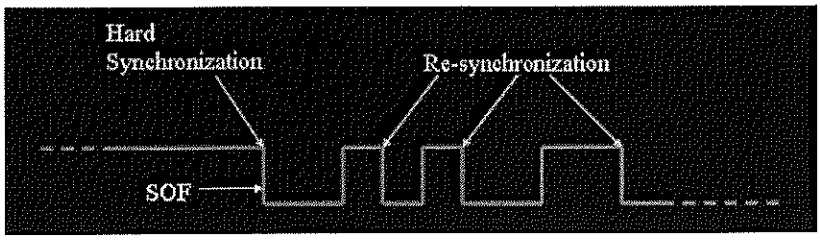
6.1 Synchronization





- no clock in the bit stream
- receivers synchronize on recessive to dominant transitions

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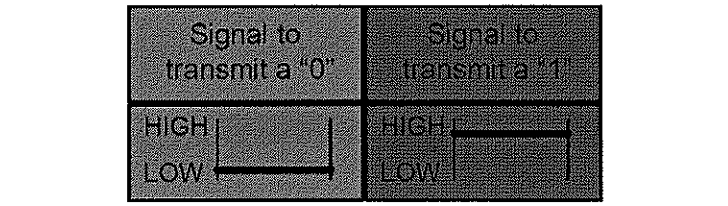
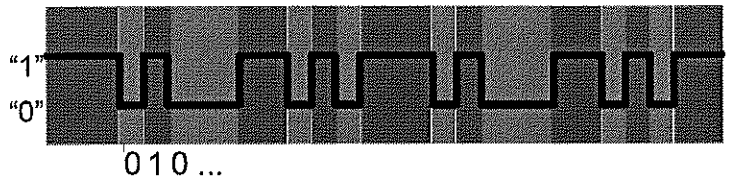
Message Coding: NRZ-Code

NRZ = Non Return to Zero





Problem: synchronisation lost for a burst of zero's or one's

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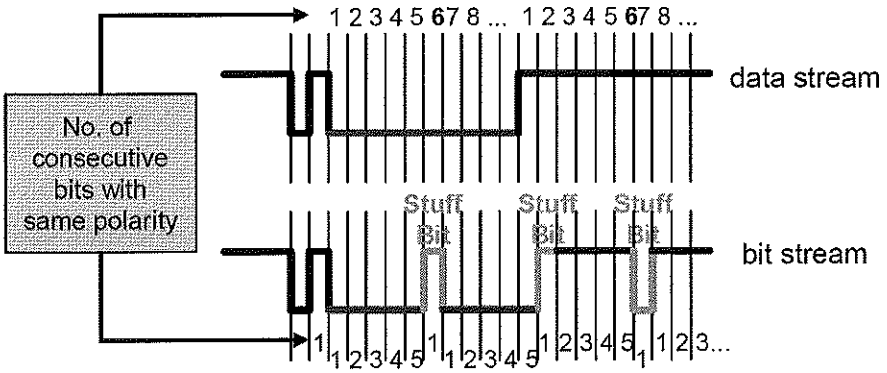
Bit Stuffing



Bit Stuffing ensures sufficient Recessive to Dominant edges:
- Stuff Bit inserted after 5 consecutive bits at the same state
- Stuff Bit is inverse of previous bit

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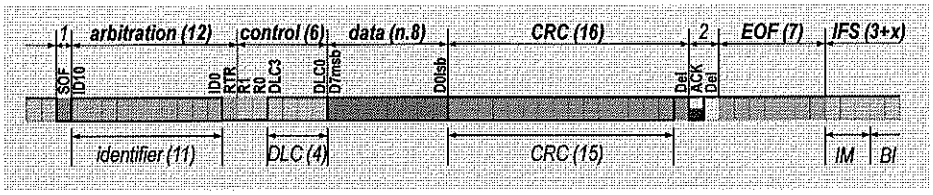
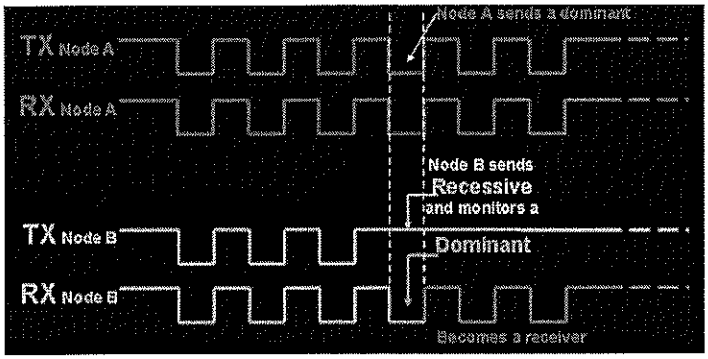
6.2 Arbitration





Non-destructive Bitwise Arbitration: The node(s) loosing arbitration become receivers and receive the message.

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CSMA/CD w AMP

Carrier Sense (CS)
Every node must monitor the bus for a period of no activity before sending a message.

Multiple Access (MA)
Once a period of no activity occurs, every node has an equal opportunity to transmit a message.

Collision Detection (CD)
If 2 nodes transmit at the same time, a collision occurs.

Arbitration on Message Priority (AMP)
Non-destructive bitwise arbitration based on the priority of the send messages to resolve collisions.

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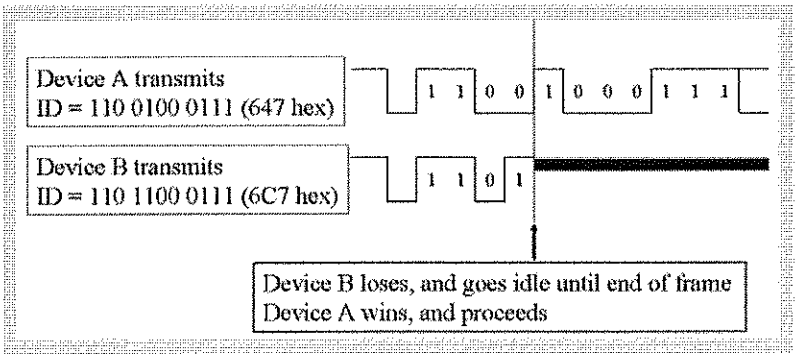
- When two devices attempt to transmit simultaneously, CAN uses non-destructive bitwise arbitration to resolve the collision.
- The arbitration ID indicates message priority (lowest numerical value has highest priority).
- The highest priority message is guaranteed to gain access to the bus.
- Lower priority messages are automatically retransmitted in the next bus cycle, or in a subsequent bus cycle if there are still other, higher priority messages waiting to be sent.
- ***A Standard Identifier wins over an Extended Identifier.***



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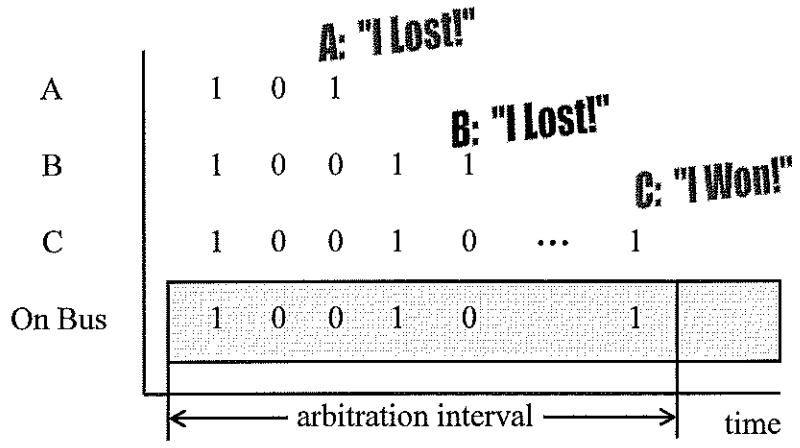
Non-destructive Bit-wise Arbitration



The lower the priority of a message is, the higher the latency jitter for the media access may be.

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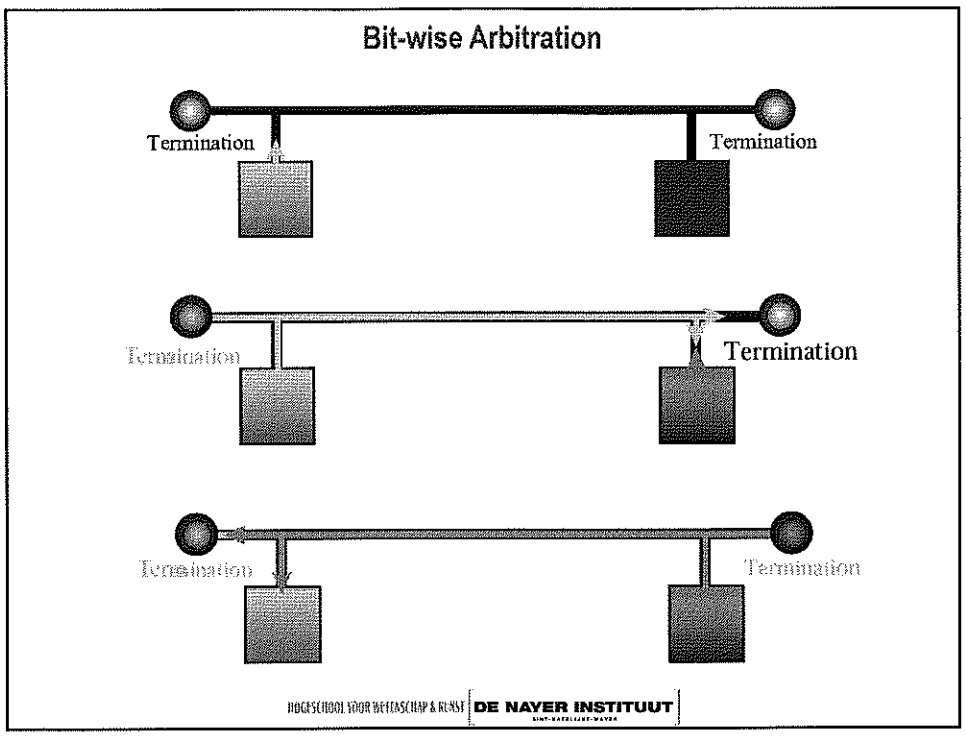
Bit-wise Arbitration
Termination
Termination
Termination
Termination
Termination
Termination
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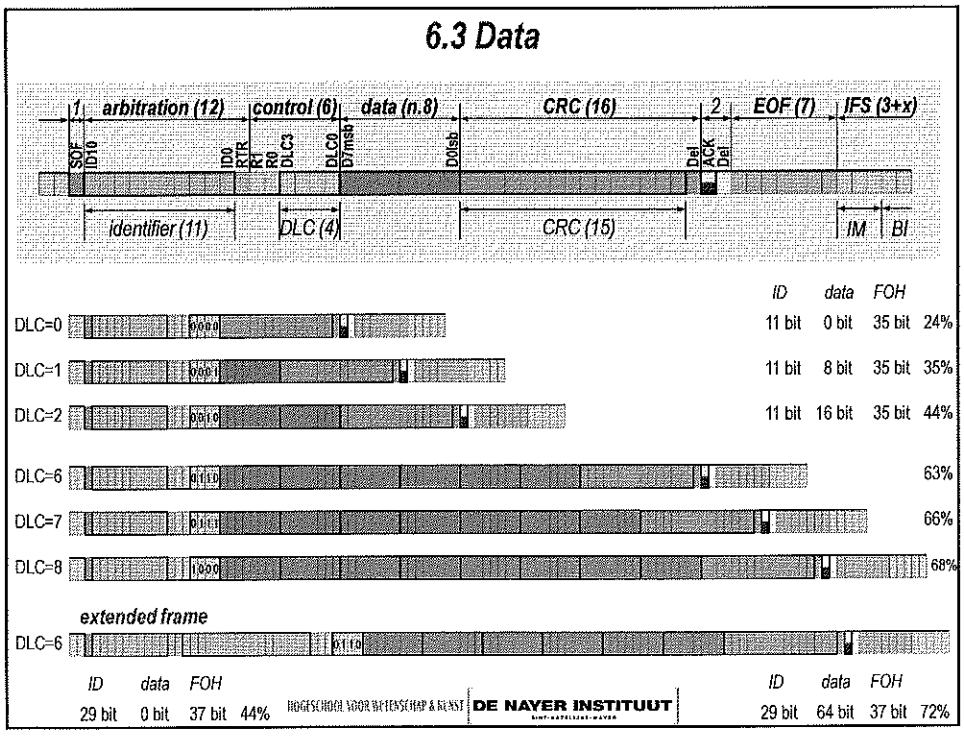
6.3 Data
1
arbitration (12)
control (6)
data (n.8)
CRC (16)
2
EOF (7)
IFS (3+x)
SOF
ID10
ID0
RTR
R1
R0
DLC3
DLC0
D7msb
D0lsb
Del
ACK
Del
identifier (11)
DLC (4)
CRC (15)
IM
BI
ID
data
FOH
DLC=0
11 bit 0 bit 35 bit 24%
DLC=1
11 bit 8 bit 35 bit 35%
DLC=2
11 bit 16 bit 35 bit 44%
DLC=6
63%
DLC=7
66%
DLC=8
68%
extended frame
DLC=6
ID data FOH
29 bit 0 bit 37 bit 44%
ID data FOH
29 bit 64 bit 37 bit 72%
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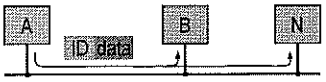
7. Message Transfer

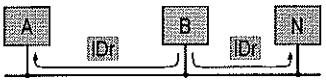
7.1 Frame Types

Data Frame



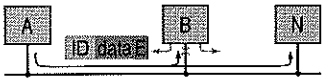
"Hello everyone, here's some data labelled ID"
carries data from a transmitter
to any or all the receivers

Remote Frame



"Hello everyone, can someone produce data labelled ID?"
request a remote node to transmit
the data frame with the same identifier

Error Frame



(everyone, aloud) "Let's try again!"
transmitted by any unit on detecting a bus error

Overload Frame

"I'm busy, could you please wait for a moment?"
transmitted to provide an extra delay between
the preceding and succeeding data or remote frames

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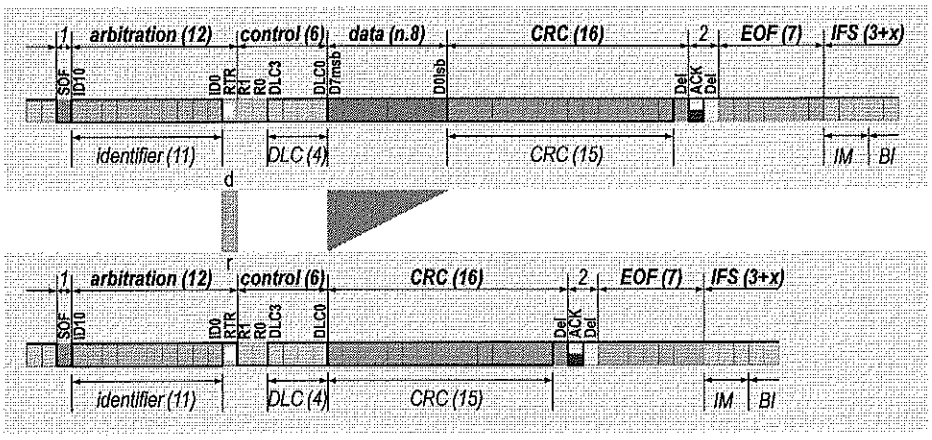
7.2 Remote Frame

standard data frame



standard remote frame

- An identifier with request RTR (recessive) will force the same identifier with data to be sent.
- The remote frame can be transmitted by any module, possibly at the same time.
- The DLC (Data Length Code) has to have the same value in the remote frame as in the data frame, but will have no data bytes.

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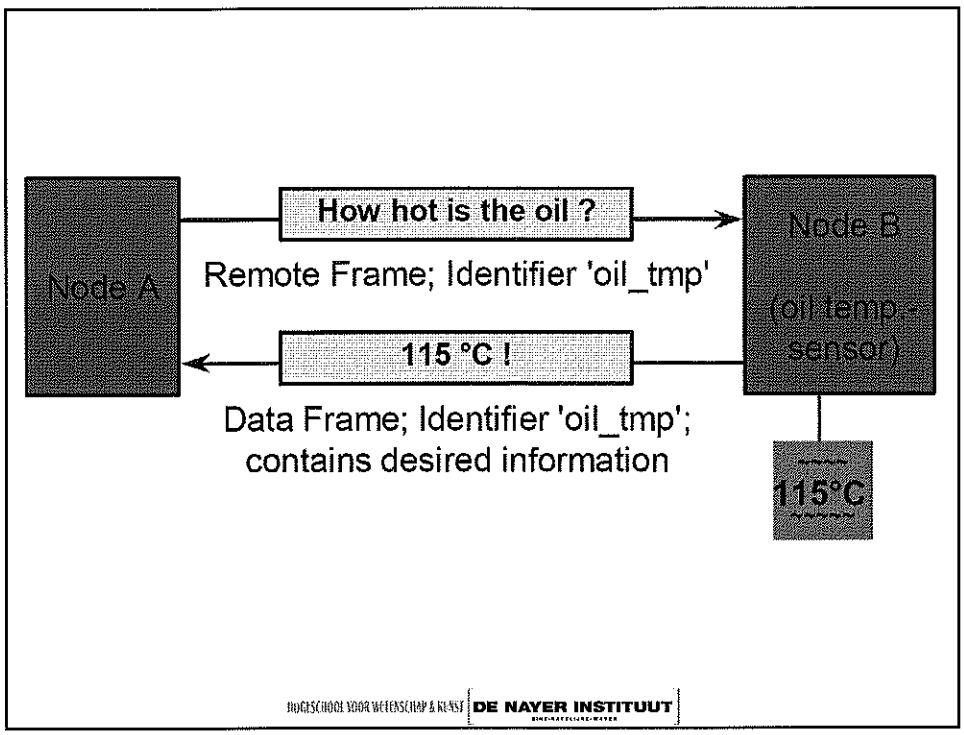
Node A
How hot is the oil ?
Remote Frame; Identifier 'oil_tmp'
115 °C !
Data Frame; Identifier 'oil_tmp';
contains desired information
Node B
(oil temp. - sensor)
115°C
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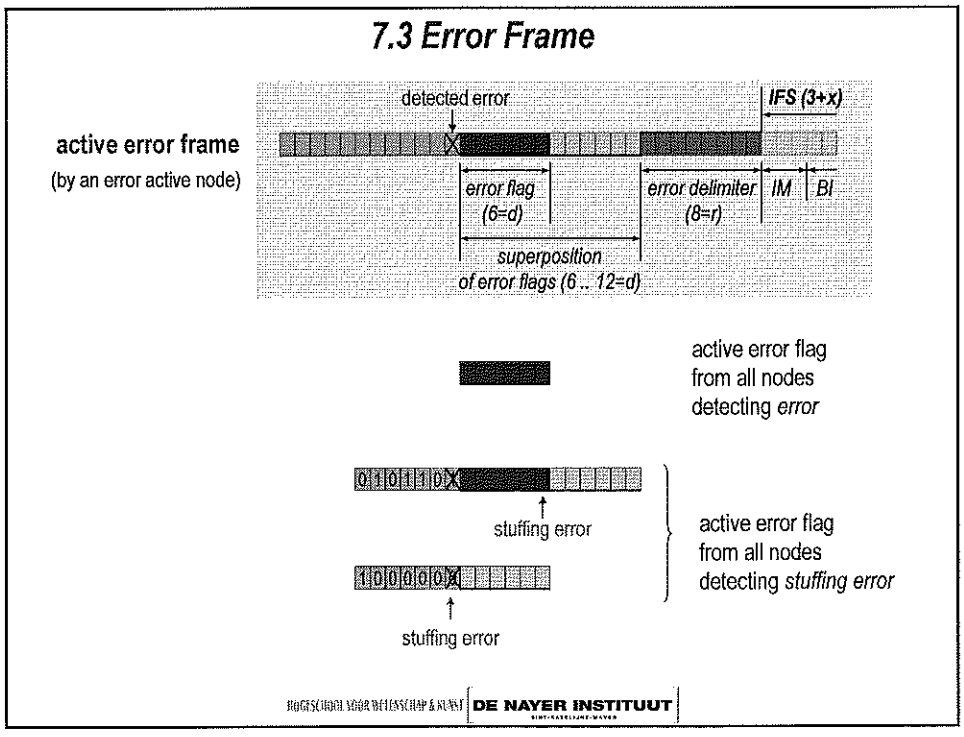
7.3 Error Frame
active error frame
(by an error active node)
detected error
IFS (3+x)
error flag
(6=d)
error delimiter
(8=r)
IM
BI
superposition
of error flags (6 .. 12=d)
active error flag
from all nodes
detecting error
stuffing error
active error flag
from all nodes
detecting stuffing error
stuffing error
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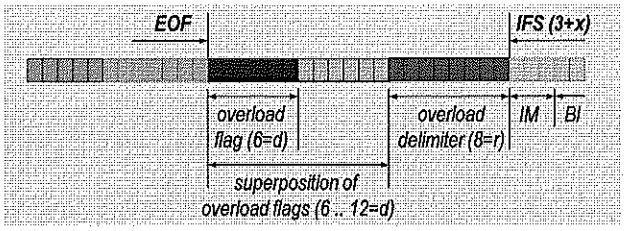
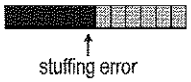
7.4 Overload Frame

Goal:
delay start of next frame



active overload flag from a node in overload condition

active overload flag from a node detecting overload condition



active error flag from all nodes detecting *stuffing error*

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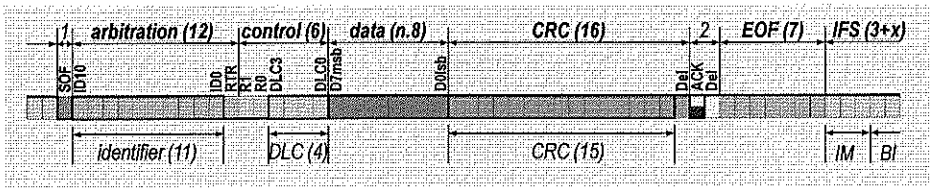
7.5 Interframe Space



Separates a frame (of whatever type) from a following Data or Remote Frame.

IM = Intermission (3 recessive bits)

BI = Bus Idle

Bus Idle time may be of any arbitrary length including zero.

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8. Error Handling

The CAN protocol provides sophisticated
error detection, signalling and correction mechanisms.

error detection

- Stuff Error
- CRC Error
- Bit Error
- ACK Error
- Form Error

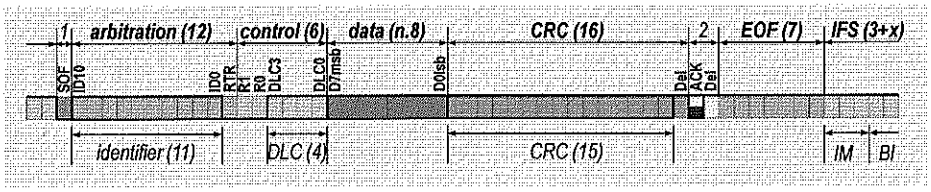
error signalling

detected error ↓ X ← error flag

error correction

frame retransmission →

8.1 Cyclic Redundancy Check Error



The CRC Field contains:

A 15-bit CRC code used for error detection.

The message is divided by the polynomial:

$G(x) = x^{15} + x^{14} + x^{10} + x^8 + x^7 + x^4 + x^3 + 1$ BER = $2^{-15} = 3.10^{-5}$

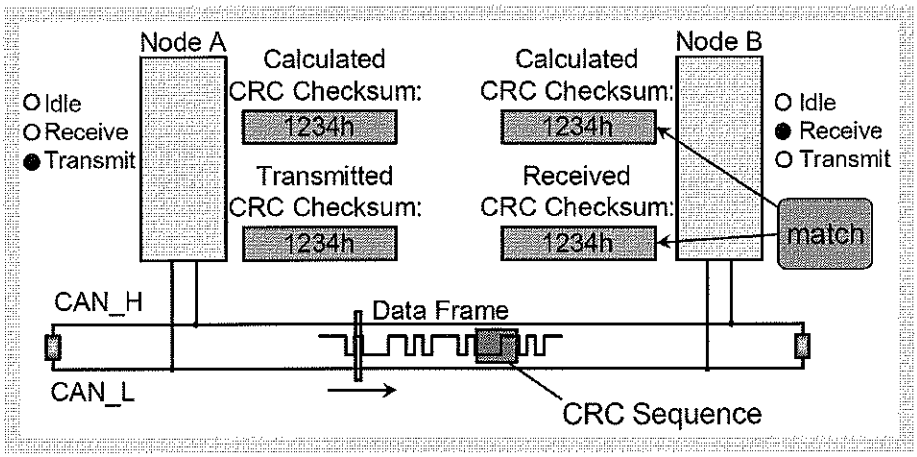
The remainder of this division is the CRC.

One recessive bit used as a delimiter.

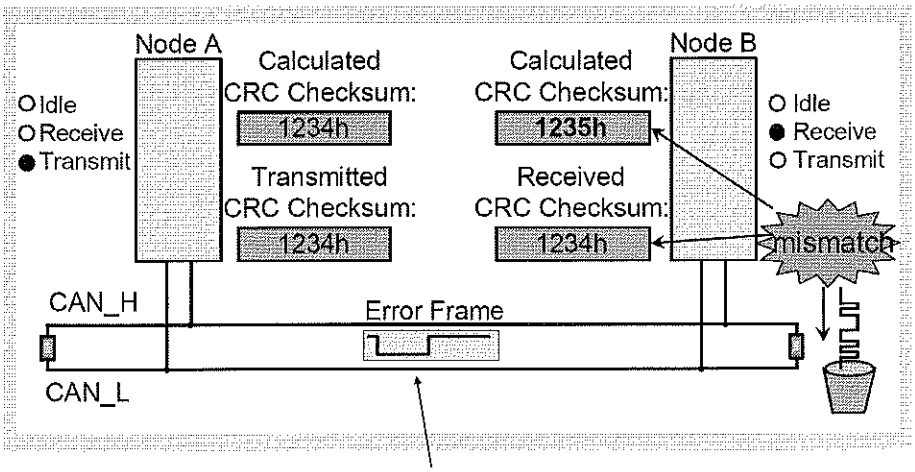
Hamming Distance = 6 → detection of up to 5 single bit errors

All nodes receive the message, calculate the CRC and verify against the CRC received.

For error free communication: calculated and received CRC must match.



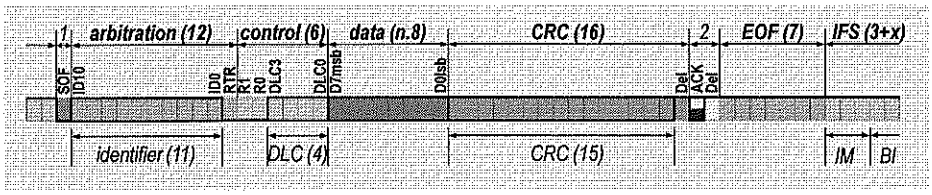
CRC Error: *The CRC code computed is different than the CRC code transmitted.*



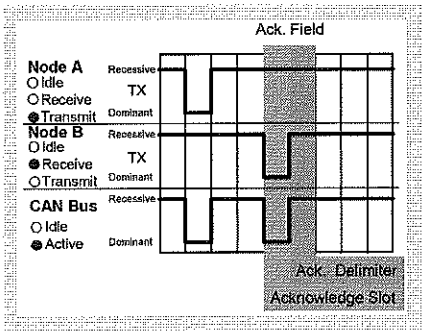
When a CRC error is detected, transmission of an error flag starts at the bit following the ACK delimiter.

Detected errors are made public to all other nodes via Error Frames.

8.2 Acknowledge Error



Tx: r – Rx: d or r



A frame must be acknowledged by at least one other node.
(otherwise ACK-Error)

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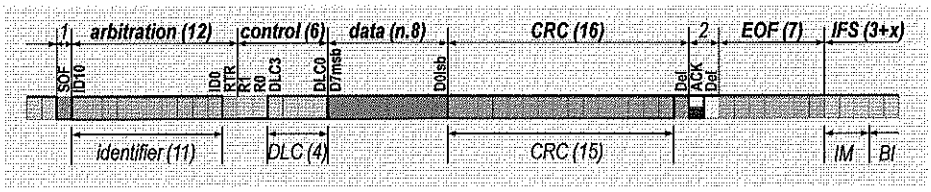
8.3 Form Error



must be recessive

↓

if not: **form error**

↓

generation of: **error flag**

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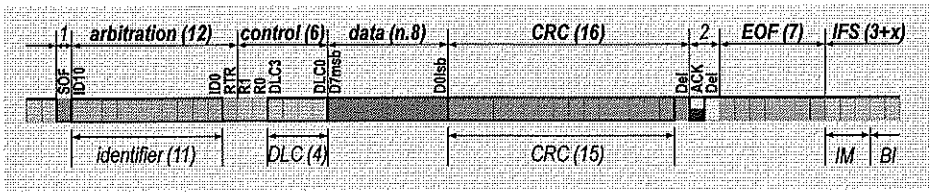
8.4 Stuff Error

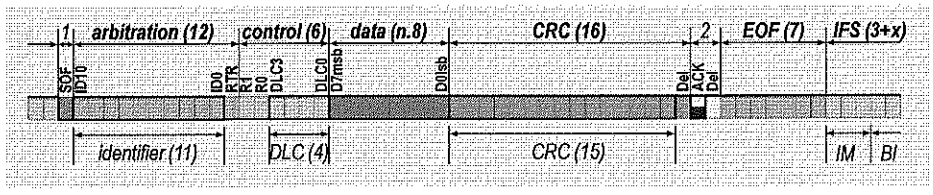


stuffing error

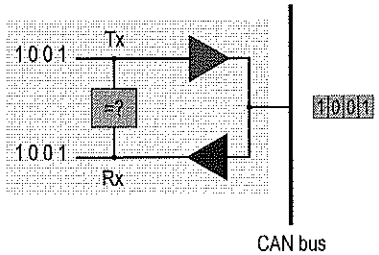
error flag

6th consecutive equal bit level
= violation of the stuffing rule

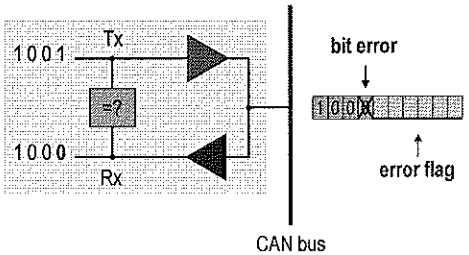
8.5 Bit Error



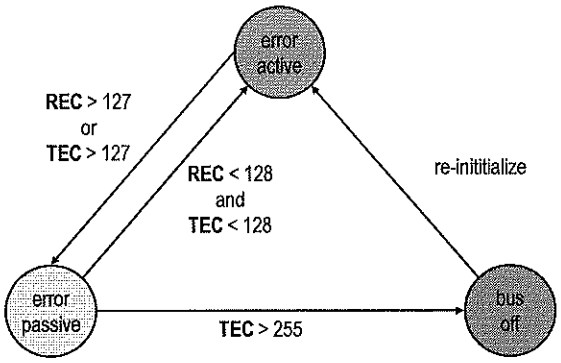
The sending node monitors the bus
to ensure that:
data transmitted = data received
(not: ACK bit, Arbitration bits)



Bit Error:
Sending node detects
data transmitted ≠ data received



9. Fault Confinement



Active Error State: normal operation, generate *active error frame*
Passive Error State: generate *passive error frame*, IFS + suspended transmission
Bus Off: don't generate any frames, nor receive frames (withdraw from bus)

TEC = Transmit error Count

REC = Receive error Count

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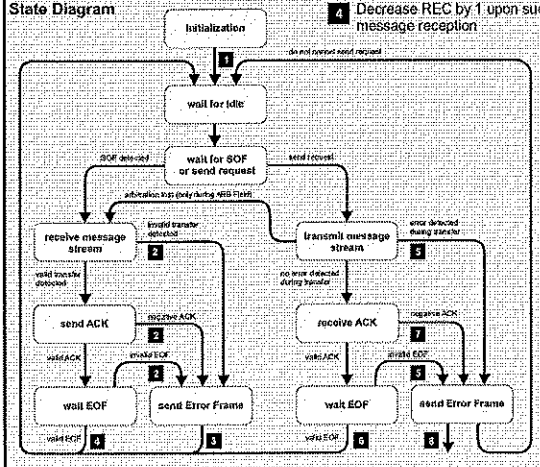
Error Counters

Error Counting Rules

1. Initialize error counters to zero upon reset
2. Increase REC by 1 when detecting an invalid transfer
3. Increase REC by 8 if receiver is first to transmit an error flag
4. Decrease REC by 1 upon successful message reception
5. Increase TEC by 8 when detecting an error during the transfer
6. Decrease TEC by 1 upon successful message transmission
7. Increase TEC by 8. Do not increase if TEC > 127
8. If TEC > 255, then disconnect CAN controller from the bus

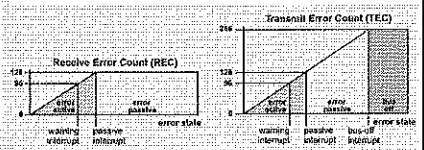
Receive / Transmit State Diagram



Do not increase REC being 128.

Do not increase TEC being 256.

Do not decrease REC or TEC being 0.



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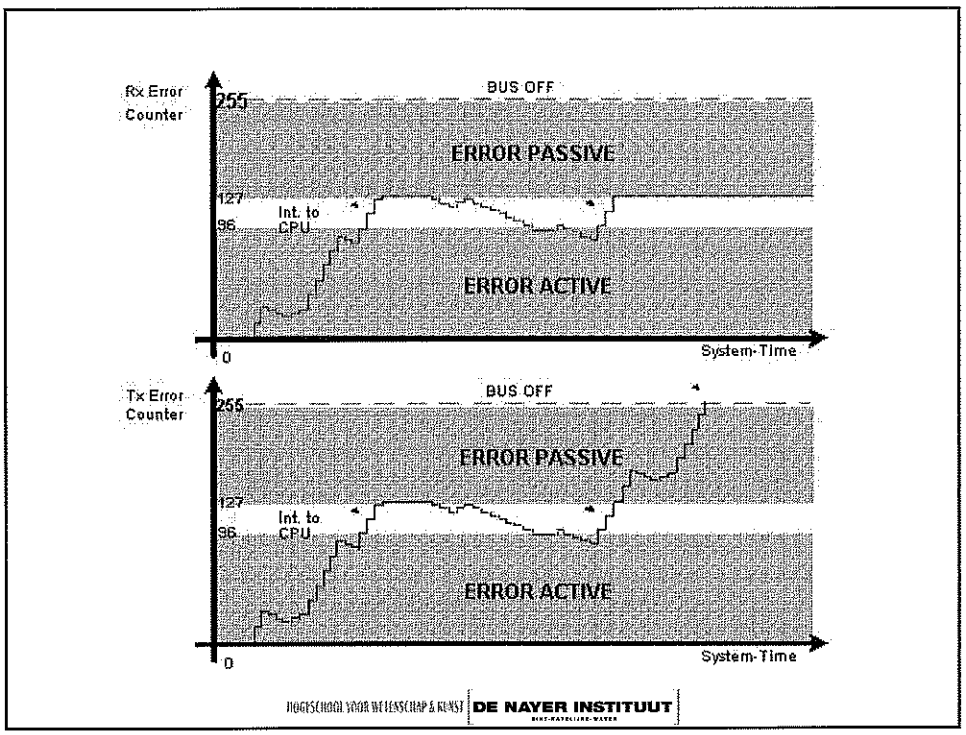
Rx Error Counter
255
BUS OFF
ERROR PASSIVE
127
96
Int. to CPU
ERROR ACTIVE
0
System-Time
Tx Error Counter
255
BUS OFF
ERROR PASSIVE
127
96
Int. to CPU
ERROR ACTIVE
0
System-Time
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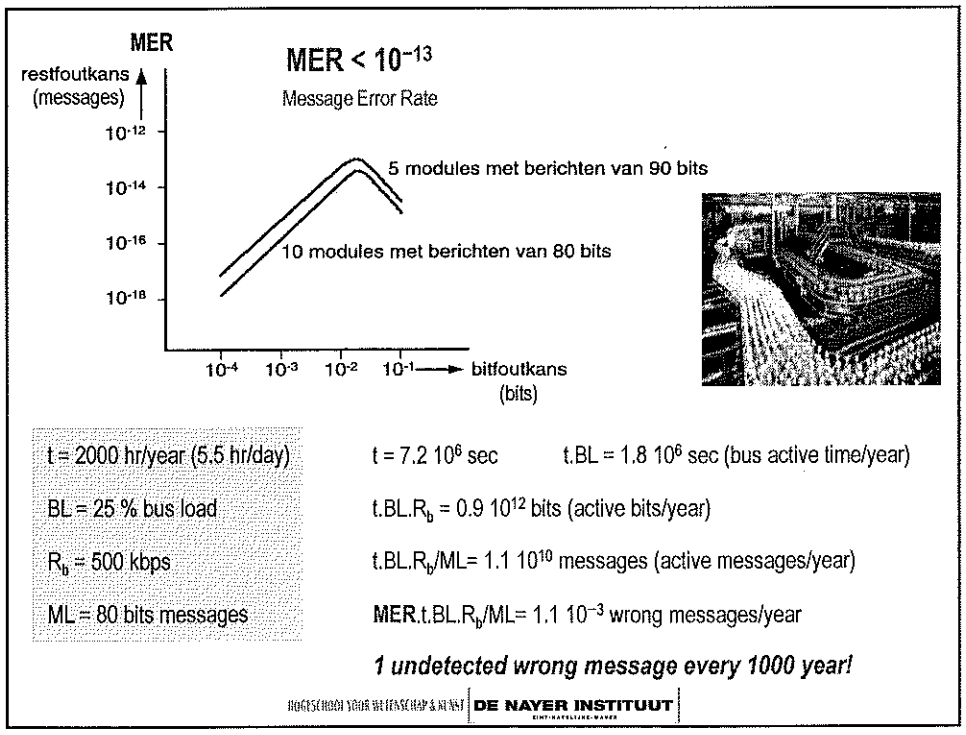
MER
restfoutkans (messages)
10^{-12}
10^{-14}
10^{-16}
10^{-18}
MER < 10^{-13}
Message Error Rate
5 modules met berichten van 90 bits
10 modules met berichten van 80 bits
10^{-4} 10^{-3} 10^{-2} 10^{-1}
bitfoutkans (bits)
t = 2000 hr/year (5.5 hr/day)
BL = 25 % bus load
R_b = 500 kbps
ML = 80 bits messages
t = 7.2 10^6 sec
t.BL = 1.8 10^6 sec (bus active time/year)
t.BL.R_b = 0.9 10^{12} bits (active bits/year)
t.BL.R_b/ML= 1.1 10^{10} messages (active messages/year)
MER.t.BL.R_b/ML= 1.1 10^{-3} wrong messages/year
1 undetected wrong message every 1000 year!
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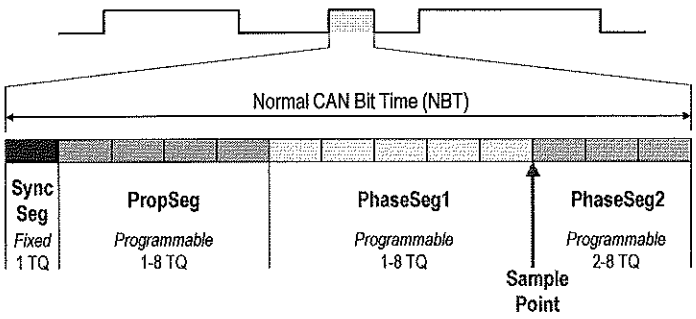
10. Bit Timing



Synchronization Segment (SyncSeg) : bit edges are expected to occur within the SyncSeg (synchronization)

Propagation Segment (PropSeg) : to compensate for the propagation delay (2 x maximum bus delay)

Phase Segment 1 (PhaseSeg1) and ***Phase Segment 2*** (PhaseSeg2) : to compensate for edge phase errors PhaseSeg1 can be lengthened or PhaseSeg2 can be shortened by resynchronization.

Sample Point : the point in the bit time in which the logic level is read and interpreted.

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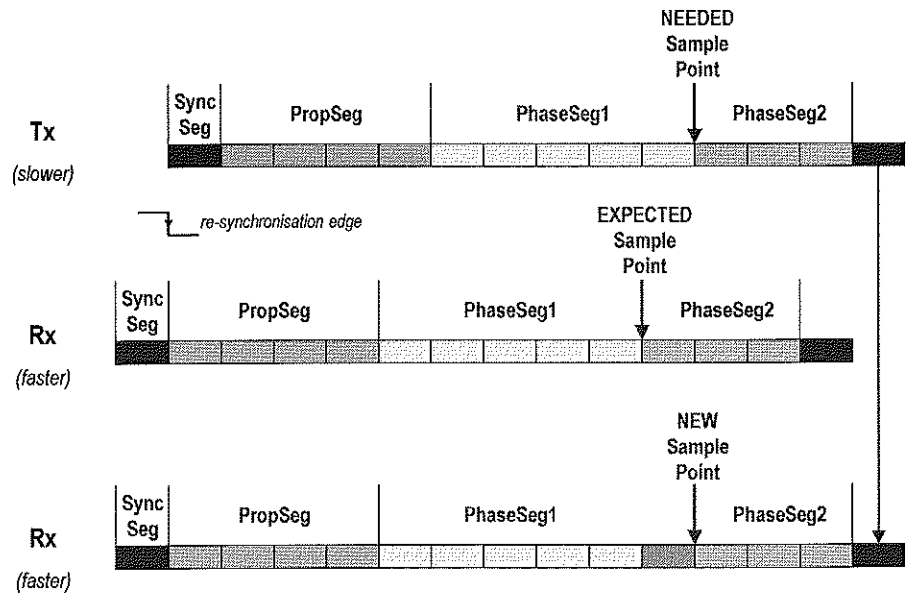
10.1 Bit Lengthening



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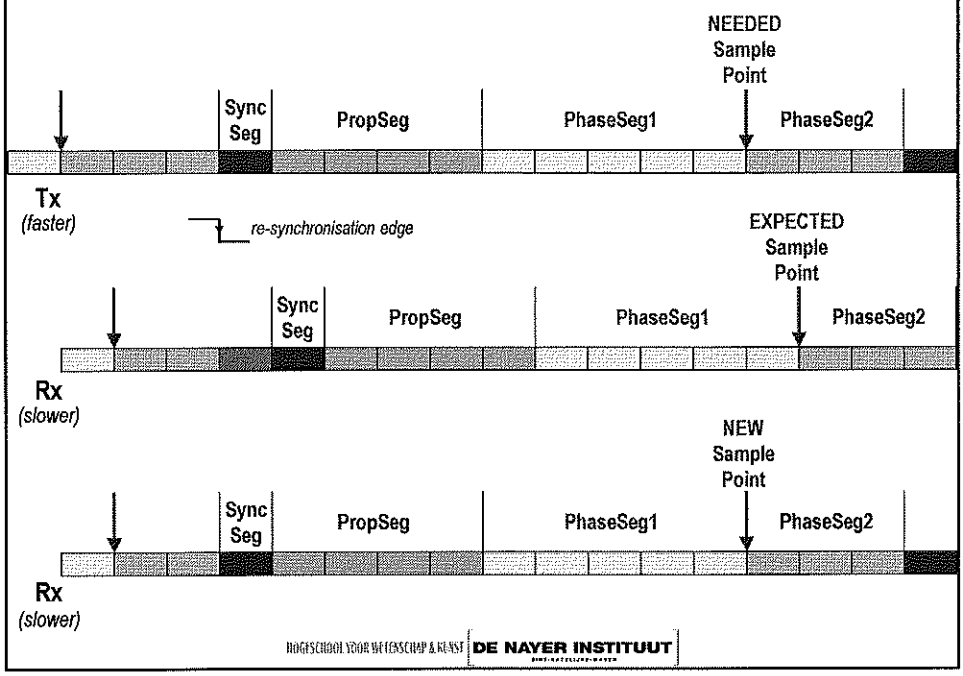
10.2 Bit Shortening



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11. Higher Level Protocols

SAE J1939 : *in-vehicle, heavy truck, and agricultural networking*

OSEK/VDX : Offene Systeme und deren Schnittstellen für die Elektronik im Kraftfahrzeug
Vehicule Distributed eXecutive
joint project of the automotive industry.

CAL/CANopen : *(CAN Application Layer)*

DeviceNet : ODVA, (Allen-Bradley, etc.)

SDS : *(Smart Distribution System)* Honeywell

CAN Kingdom: Kvaser – *mobile hydraulics*

} **CiA (CAN in Automation)**

CDA 101 : *(Common Digital Architecture)* DoD – *airplane*

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12. References

[1] **CAN Specification 2.0 Part A**
Bosch (September, 1991)

[2] **CAN Specification 2.0 Part B**
Bosch (September, 1991)

[3] **Understanding Microchip's CAN Module Bit Timing (AN754)**
Microchip Technology Inc (2001)

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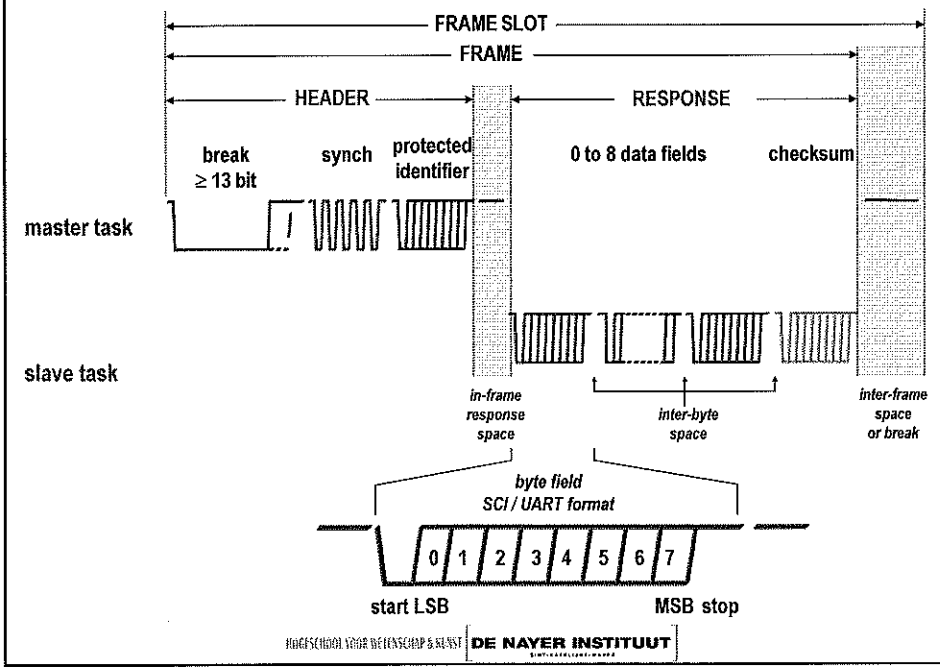
SINT-KATELIJNE-WAVER

In Vehicle Networks Formularium

EmSD
Embedded System Design

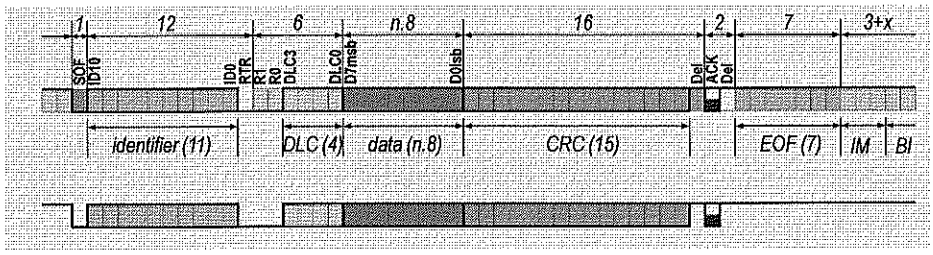
ir. J. Meel
sept 2008

LIN Frame Structure



CAN Frame Structure

Standard Frame (CAN 2.0 part A)



Tx: r = recessive ("1")
Tx: d = dominant ("0")
Tx: d or r
Tx: r – Rx: d or r

SOF = Start Of Frame
CRC = Cyclic Redundancy Check
ACK = Acknowledge
EOF = End Of Frame
IFS = Inter Frame Space

DLC = Data Length Code
IM = Intermission [pause] (r)
BI = Bus Idle (r)
RTR = Remote Transmission Request
R0,R1 = Reserved for future use (d)
Del = Delimiter (r)

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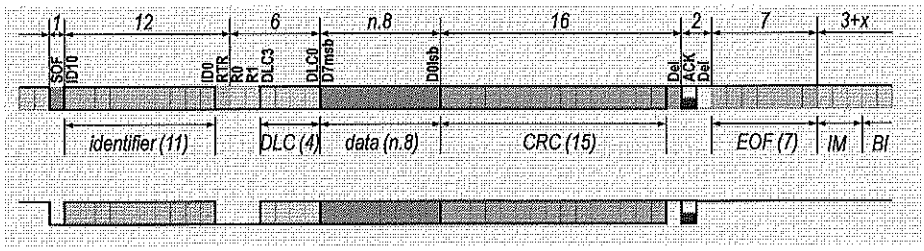
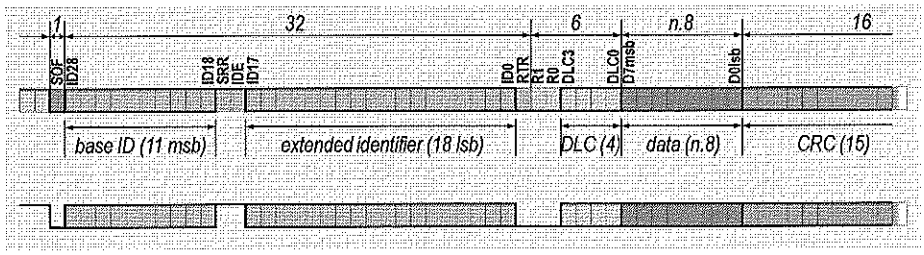
Standard Frame (CAN 2.0 part A)

2^{11} = 2048 ID's



Extended Frame (CAN 2.0 part B)

2^{29} = 536 10^6 ID's



SRR = Substitute Remote Request (SRR) bit **IDE = Identifier Extension bit**

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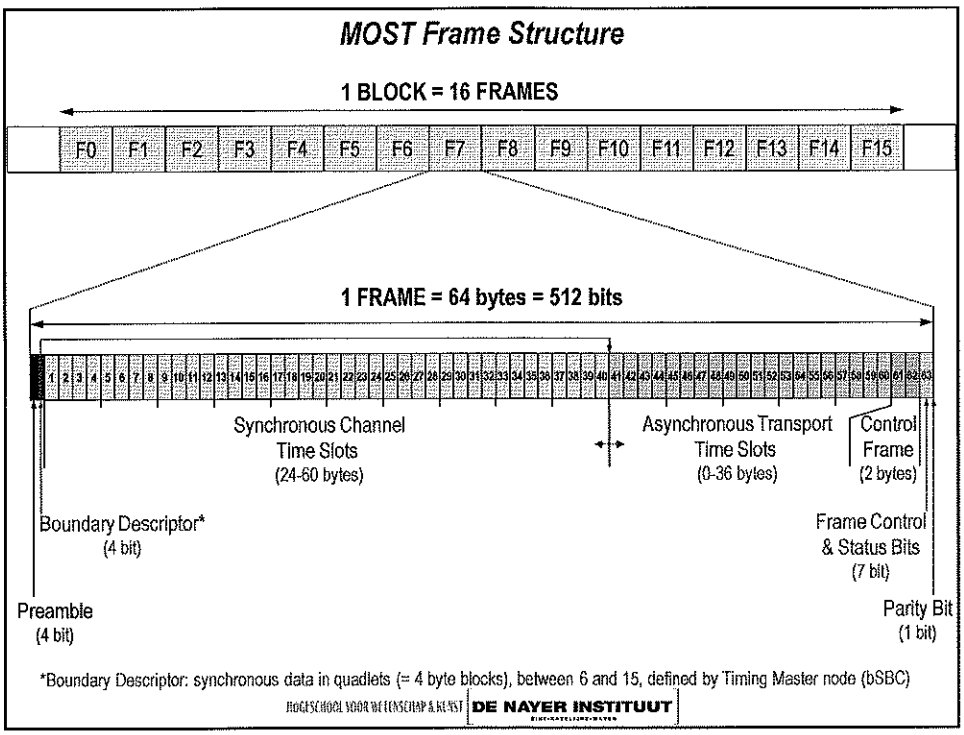
MOST Frame Structure
1 BLOCK = 16 FRAMES
F0 F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15
1 FRAME = 64 bytes = 512 bits
Synchronous Channel Time Slots (24-60 bytes)
Asynchronous Transport Time Slots (0-36 bytes)
Control Frame (2 bytes)
Boundary Descriptor* (4 bit)
Frame Control & Status Bits (7 bit)
Preamble (4 bit)
Parity Bit (1 bit)
*Boundary Descriptor: synchronous data in quadlets (= 4 byte blocks), between 6 and 15, defined by Timing Master node (bSBC)
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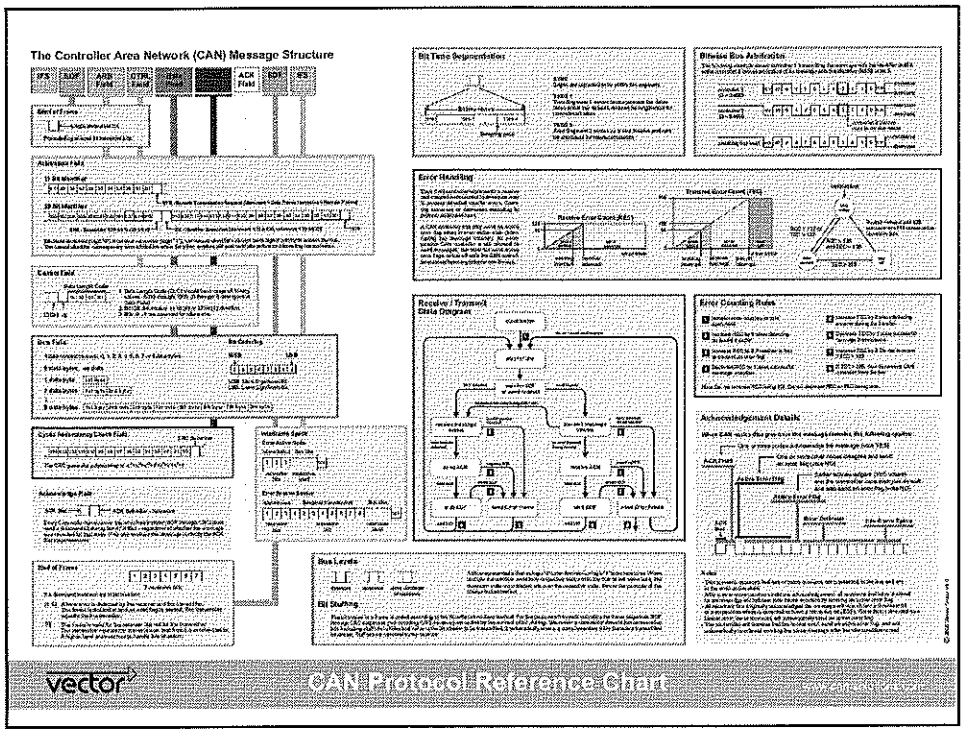

The Controller Area Network (CAN) Message Structure
vector
CAN Protocol Reference Card

The Controller Area Network (CAN) Message Structure

Start of Frame

single dominant bit

Preceded by at least 11 recessive bits

Arbitration Field

11 Bit Identifier

b10 b9 b8 b7 b6 b5 b4 b3 b2 b1 b0 — RTR

29 Bit Identifier

b28 b27 b26 b25 b24 b23 b22 b21 b20 b19 b18 — b17 b16 b15 b14 b13 b12 b11 b10 b9 b8 b7 b6 b5 b4 b3 b2 b1 b0 — RTR

SRR - Substitute RTR bit for 29 bit ID — IDE - Identifier Extension [dominant = 11 bit ID, recessive = 29 bit ID]

RTR - Remote Transmission Request [dominant = Data Frame, recessive = Remote Frame]

Because dominant (logic "0") wins over recessive (logic "1"), low-valued identifiers always have higher priority to access the bus. The lowest identifier subsequently wins arbitration while the other senders will wait until idle before re-attempting transmission.

Control Field

Data Length Code: b3 b2 b1 b0

IDE/r1 r0

1. Data Length Code (DLC) should be in range of binary values - 0000 through 1000. (0 through 8 data bytes in Data Field)
2. Bit IDE determines 11 bit (0) or 29 bit (1) identifier.
3. Bits r0, r1 are reserved for future use.

Data Field

9 data content choices : 0, 1, 2, 3, 4, 5, 6, 7 or 8 data bytes

0 data bytes	no data
1 data byte	1st byte
2 data bytes	1st byte 2nd byte
⋮	
8 data bytes	1st byte 2nd byte 3rd byte 4th byte 5th byte 6th byte 7th byte 8th byte

Bit Ordering

MSB 7 6 5 4 3 2 1 0 LSB

MSB: Most Significant Bit
LSB: Least Significant Bit

Cyclic Redundancy Check Field

b14 b13 b12 b11 b10 b9 b8 b7 b6 b5 b4 b3 b2 b1 b0 — CRC Delimiter

The CRC generator polynominal is: $x^{15}+x^{14}+x^{10}+x^8+x^7+x^4+x^3+1$

Acknowledge Field

ACK Slot — ACK Delimiter - recessive

Every CAN node that receives any error-free transfer (SOF through CRC) must send a dominant bit during the ACK Slot - regardless of whether the message was intended for that node. If no one receives the message correctly the ACK Slot stays recessive.

Interframe Space

Error Active Node

Intermission: 1 2 3 (recessive bits) — Bus idle: SOF (recessive level)

Error Passive Sender:

Intermission: 1 2 3 (recessive bits) — Suspend transmission: 1 2 3 4 5 6 7 8 (recessive bits) — Bus idle: SOF (recessive level)

End of Frame

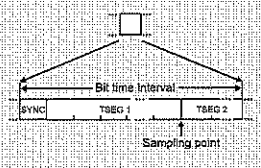
1 2 3 4 5 6 7 — 7 recessive bits

If a dominant level occurs in bit number:

[1..6] A form error is detected by the receiver and the transmitter. The frame is discarded and an error flag is started. The transmitter repeats the transmission.

[7] The frame is valid for the receiver, but not for the transmitter. The transmitter repeats the transmission, that frame is received twice. A higher layer protocol has to handle this situation.

Bit Time Segmentation



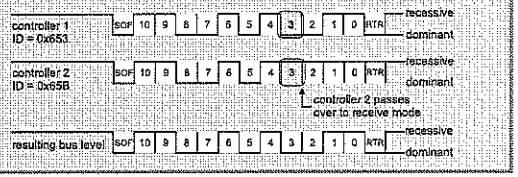
SYNC
Edges are expected to lie within this segment

TSEG 1
Time Segment 1 serves to compensate the delay times within the network and can be lengthened for resynchronization

TSEG 2
Time Segment 2 serves as a time reserve and can be shortened for resynchronization

Bitwise Bus Arbitration

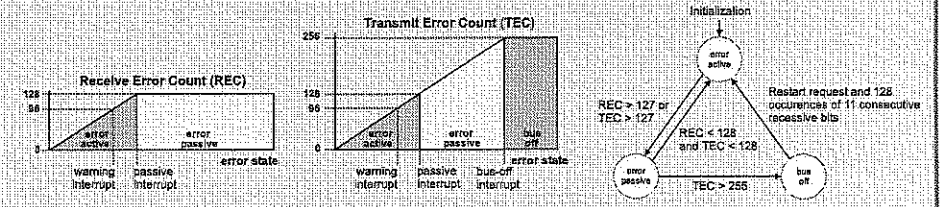
The following example shows controller 1 transmitting the message with the identifier 0x653, while controller 2 looses arbitration of its message with the identifier 0x65B in bit 3.



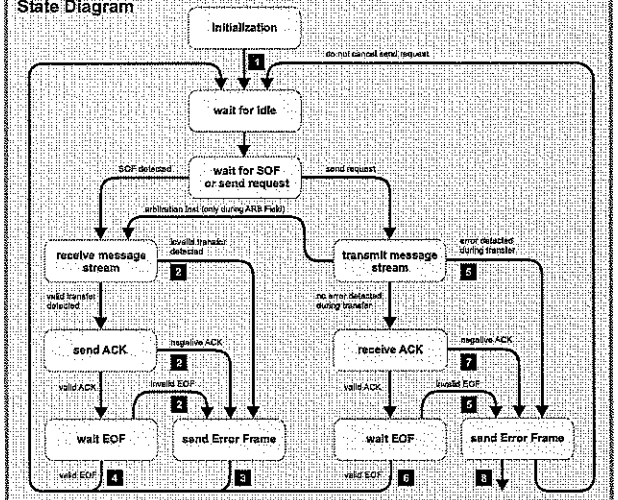
Error Handling

Each CAN controller implements a receive and transmit error counter to determine how to process detected transfer errors. Counting increases or decreases according to protocol states and rules.

A CAN controller can only send an active error flag when in error-active state (interrupting the message transfer). An error-passive CAN controller is still allowed to send messages, but must not send active error flags. In bus-off state the CAN controller must not have any influence on the bus.



Receive / Transmit State Diagram



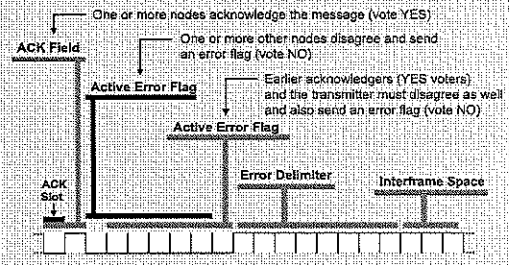
Error Counting Rules

1. Initialize error counters to zero upon reset
2. Increase REC by 1 when detecting an invalid transfer
3. Increase REC by 8 if receiver is first to transmit an error flag
4. Decrease REC by 1 upon successful message reception
5. Increase TEC by 8 when detecting an error during the transfer
6. Decrease TEC by 1 upon successful message transmission
7. Increase TEC by 8. Do not increase if TEC > 127
8. If TEC > 255, then disconnect CAN controller from the bus

Note: Do not increase REC being 128. Do not decrease REC or TEC being zero.

Acknowledgement Details

When CAN nodes disagree over the message transfer, the following applies:



Notes

- This scenario assumes that two or more receivers are connected to the bus and are in the error active state.
- After one or more receivers indicate acknowledgement, all receivers that have declined to acknowledge will indicate their frame rejection by sending an active error flag.
- All receivers that originally acknowledged the message will now detect a dominant bit in a bit position which is expected to have a recessive bit (EOF). Since this is detected as a format error, these receivers will subsequently send an active error flag.
- The transmitter will likewise find the format error, send an active error flag, and will automatically re-attempt sending the same message after the idle condition is met.

Bus Levels

A bit is represented either as logic "0" to be dominant or logic "1" to be recessive. When multiple transmitters send their respective states onto the bus at the same time, the dominant state must always win over the recessive state. This is the principle of the bitwise bus arbitration.

Bit Stuffing

The bit stream in a frame is coded according to the Non-Return-to-Zero method. For the purpose of resynchronization the frame segments SOF through CRC sequence (not including CRC delimiter) are coded by the method of bit stuffing. Whenever a transmitter detects five consecutive bits (including stuff bits) of identical value in the bit stream to be transmitted, it automatically inserts a complementary bit in the actual transmitted bit stream. Stuff bits are removed by the receiver.

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CAN Protocol Reference Chart

www.can-solutions.com