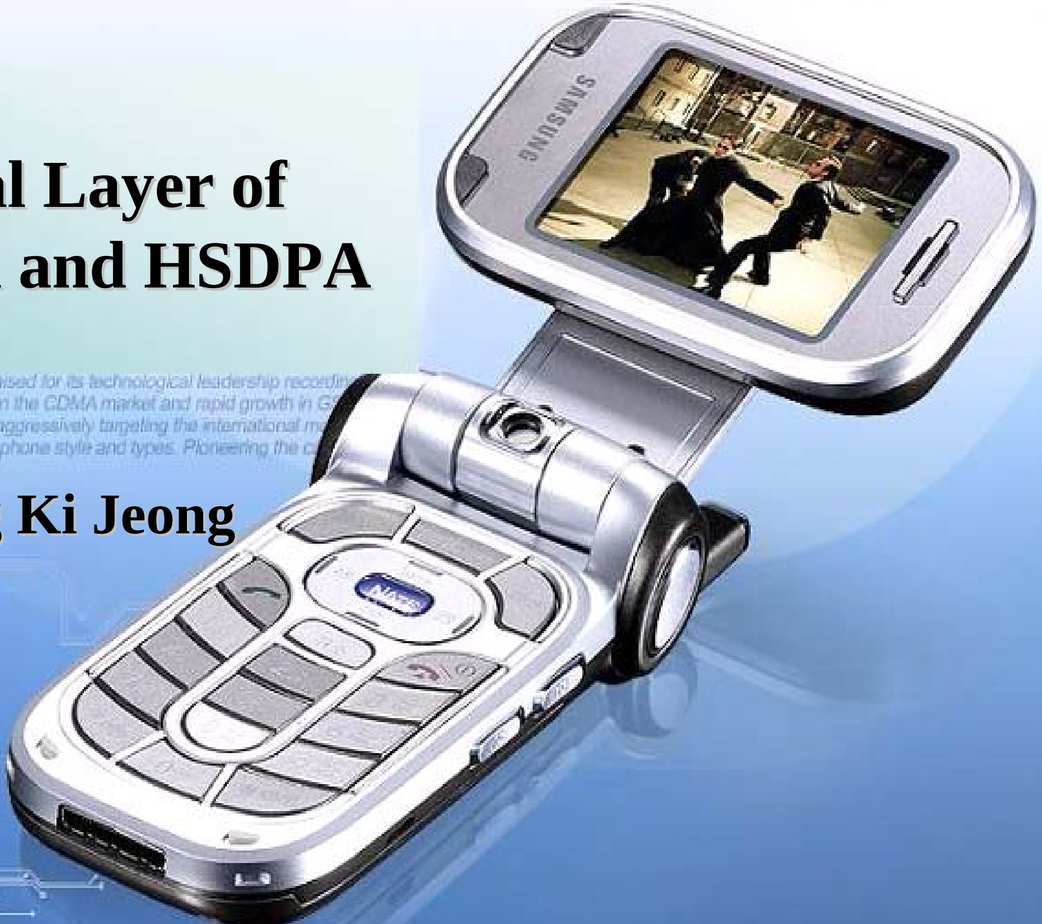
Physical Layer of W-CDMA and HSDPA

Chang Ki Jeong



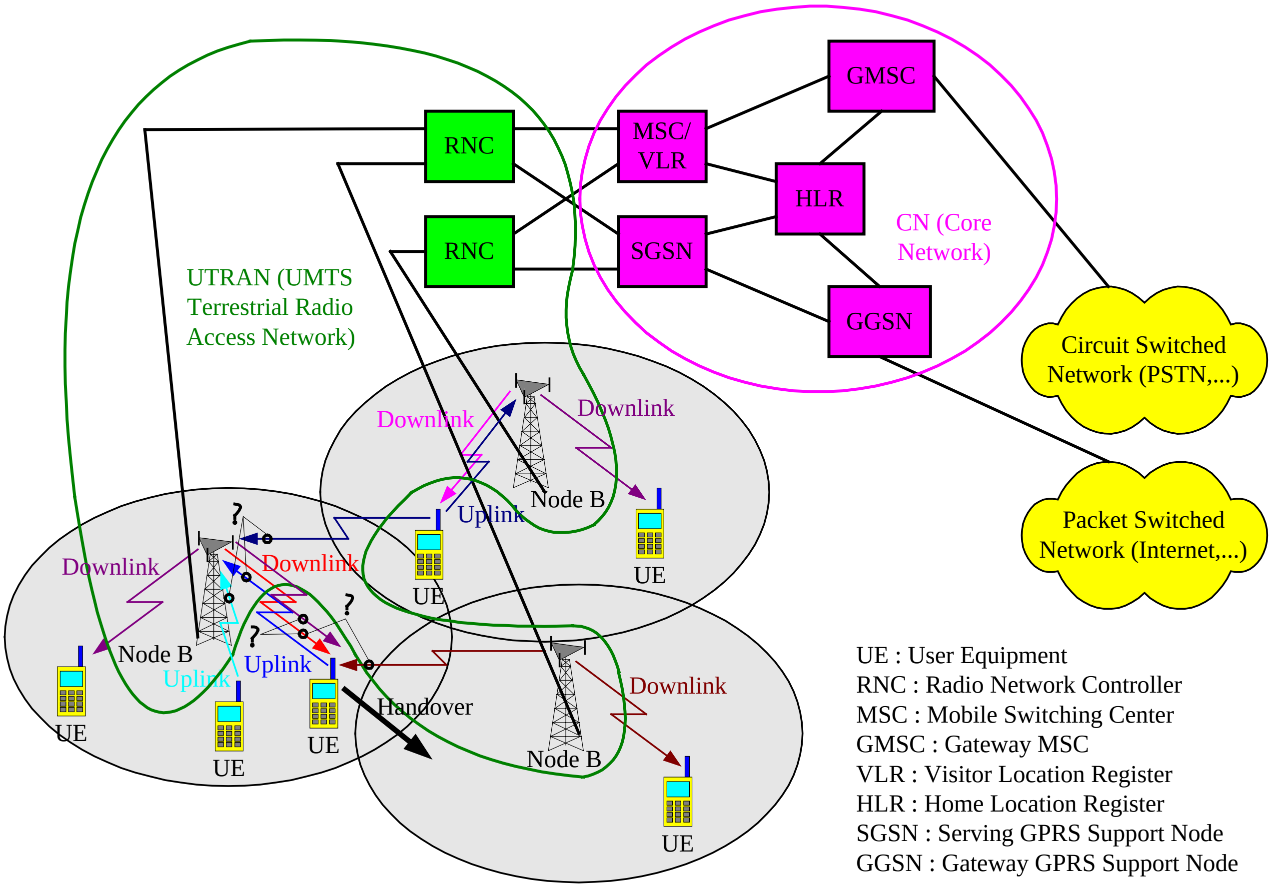
Contents

- Design Considerations
- Downlink Physical Channels
- Uplink Physical Channels
- HSDPA
- 4G Cellular Communication

Design Considerations

- UMTS Architecture
- Spreading Procedure
- Protocol Architecture, etc.

UMTS Architecture



UE : User Equipment
RNC : Radio Network Controller
MSC : Mobile Switching Center
GMSC : Gateway MSC
VLR : Visitor Location Register
HLR : Home Location Register
SGSN : Serving GPRS Support Node
GGSN : Gateway GPRS Support Node

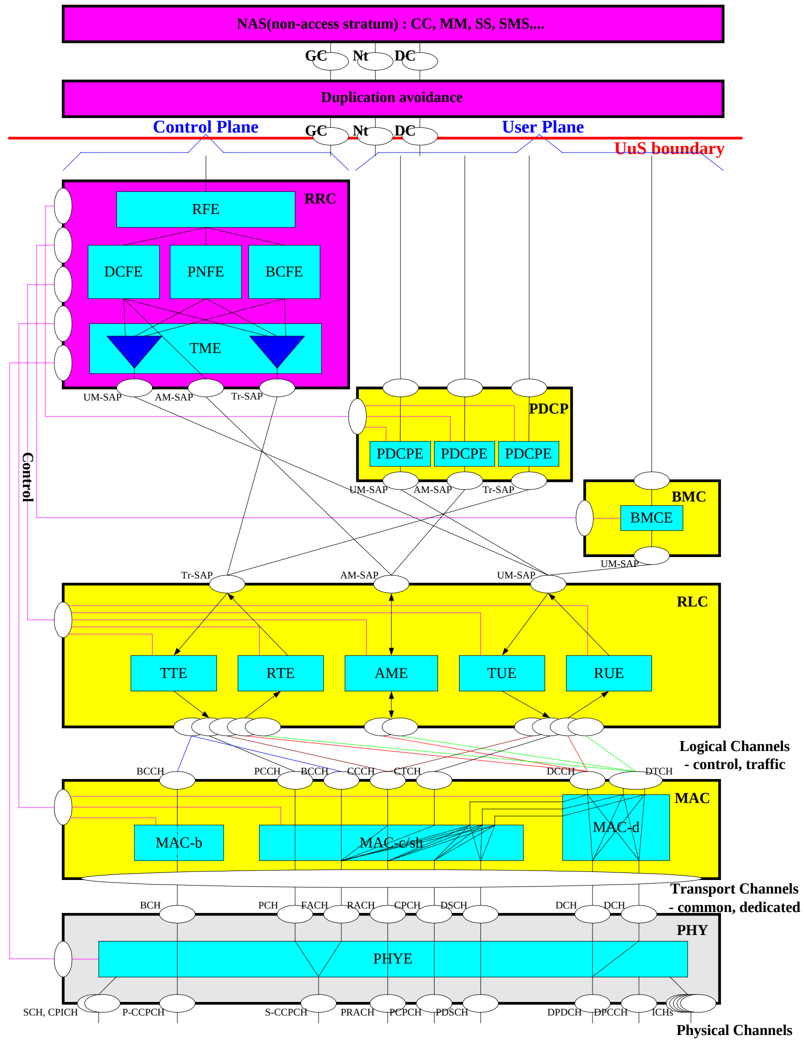
Elements of UMTS Architecture (1)

- UE
  - ME(mobile equipment) : radio terminal used for communication over radio interface
  - USIM(UMTS subscriber identity module)
- Node B
  - conversion the data flow between UE and RNC
  - mainly, physical layer functions
- RNC
  - access point for all services that UTRAN provides to the CN
  - Controlling RNC, serving RNC, drift RNC
  - functions of physical layer as well as higher layers if macro-diversity applies for soft handover
  - functions of higher layers if no macro-diversity applies

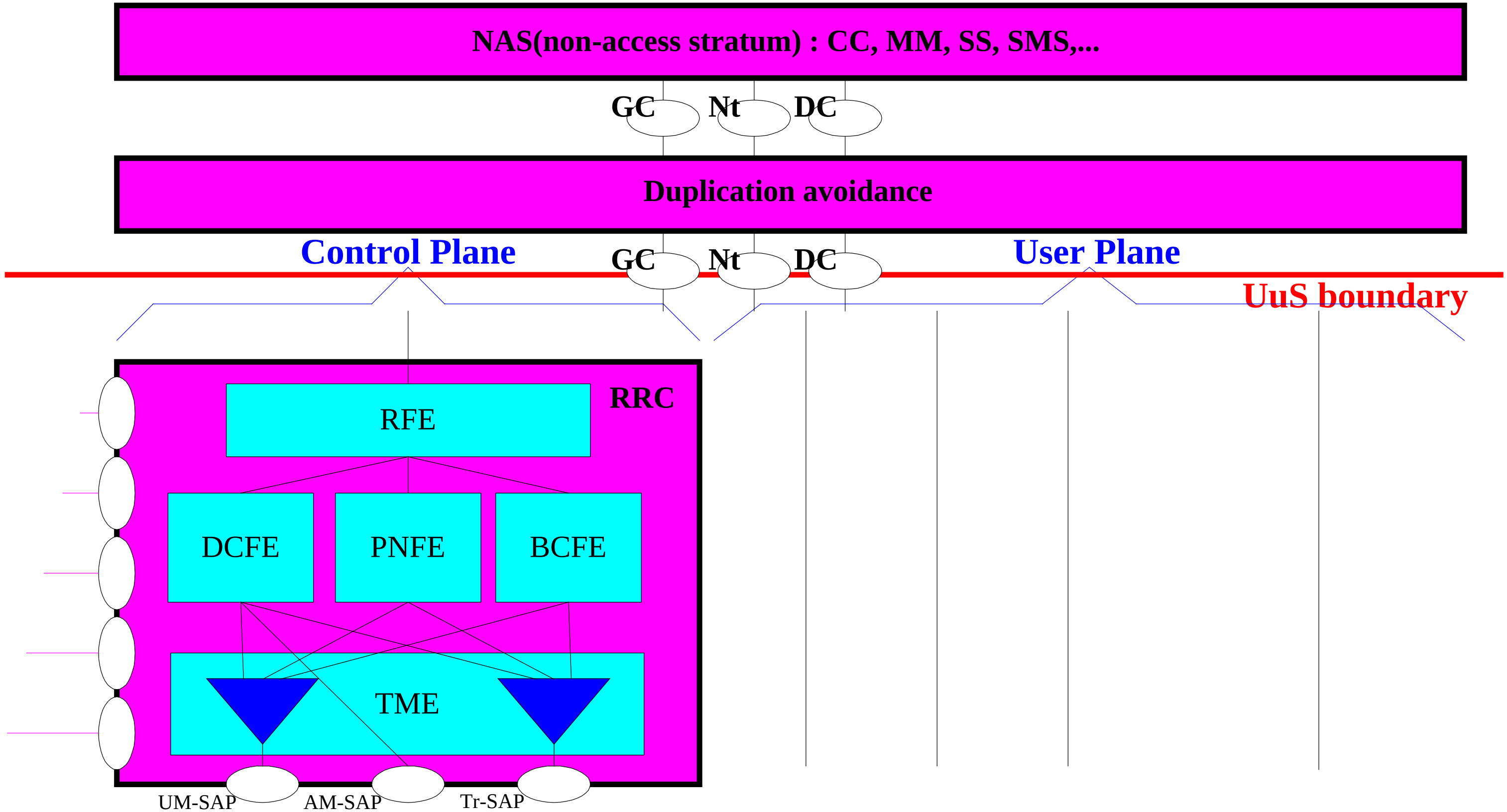
Elements of UMTS Architecture (2)

- MSC : switch used for CS transactions
- VLR
  - database that holds a copy of the visiting user’s service profile for CS services
- HLR
  - database located in the user’s home system that stores the master copy of the user’s service profile
- GMSC
  - switch at the point where UMTS is connected to external CS networks
- SGSN : switch (similar to MSC) and database (similar to VLR) for PS services
- GGSN : gateway for PS services

Protocol Architecture



Network Layer (Layer 3)



Sublayers and SAPs of Layer 3 (1)

- NAS(non-access stratum)
  - protocols between UE and the core network that are not terminated in the UTRAN
  - CC(call control), MM(mobility management), SMS(short message service), SS(supplementary service), ...
- Duplication avoidance
  - terminates in the CN but is part of the access stratum
- RRC(radio resource control)
  - exists in the control plane only
  - interfaces with layer 2 and terminates in the UTRAN
  - signaling of layer 3 between the UEs and UTRAN

Sublayers and SAPs of Layer 3 (2)

- RRC(radio resource control) (Cont.)
  - broadcast of NAS and access stratum information, establishment, re-establishment, maintenance, and release of an RRC connection, establishment, reconfiguration, and release of radio bearers, RRC connection mobility functions, paging/notification, UE measurement reporting and control of the reporting, ...
- SAPs
  - GC(general control) : information broadcast service
  - Nt(notification) : paging/notification broadcast service
  - DC(dedicated control) : services for establishment/release of a connection and transfer of messages using this connection

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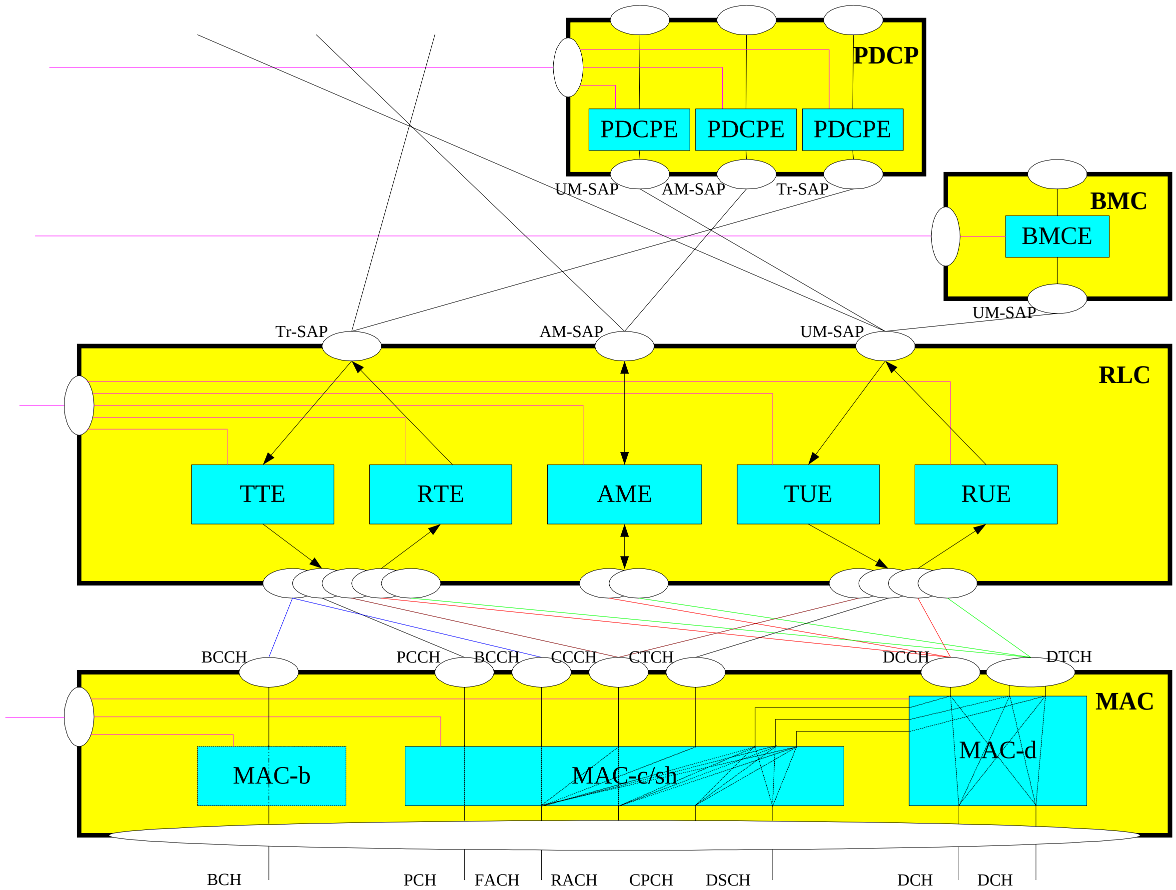
Data Link Layer (Layer 2)



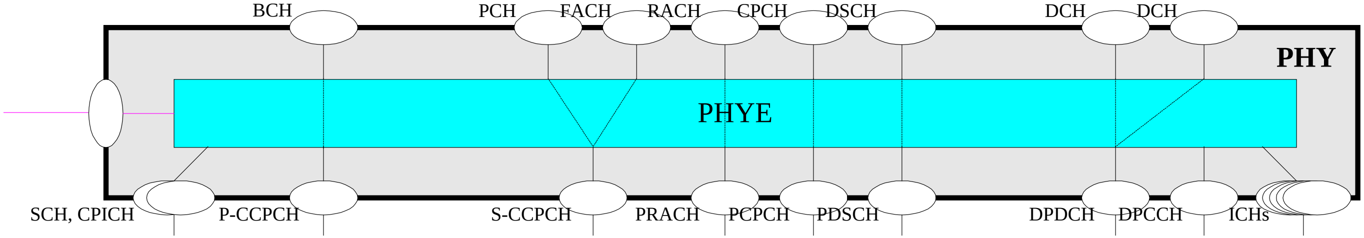
Sublayers of Layer 2 (1)

- PDCP(packet data convergence protocol)
  - exists in the user plane only
  - transmission and reception of network PDUs in acknowledged, unacknowledged, and transparent mode
  - TCP/IP header compression/decompression
- BMC(broadcast/multicast control)
  - exists in the user plane only
  - broadcast/multicast transmission service for common user data
  - storage, scheduling, and transmission of BMC messages

Sublayers of Layer 2 (2)

- RLC(radio link control)
  - transparent, unacknowledged and acknowledged data transfer
  - segmentation/reassembly, concatenation, padding, transfer of user data, error correction, in-sequence delivery of higher layer PDUs, duplicate detection, flow control, ciphering, ...
- MAC(medium access control)
  - unacknowledged data transfer
  - mapping between logical channels and transport channels, selection of appropriate transport format, priority handling, identification of UEs on common transport channels, multiplexing/demultiplexing of higher layer PDUs, traffic volume monitoring, ciphering, ASC selection, ...

Physical Layer (Layer 1)

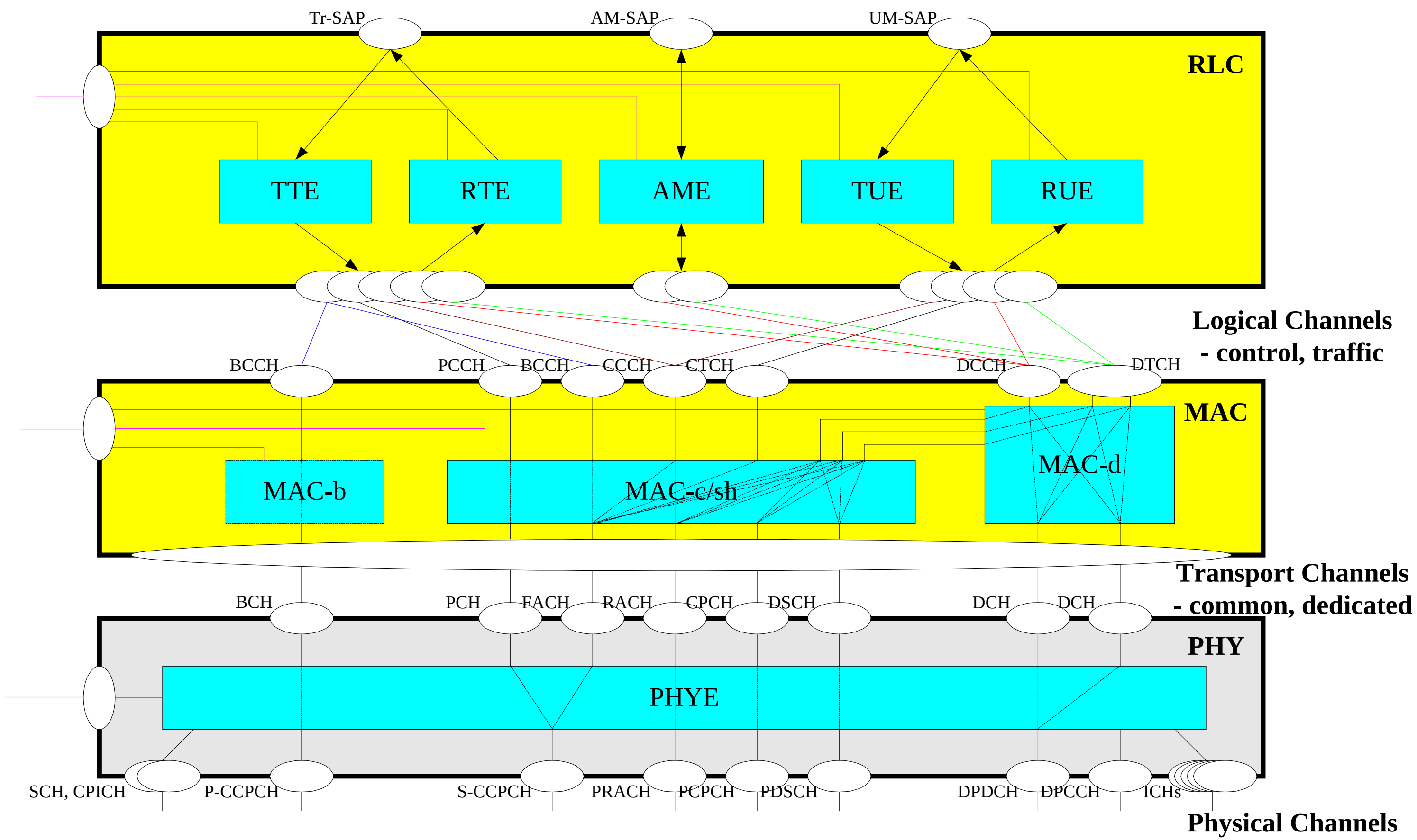


- Information transfer services to MAC and higher layers
- Macro-diversity distribution/combining, soft handover execution, FEC encoding/decoding and interleaving/deinterleaving of transport channels, multiplexing of transport channels and demultiplexing of coded composite transport channels (CCTrCHs), rate matching, mapping of CCTrCHs on physical channels, modulation/demodulation and spreading/ despreading of physical channels, closed loop power control, ...

Classification of Channels (1)

- Logical channel defined by the type of information transferred
  - information stream dedicated to the transfer of a specific type of information over the radio interface
- Transport channel(TrCH)
  - channel offered by the physical layer to Layer 2 for data transport between peer L1 entities
  - classification of how and with which characteristics data are transferred on the physical layer
- Physical channel(PhCH)
  - defined by code, frequency, and relative phase(in the uplink)
  - required to support variable bit rate TrCHs to offer bandwidth-on-demand services and to be able to multiplex several services to one connection

Classification of Channels (2)



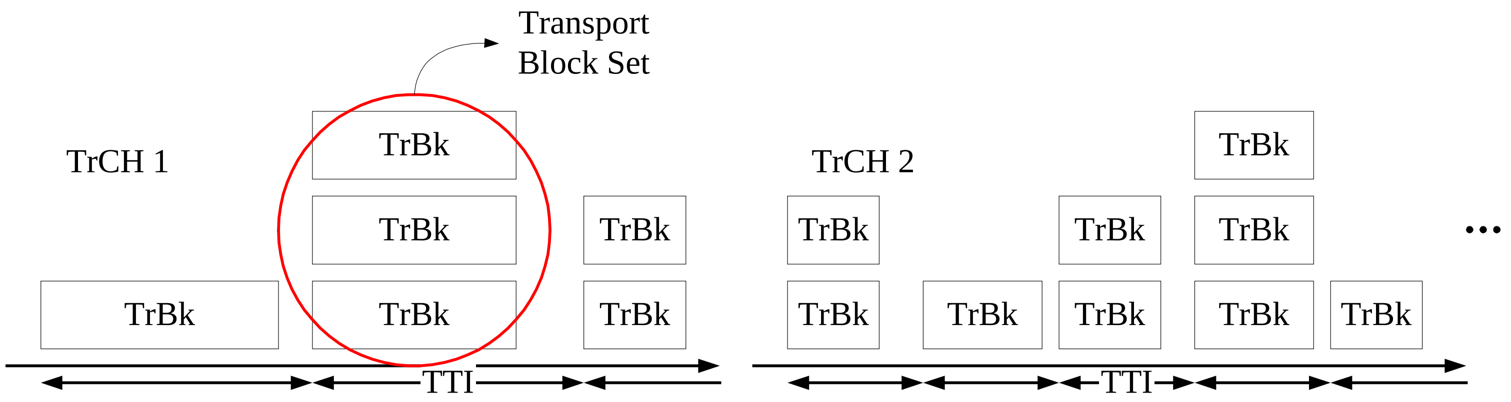
Logical Channels

- Control channels(CCHs) to transfer control plane information
  - BCCH(broadcast CCH) for broadcasting information
  - PCCH(paging CCH) for paging information
  - DCCH(dedicated CCH) for dedicated control information
    - point-to-point bidirectional channel
  - CCCH(common CCH) for common control information
    - channel mapped onto RACH/FACH transport channels
- Traffic channels(TCHs) to transfer user plane information
  - DTCH(dedicated TCH) for user information
    - point-to-point bidirectional channel
  - CTCH(common TCH) for dedicated user information to all or a group of specified UEs
    - point-to-multipoint unidirectional channel

Transport Channels

- Dedicated channels reserved for a specific UE only
  - DCH(dedicated CH) for user information including data for the actual service as well as higher layer control information
- Common (and shared) channels not dedicated to a specific UE
  - BCH(broadcast CH) for the information specific to the UTRAN
  - FACH(forward access CH) for control information to UEs known to locate in the given cell
  - PCH(paging CH) for data relevant to the paging procedure
  - DSCH(downlink shared CH) for dedicated user data and/or control information : channel shared by several UEs
  - RACH(random access CH) for control information from UE
  - CPCH(common packet CH) for packet-based user data : channel shared in a time division manner by several UEs

Terminology about Transport Channels (1)



- Transport block(TrBk) or MAC PDU
  - basic data unit exchanged between L1 and MAC
- Transport block set or MAC PDU set
  - set of transport blocks exchanged between L1 and MAC at the same time instance using the same transport channel
- Transmission time interval(TTI)
  - inter-arrival time of transport block sets

Terminology about Transport Channels (2)

- Transport format(TF)
  - format offered by L1 to MAC (and vice versa) for the delivery of a transport block set during a TTI on a TrCH
  - dynamic part : transport block size, transport block set size
  - semi-static part : TTI, error protection scheme to apply, size of CRC
- Transport format set(TFS)
  - set of transport formats associated to a TrCH

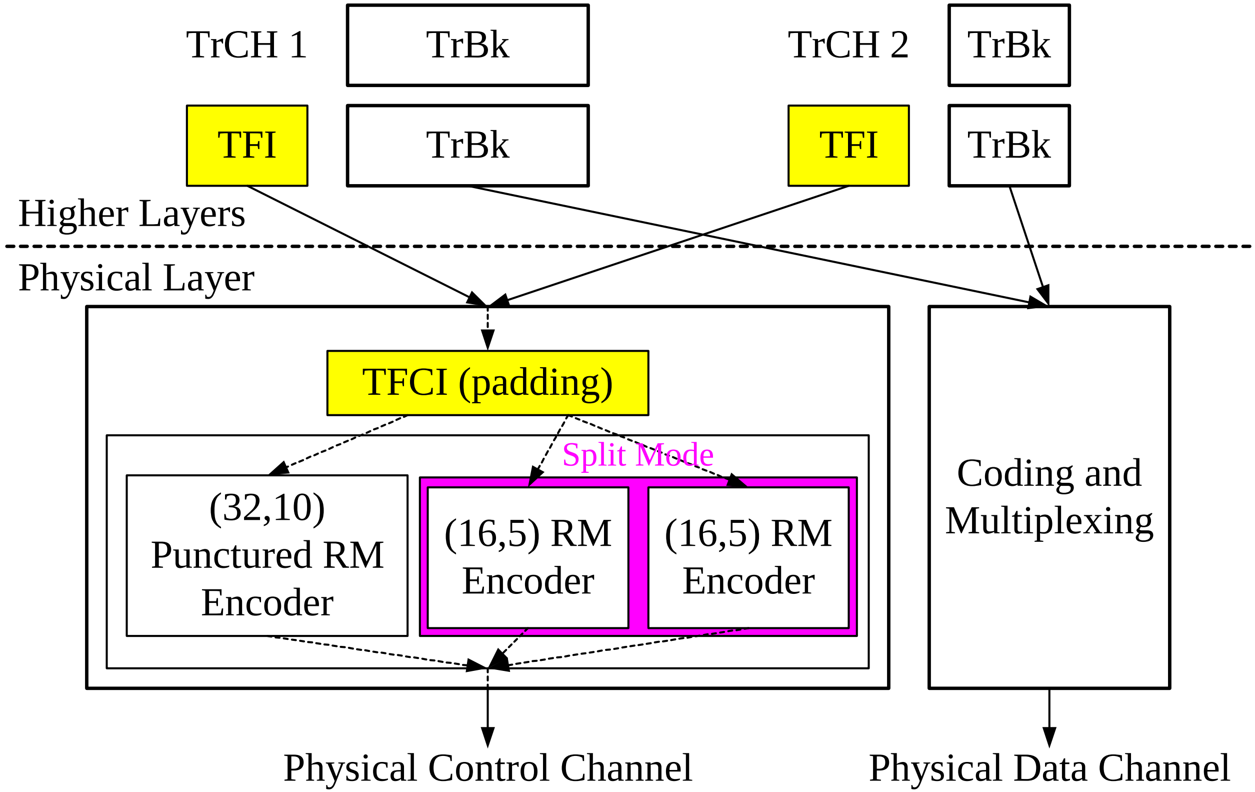
Variable bit rate on a TrCH may be achieved by changing between each TTI one of the transport block size and both the transport block size and the transport block set size.

Terminology about Transport Channels (3)

- Transport format combination(TFC)
  - combination of currently valid transport formats that can be submitted simultaneously to L1 for transmission on a CCTrCH of an UE
- Transport format combination set(TFCS)
  - set of transport format combinations on a CCTrCH
- Transport format indicator(TFI)
  - label for a specific transport format within a TFS
- Transport format combination indicator(TFCI)
  - representation of the current transport format combination
  - allows the receiver to perform TFCI based detection

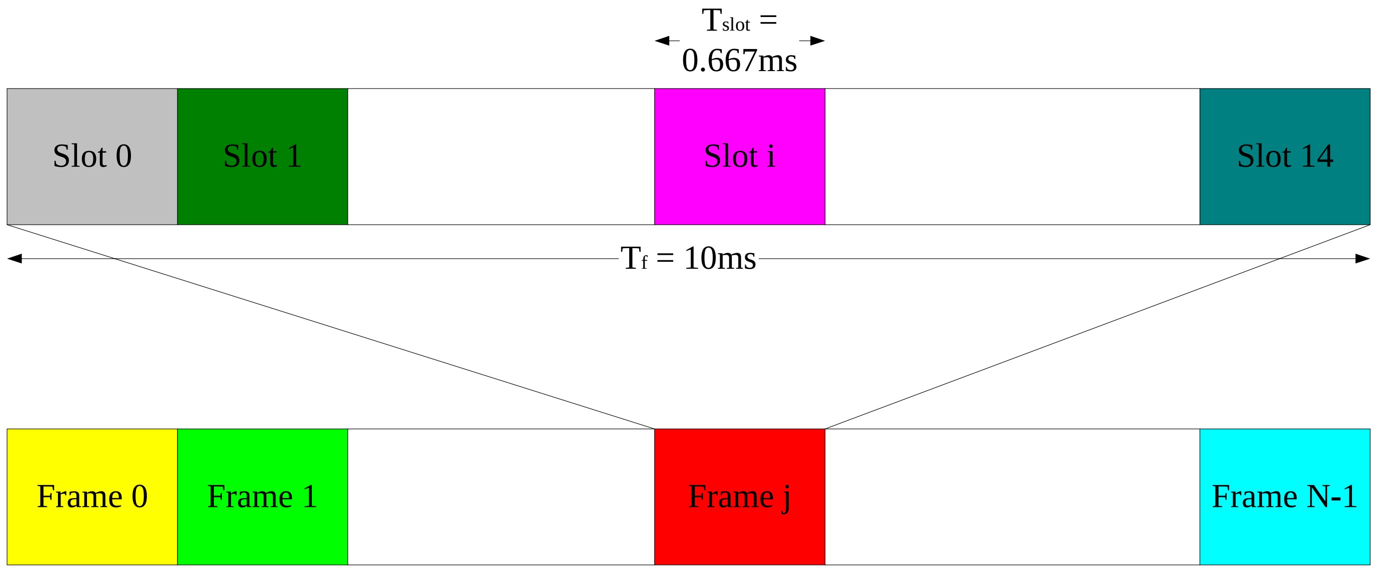
If TFCI is not used, the receiver must perform explicit blind detection or guided detection.

TFI and TFCI

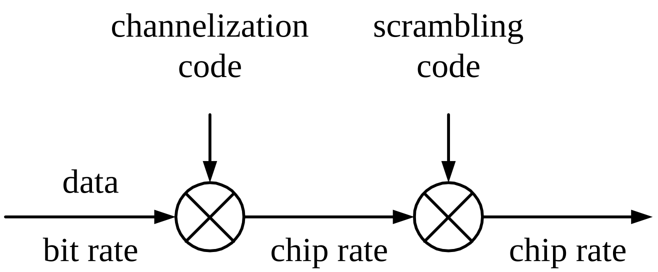

TrCH 1
TrBk
TFI
TrBk
TrCH 2
TrBk
TFI
TrBk
Higher Layers
Physical Layer
TFCI (padding)
Split Mode
(32,10) Punctured RM Encoder
(16,5) RM Encoder
(16,5) RM Encoder
Coding and Multiplexing
Physical Control Channel
Physical Data Channel

Frame Structure

- Radio frame : 15 slots, 38400 chips
- Slot : 0.667ms time slot, 2560 chips

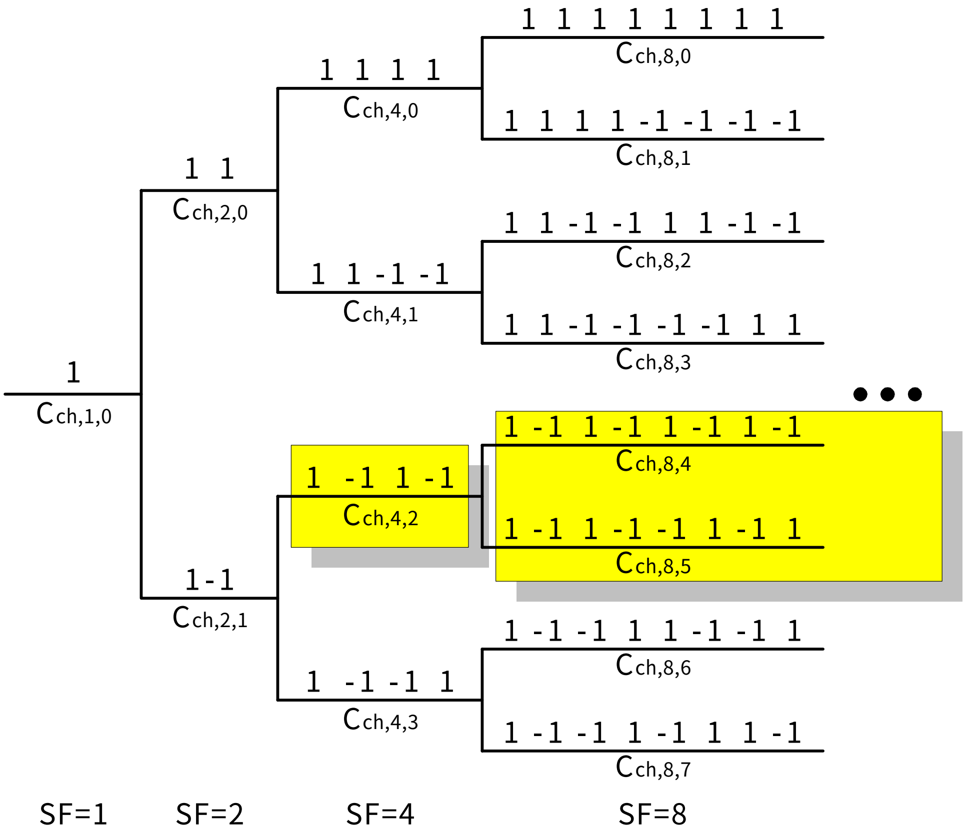


Spreading Procedure



- Channelization (or spreading) code : OVSF code
  - separates transmissions from a single source
  - transforms every data into a number of chips
  - increases the bandwidth of the signal
- Scrambling code : Gold code, Extended S(2) code
  - separates transmissions from different sources
  - applied to the spread signal

OVSF(Orthogonal Variable Spreading Factor) Code



Gold Code

- Sequences with good periodic cross-correlation

  (For asynchronous CDMA, a large set of sequences that have small cross-correlation is required.)
- Preferred-pair of m-sequences with identical period
  - b : m-sequence of length $N=2^n-1$, $b' = b[q]$: sequence obtained by sampling every qth symbol of b
    - $n \neq 0 \bmod 4$ (n : odd or n=2 mod 4)
    - q : odd and either $q=2^k+1$ or $q=2^{2k}-2^k+1$
    - gcd(n,k) = 1 for n odd, 2 for n=2 mod 4
- Set of Gold code = $\{b, b', b \oplus b', b \oplus T^{-1}b', b \oplus T^{-2}b', \ldots, b \oplus T^{-(N-1)}b'\}$,

  $T^{-1}b'$: a left cyclic shift of b'
- Cross-correlation values = $-t(n)/N$, $-1/N$, $(t(n)-2)/N$

  $t(n) = 1+2^{0.5(n+1)}$ for n odd, $1+2^{0.5(n+2)}$ for n even

Downlink Physical Channels

- Coding and Multiplexing
- Spreading and Modulation
- Downlink Physical Channels

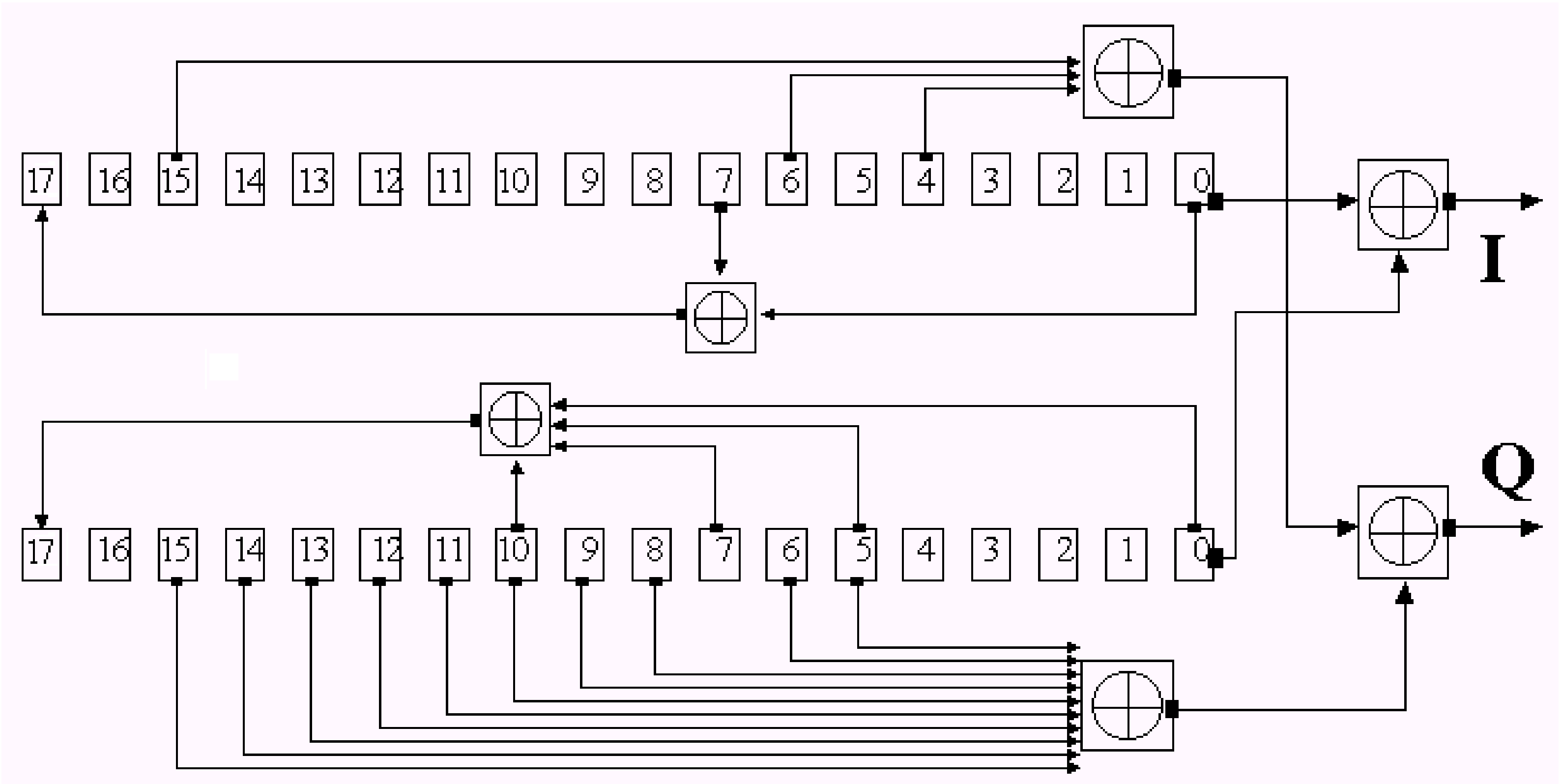
Downlink Scrambling Codes

- Each cell uses a different scrambling code.
- For $0 \le n \le 2^{18}-2$, the nth scrambling code uses a 10ms segment of the nth Gold sequence.
- nth Gold sequence
  - $z_n(i) = (x((i+n) \bmod (2^{18}-1)) + y(i)) \bmod 2,\ i=0,1,\ldots, 2^{18}-2$

    x(i), y(i) : ith symbol in two binary m-sequences
  - initial conditions
    - $x(0)=1,\ x(1)=\ldots=x(17)=0,\ y(0)=y(1)=\ldots=y(17)=1$
  - real valued sequences
    - $Z_n(i) = -2z_n(i) + 1$
- nth complex scrambling sequence
  - $S_{dl,n}(i) = Z_n(i) + jZ_n((i+2^{17}) \bmod (2^{18}-1)),\ i=0,1,\ldots,38399$

Downlink Scrambling Code Generator

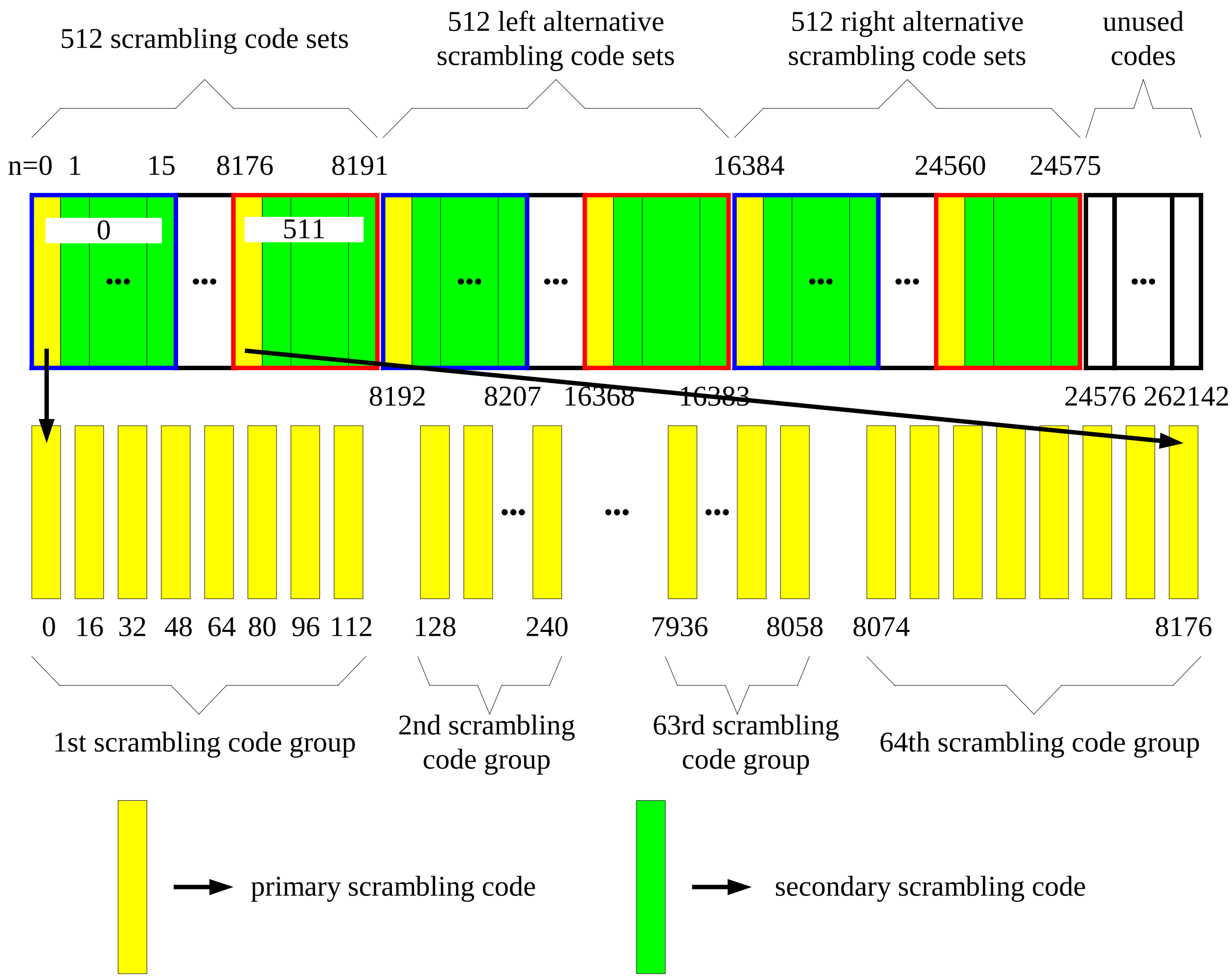
- nth complex scrambling sequence $S_{dl,n}$ = I+jQ
- I and Q depend on a scrambling number n.



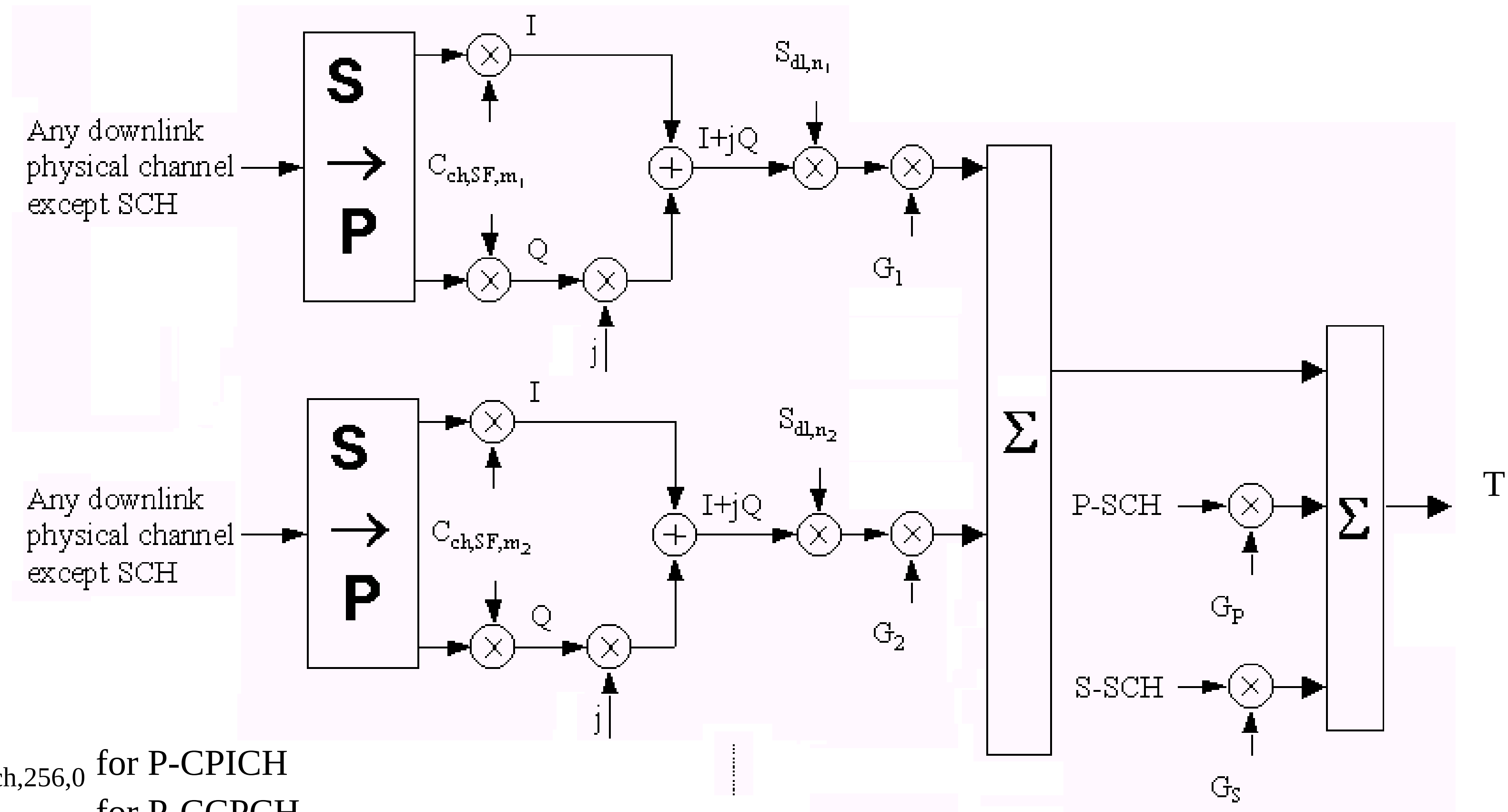
Downlink Scrambling Code

- Complex combination of two 38400-chip (10 ms) segments of a length 2^{18}-1 real Gold code, repeated each frame
- The start of the sequence is time aligned to the beginning of the P-CCPCH frame for all channels.
- Primary codes
  - Used for P-CCPCH, P-CPICH, all ICHs, S-CCPCH carrying PCH
  - May be used for other channels
  - Divided into 64 groups to reduce the cell searching time
  - The S-SCH encodes the group number from which the cell primary code is taken using comma-free RS code.
- Secondary codes
  - 15 secondary codes are associated with each primary code.
  - May be used for any channel not specifically assigned to the primary codes above

Scrambling Code Group

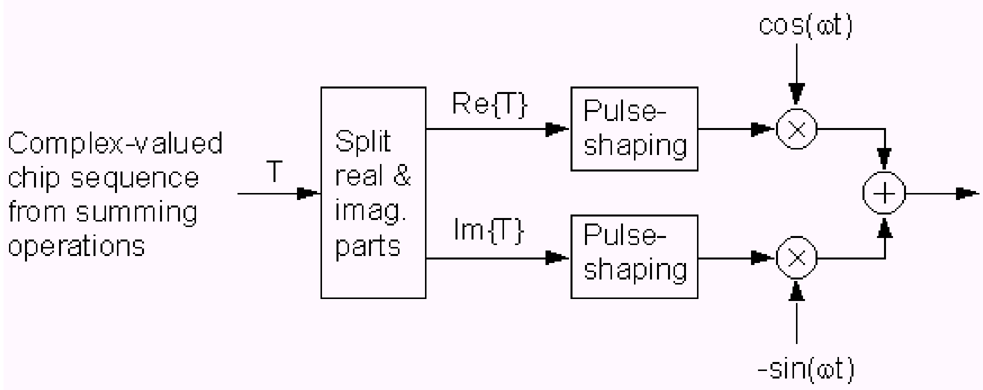


Downlink Spreading



$C_{ch,256,0}$ for P-CPICH
$C_{ch,256,1}$ for P-CCPCH

Downlink Modulation



- QPSK, 16-QAM
- Pulse-shaping filter
  - root-raised cosine(RRC) filter with roll-off α=0.22

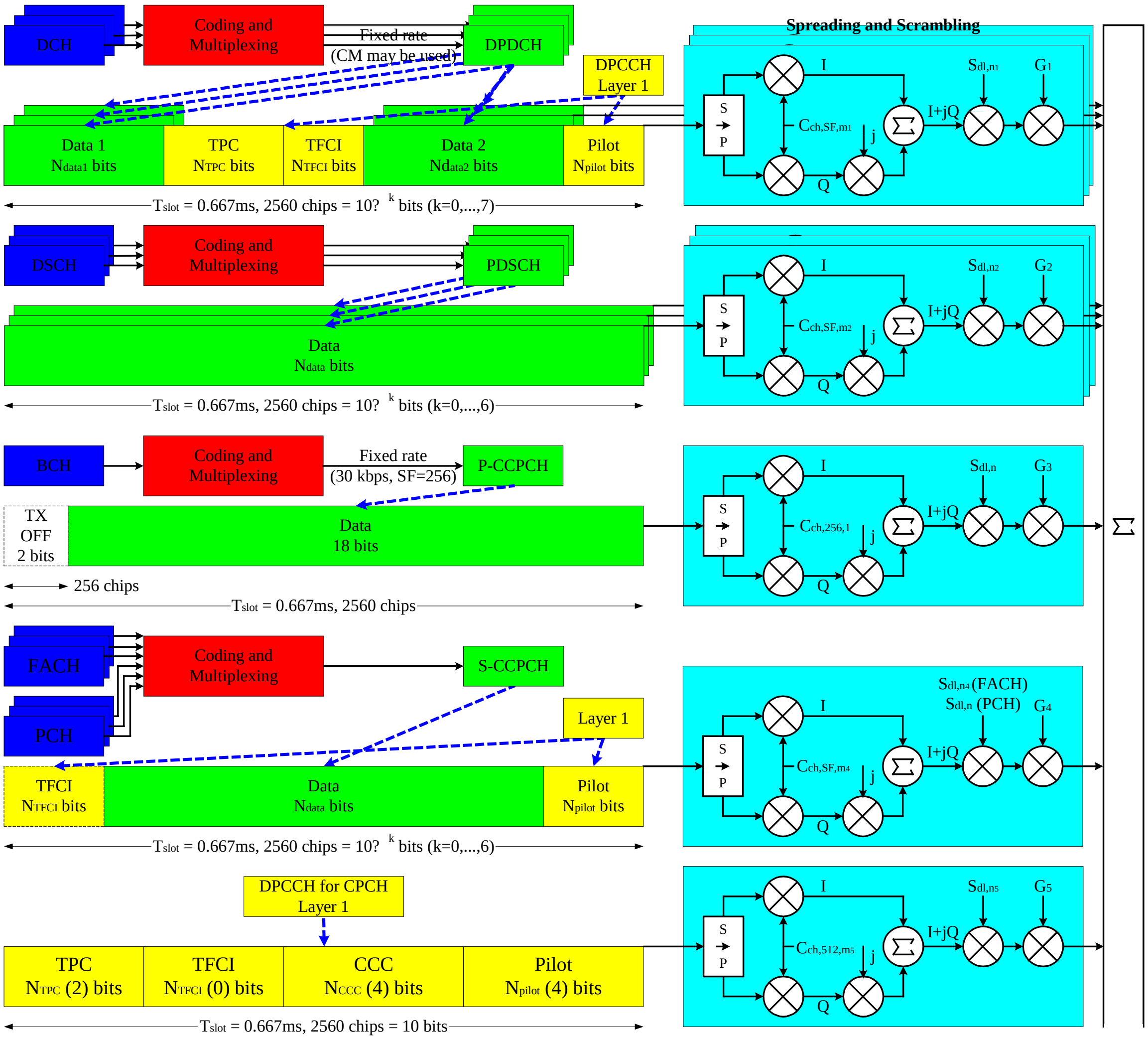
$$RC_0(t) = \frac{\sin\left(\pi \frac{t}{T_c}(1-\alpha)\right) + 4\alpha \frac{t}{T_c}\cos\left(\pi \frac{t}{T_c}(1+\alpha)\right)}{\pi \frac{t}{T_c}\left(1-\left(4\alpha \frac{t}{T_c}\right)^2\right)}$$

$$T_c = \frac{1}{chiprate} \approx 0.26042\,\mu s$$

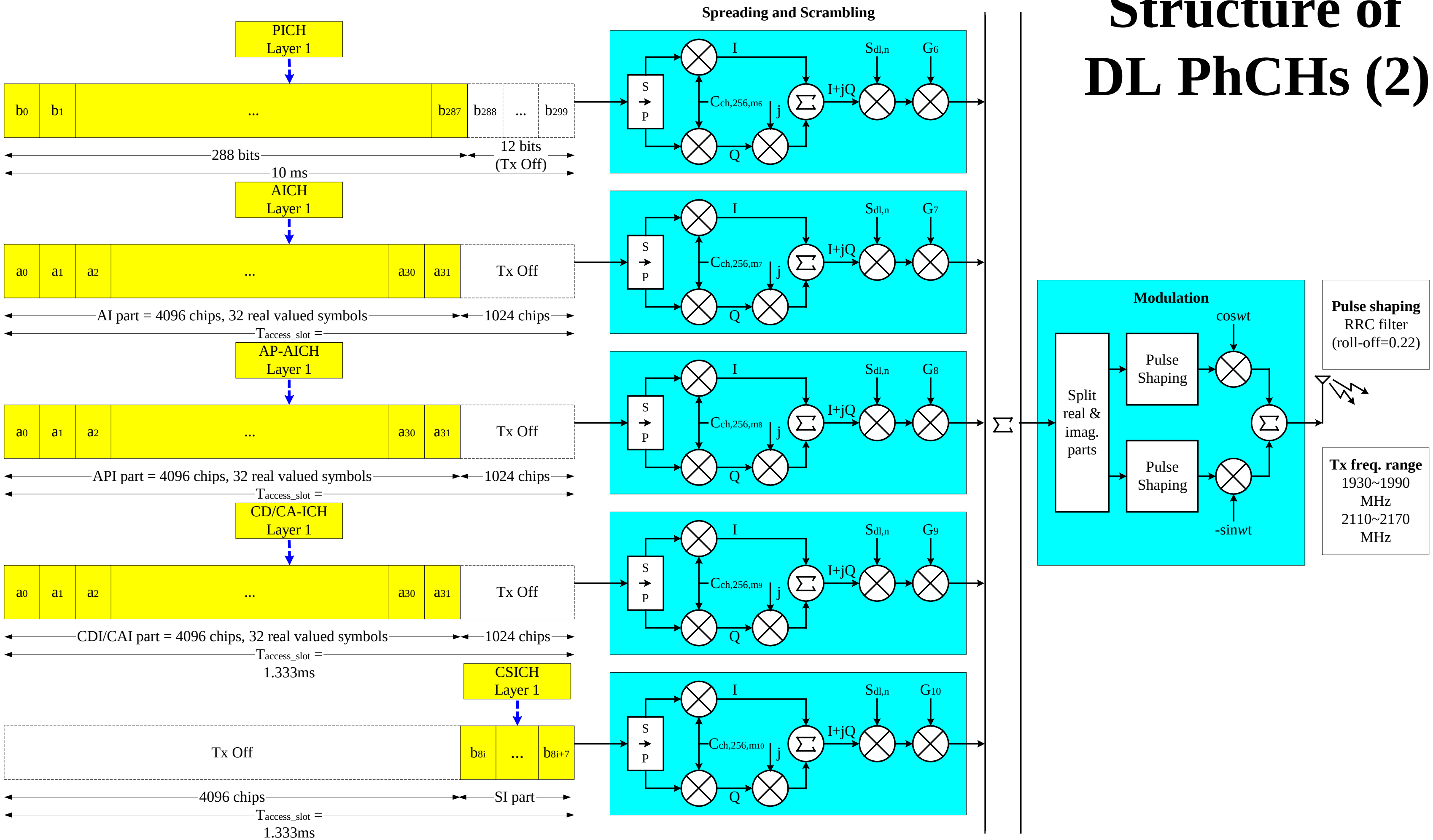
Downlink Physical Channels (DL PhCHs)

- DPCH(dedicated physical channel)
  - DPDCH(dedicated physical data channel)
  - DPCCH(dedicated physical control channel)
- PDSCH(physical downlink shared channel)
- P-CCPCH(primary common control physical channel)
- S-CCPCH(secondary common control physical channel)
- P-CPICH(primary common pilot channel)
- S-CPICH(secondary common pilot channel)
- P-SCH(primary synchronization channel)
- S-SCH(secondary synchronization channel)
- ICHs(indicator channels)
  - AICH(acquisition ICH), PICH(paging ICH), AP-AICH (CPCH access preamble AICH), CD/CA-ICH(CPCH collision detection/channel assignment ICH), CSICH(CPCH status ICH)

Structure of DL PhCHs (1)



Structure of DL PhCHs (2)



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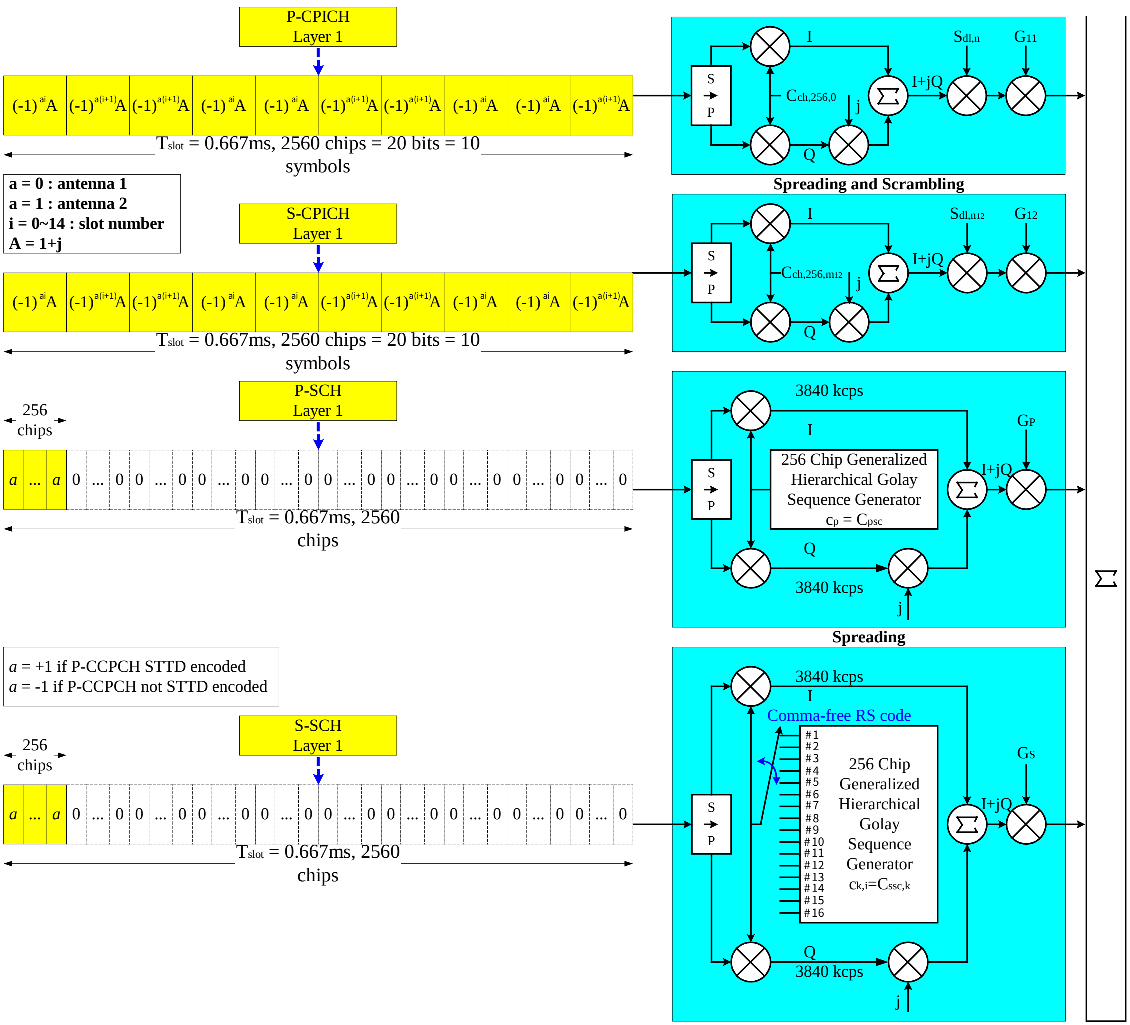
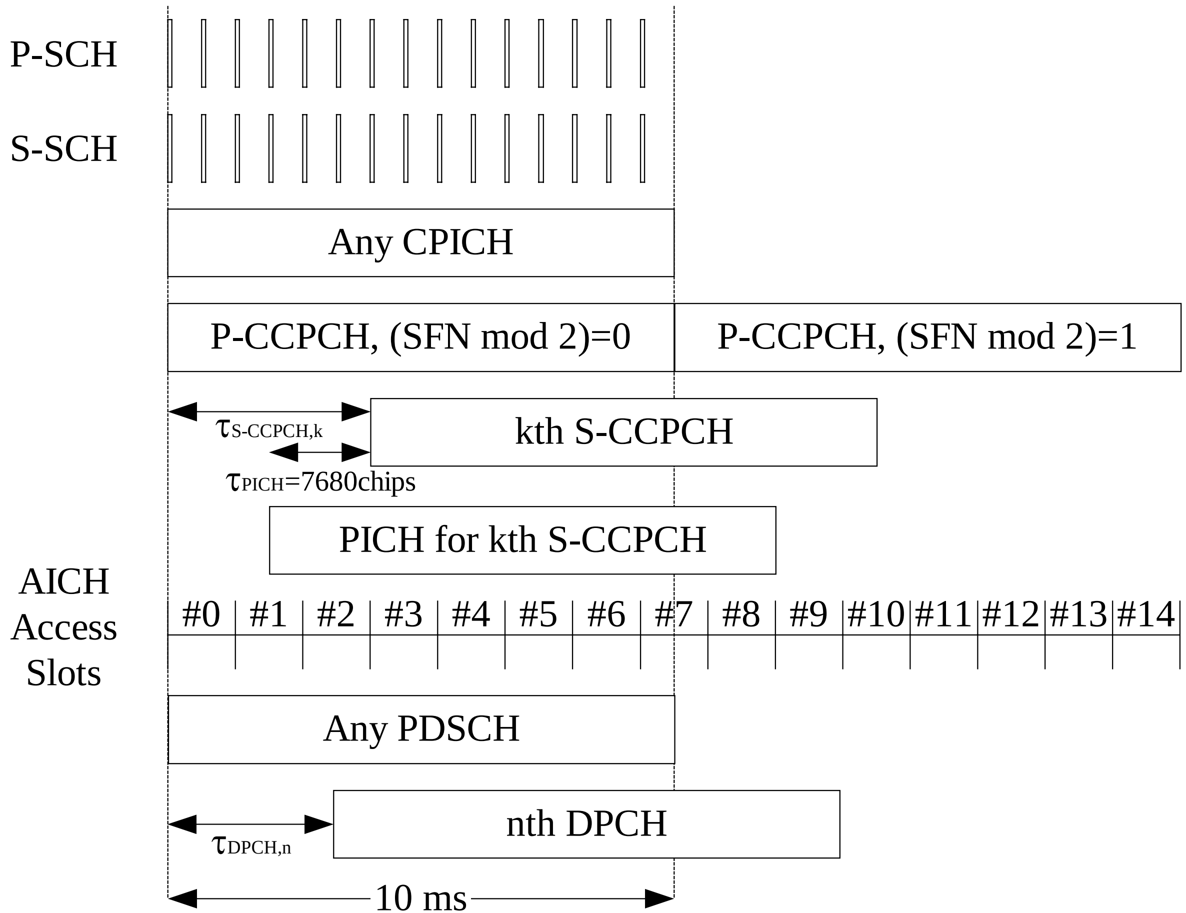
Structure of DL PhCHs (3)



Timing Relationship among DL PhCHs



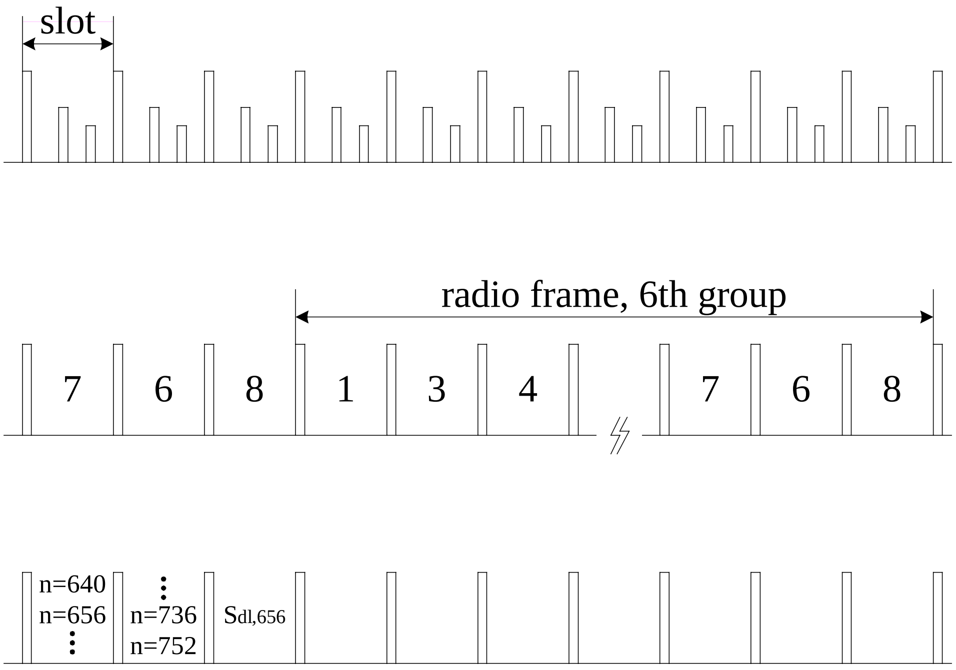
Initial Cell Search

- Slot synchronization based on P-SCH
  - Acquire a timing reference using two matched filters.
- Frame synchronization and scrambling code group identification based on S-SCH
  - Read a pattern using correlators and an RS decoder.
  - Identify a scrambling code group from the pattern.
- Scrambling code identification based on CPICH
  - Find a primary scrambling code from the identified group using correlators.
- Frequency acquisition based on CPICH
- Cell identification based on P-CCPCH
  - Read the broadcast information.

Target cell search does not need the last two steps.

Cell Search

- Step 1
- Step 2
- Step 3



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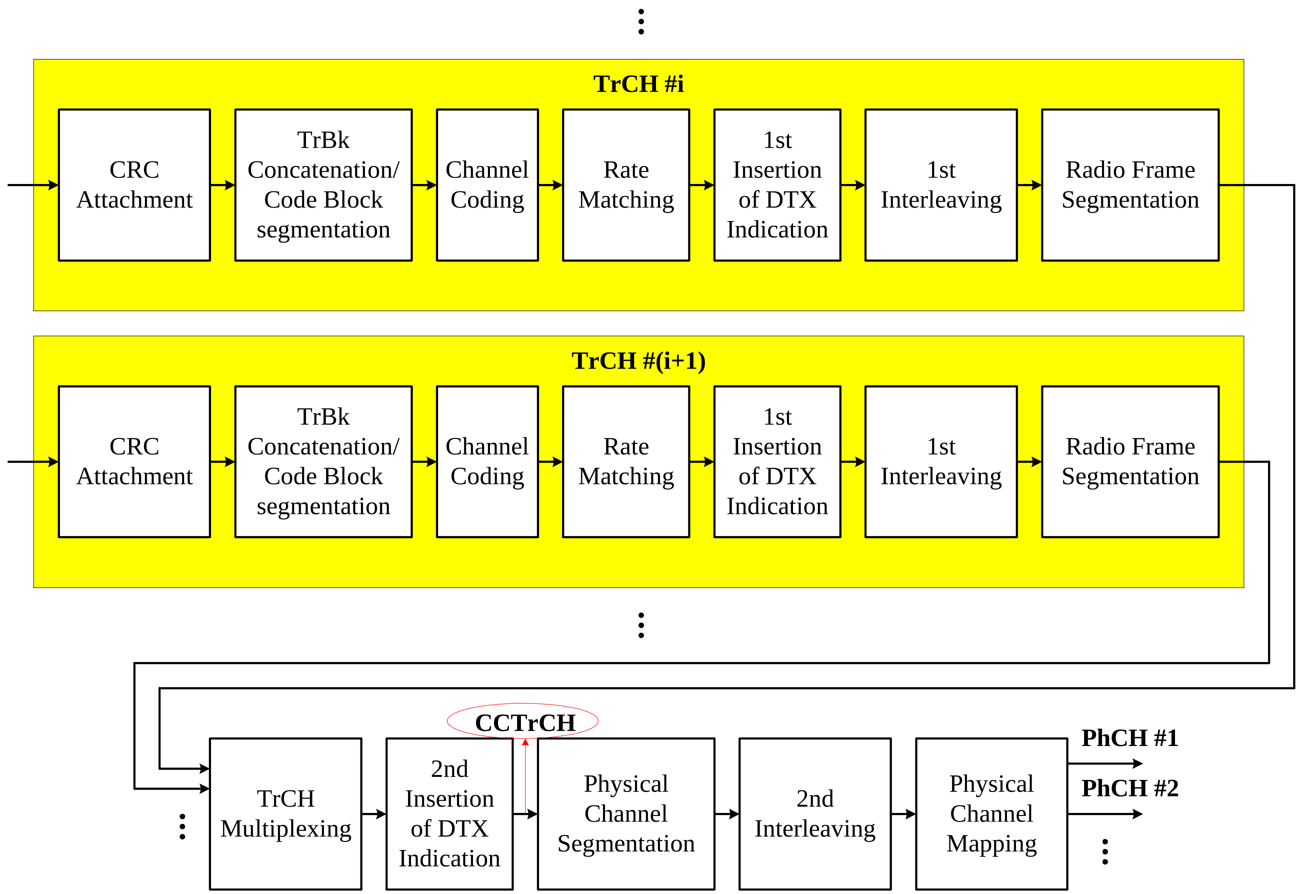
Coding and Multiplexing



Uplink Physical Channels

- Coding and Multiplexing
- Spreading and Modulation
- Uplink Physical Channels

Uplink Scrambling Codes

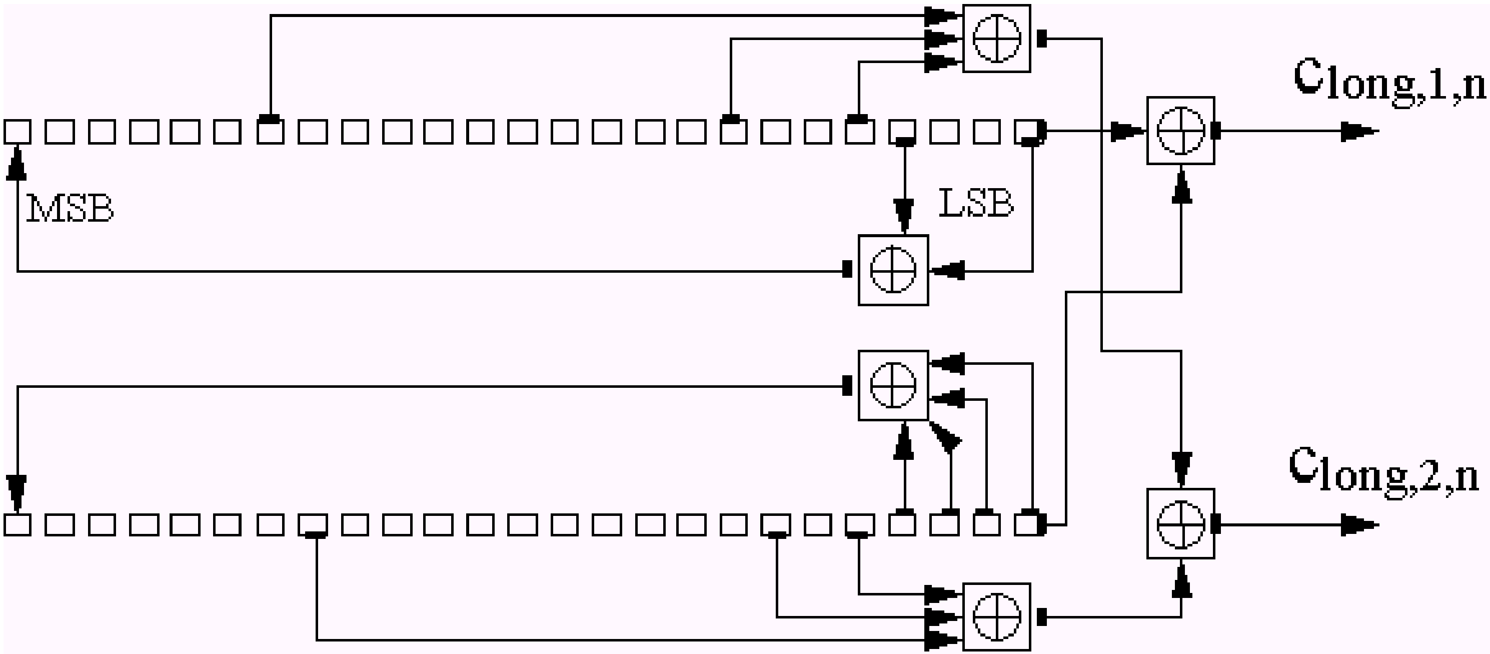
- 2^{24} long and 2^{24} short scrambling codes assigned by higher layers
- Long scrambling codes
  - used in general
  - Gold codes
- Short scrambling codes
  - used to cancel out the power from all other mobiles at the cell (joint or multiuser detection)
  - extended S(2) codes

Long Scrambling Codes

- nth Gold sequence, $0 \le n = n_{23} \ldots n_0 \le 2^{24}-1$
  - $z_n(i) = x_n(i) + y(i) \bmod 2,\ i=0,1,\ldots,\ 2^{25}-2$

    $x_n(i)$, $y(i)$: ith symbol in two binary m-sequences
  - initial conditions
    - $x_n(0)=n_0,\ldots,x_n(23)=n_{23},x_n(24)=1,\ y(0)=y(1)=\ldots=y(24)=1$
  - real valued sequences
    - $c_{long,1,n}(i) = Z_n(i) = -2z_n(i) + 1$
    - $c_{long,2,n}(i) = Z_n((i + 16777232) \bmod (2^{25}-1))$
- nth complex long scrambling sequence, $0 \le n = n_{23} \ldots n_0 \le 2^{24}-1$
  - $C_{long,n}(i) = c_{long,1,n}(i)(1+j(-1)^i c_{long,2,n}(2\lfloor i/2 \rfloor)),\ i=0,1,\ldots,\ 2^{25}-2$

Long Scrambling Sequence Generator



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Extended Quaternary S(2) Codes

- nth quaternary S(2) sequence, $0 \le n=n_{23}...n_0 \le 2^{24}-1$
  - $z_n(i) = a(i) + 2b(i) + 2d(i) \bmod 4$, $i=0,1,..., 2^8-2$

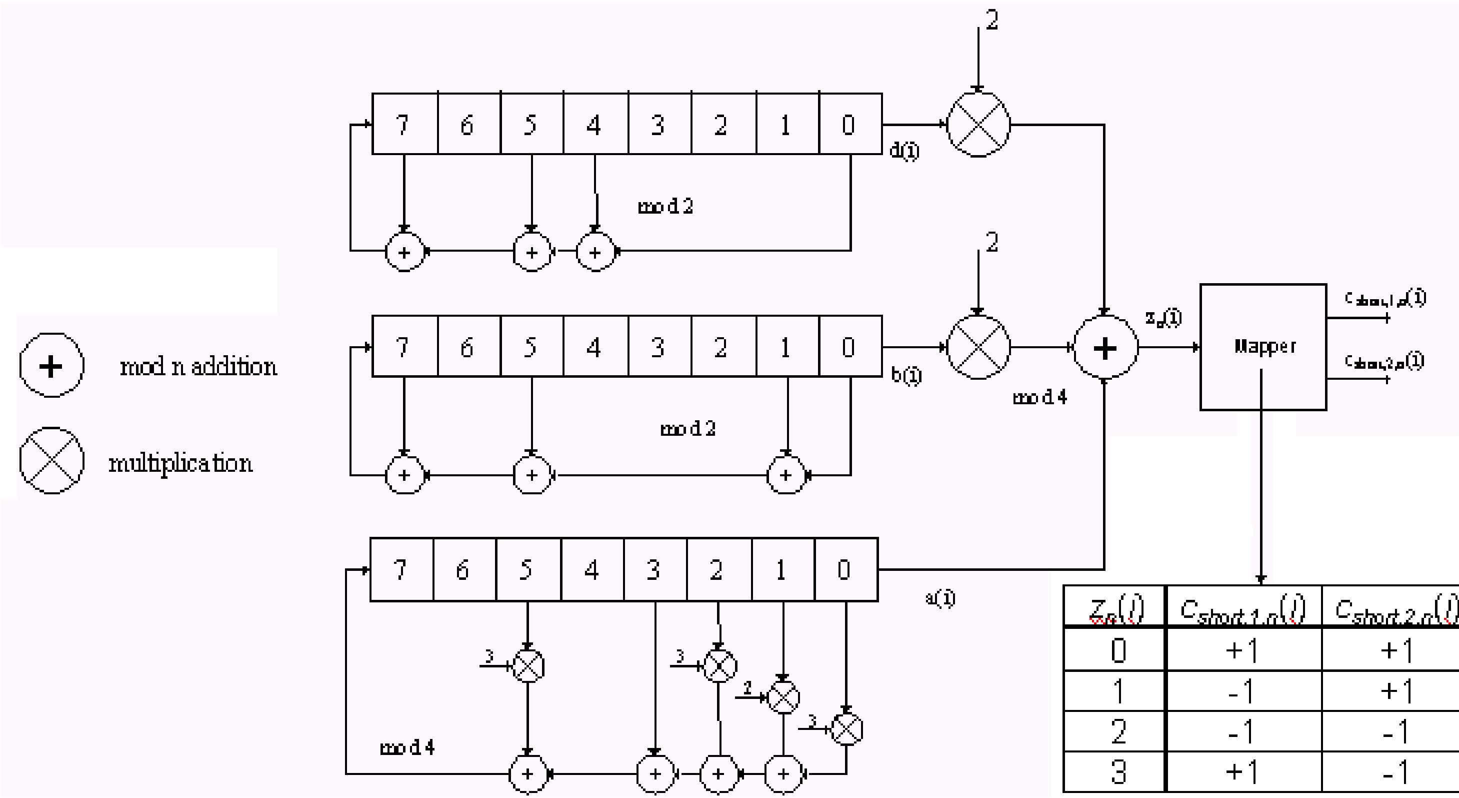
    a(i), b(i), d(i) : ith symbol in three sequences
  - initial conditions
    - $a(0)=2n_0+1 \bmod 4$, $a(i)=2n_i \bmod 4$, $i=1,...,7$, $a(i)=3a(i-3)+a(i-5)+3a(i-6)+2a(i-7)+3a(i-8) \bmod 4$, $i=8,..., 2^8-2$
    - $b(i)=n_{8+i} \bmod 2$, $i=1,...,7$, $b(i)=b(i-1)+b(i-3)+b(i-7)+b(i-8) \bmod 2$, $i=8,9,..., 2^8-2$
    - $d(i)=n_{16+i} \bmod 2$, $i=1,...,7$, $d(i)=d(i-1)+d(i-3)+d(i-4)+d(i-8) \bmod 2$, $i=8,9,..., 2^8-2$
- nth extended quaternary S(2) sequence
  - $z_n(255) = z_n(0)$

Short Scrambling Codes

- Mapping from $z_n(i)$ to $c_{short,1,n}(i)$ and $c_{short,2,n}(i)$
  - $c_{short,1,n}(i) = 1$, $c_{short,2,n}(i) = 1$ for $z_n(i) = 0$
  - $c_{short,1,n}(i) = -1$, $c_{short,2,n}(i) = 1$ for $z_n(i) = 1$
  - $c_{short,1,n}(i) = -1$, $c_{short,2,n}(i) = -1$ for $z_n(i) = 2$
  - $c_{short,1,n}(i) = 1$, $c_{short,2,n}(i) = -1$ for $z_n(i) = 3$
- nth complex short scrambling sequence, $0 \leq n = n_{23} \ldots n_0 \leq 2^{24}-1$
  - $C_{short,n}(i) = c_{short,1,n}(i \bmod 256)$

    $(1+j(-1)^i c_{short,2,n}(2\lfloor (i \bmod 256)/2 \rfloor)),\ i=0,1,\ldots, 2^8-2$

Short Scrambling Sequence Generator

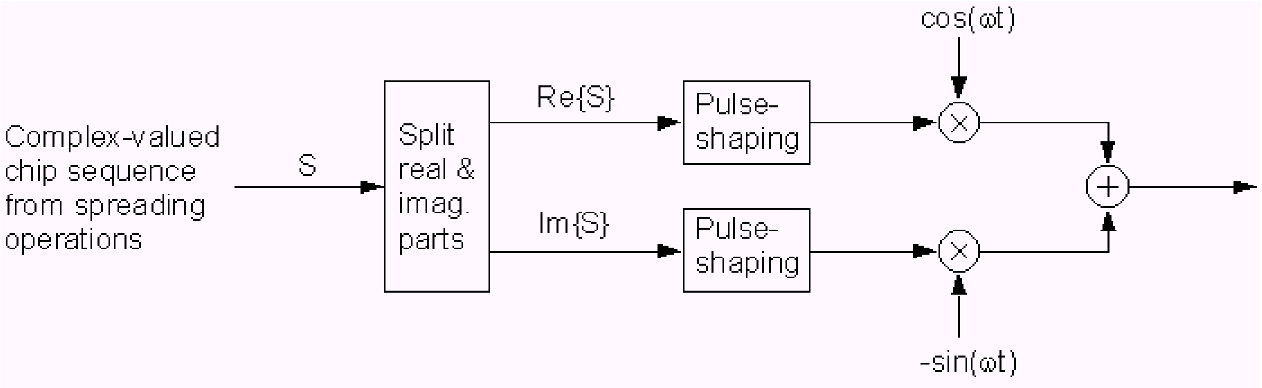


$z_n(i)$	$c_{short,1,n}(i)$	$c_{short,2,n}(i)$
0	+1	+1
1	-1	+1
2	-1	-1
3	+1	-1

HPSK(Hybrid PSK) Scrambling

- For low PAPR
  - single channel : OQPSK, MSK, GMSK, ...
  - multiple channels : HPSK (or OCQPSK)
- Reduction of zero transition probability and symbol repetition probability from 1/4 to 1/8
  - reduces the PAPR of signal for transmission of multiple channels with different amplitude levels

Uplink Modulation



- QPSK (dual code BPSK)
- Pulse-shaping filter
  - root-raised cosine(RRC) filter with roll-off α=0.22

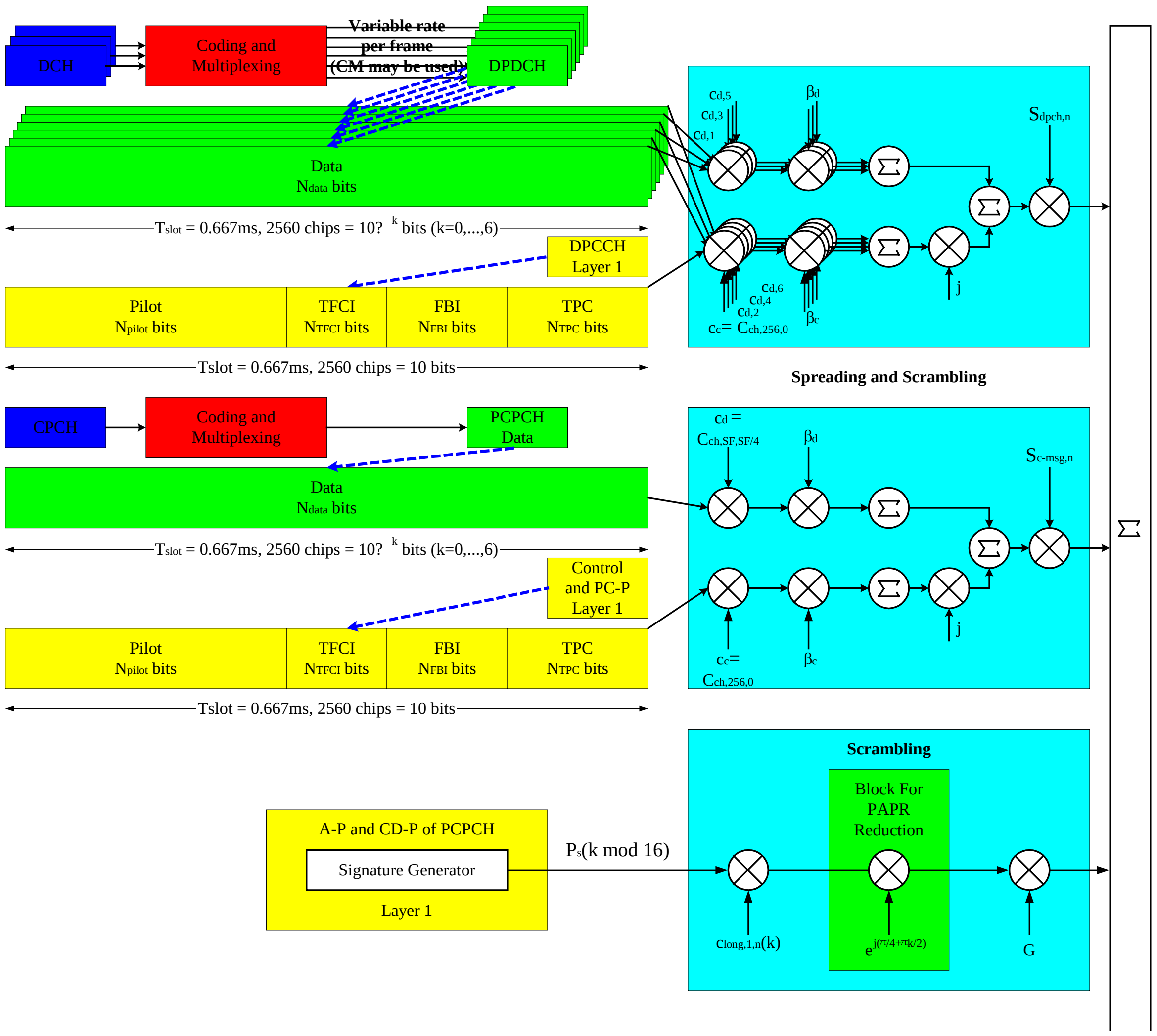
$$RC_0(t) = \frac{\sin\left(\pi \frac{t}{T_C}(1-\alpha)\right) + 4\alpha \frac{t}{T_C} \cos\left(\pi \frac{t}{T_C}(1+\alpha)\right)}{\pi \frac{t}{T_C}\left(1 - \left(4\alpha \frac{t}{T_C}\right)^2\right)}$$

$$T_c = \frac{1}{chiprate} \approx 0.26042\,\mu s$$

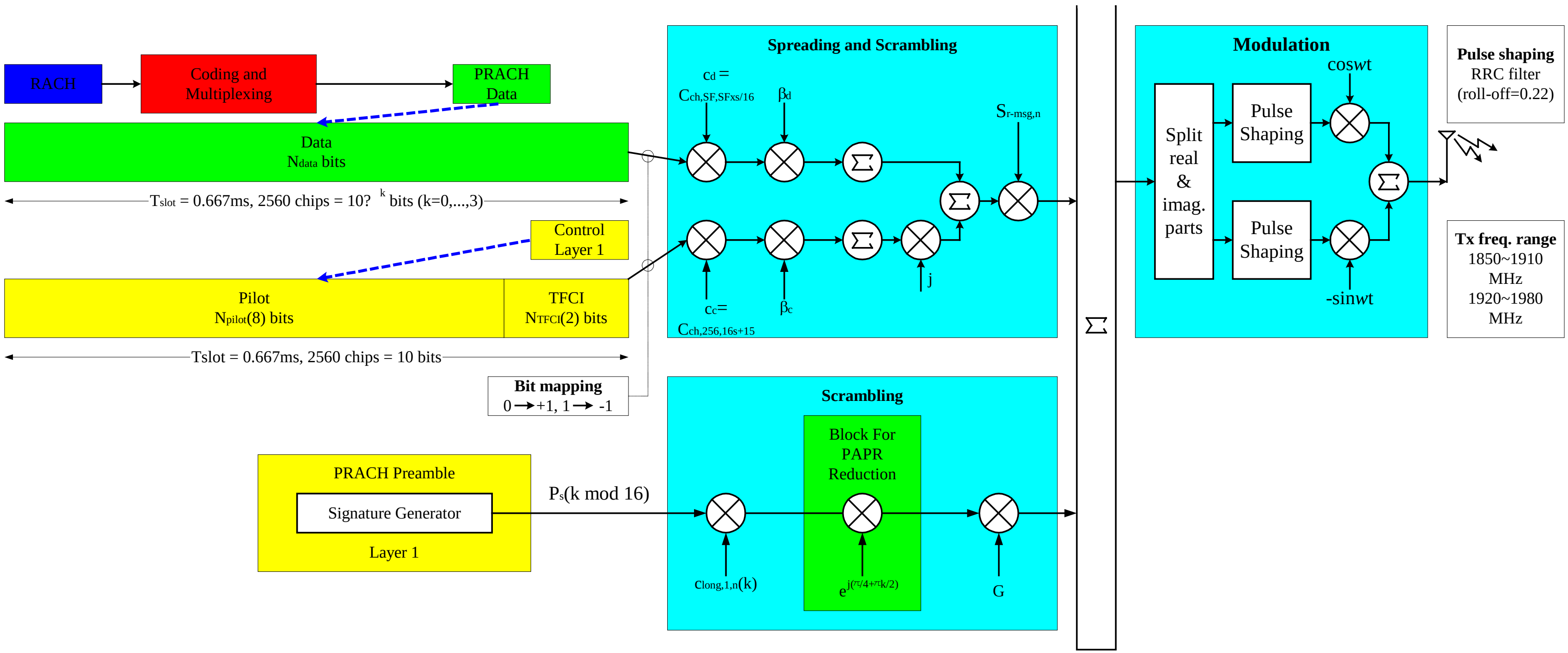
Uplink Physical Channels (UL PhCHs)

- DPCH(dedicated physical channel)
  - DPDCH(dedicated physical data channel)
  - DPCCH(dedicated physical control channel)
- PCPCH(physical common packet channel)
- PRACH(physical random access channel)

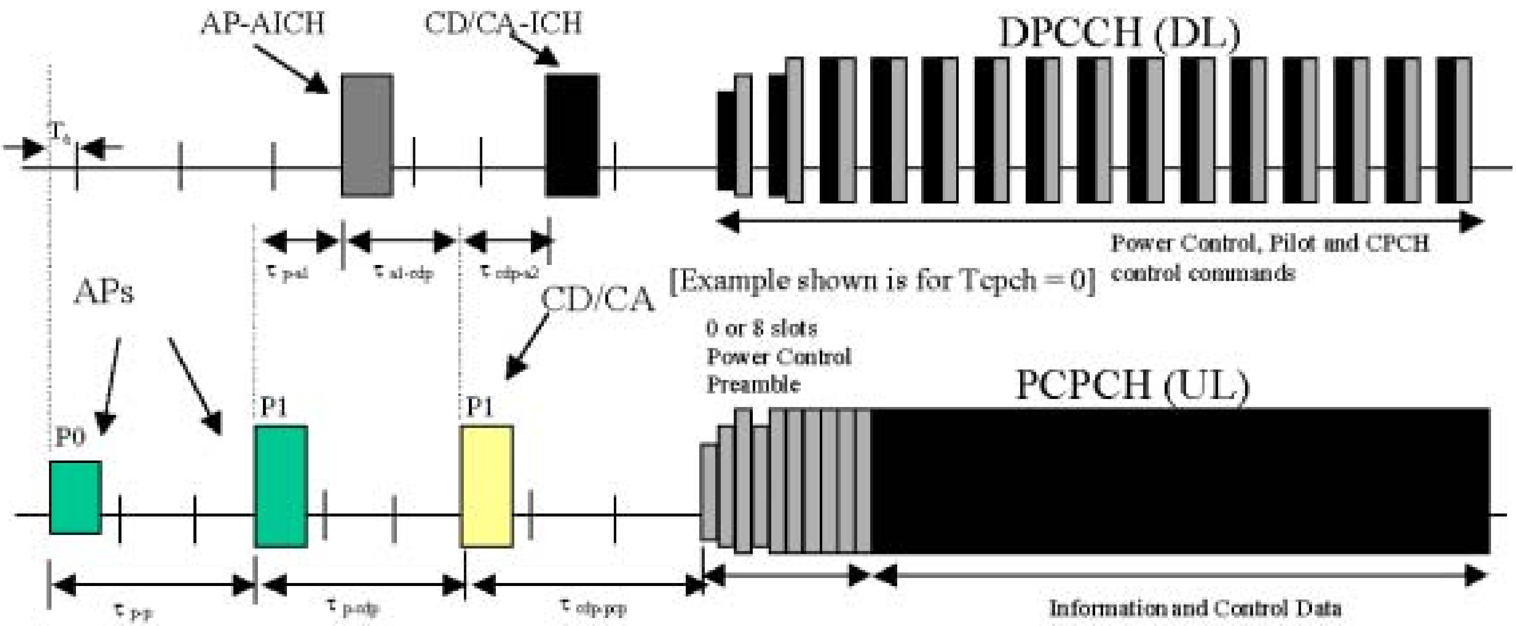
Structure of UL PhCHs (1)



Structure of UL PhCHs (2)



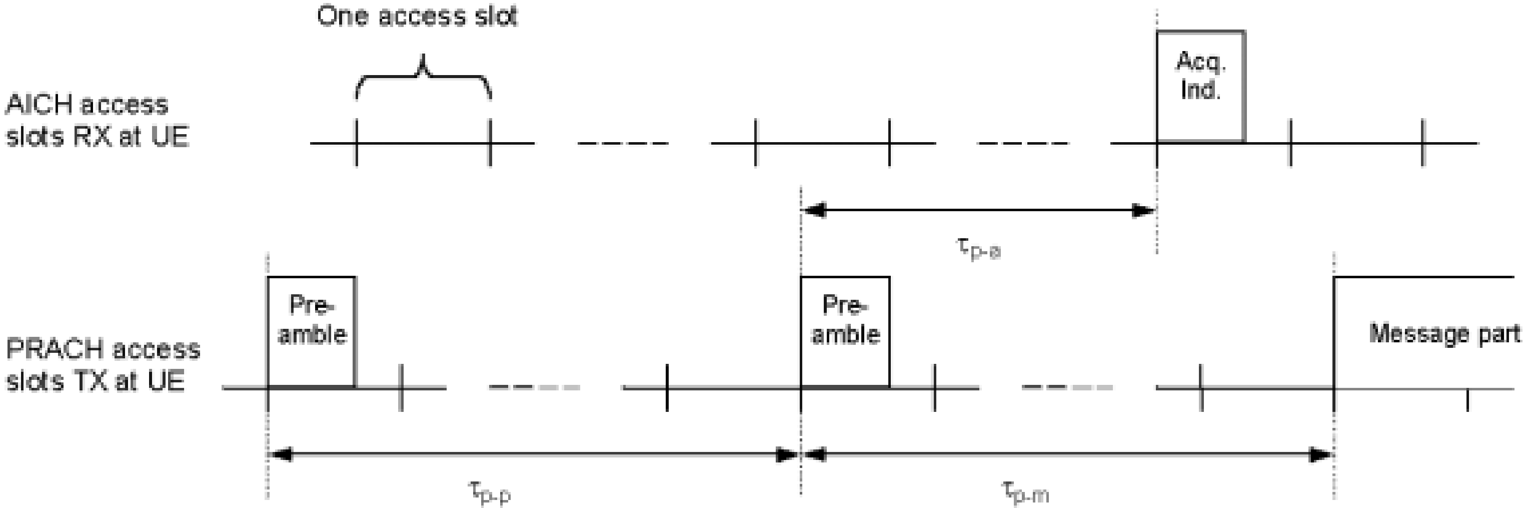
Timing Relationship among PCPCH and AP-AICH, CD/CA-ICH (1)



Timing Relationship among PCPCH and AP-AICH, CD/CA-ICH (2)

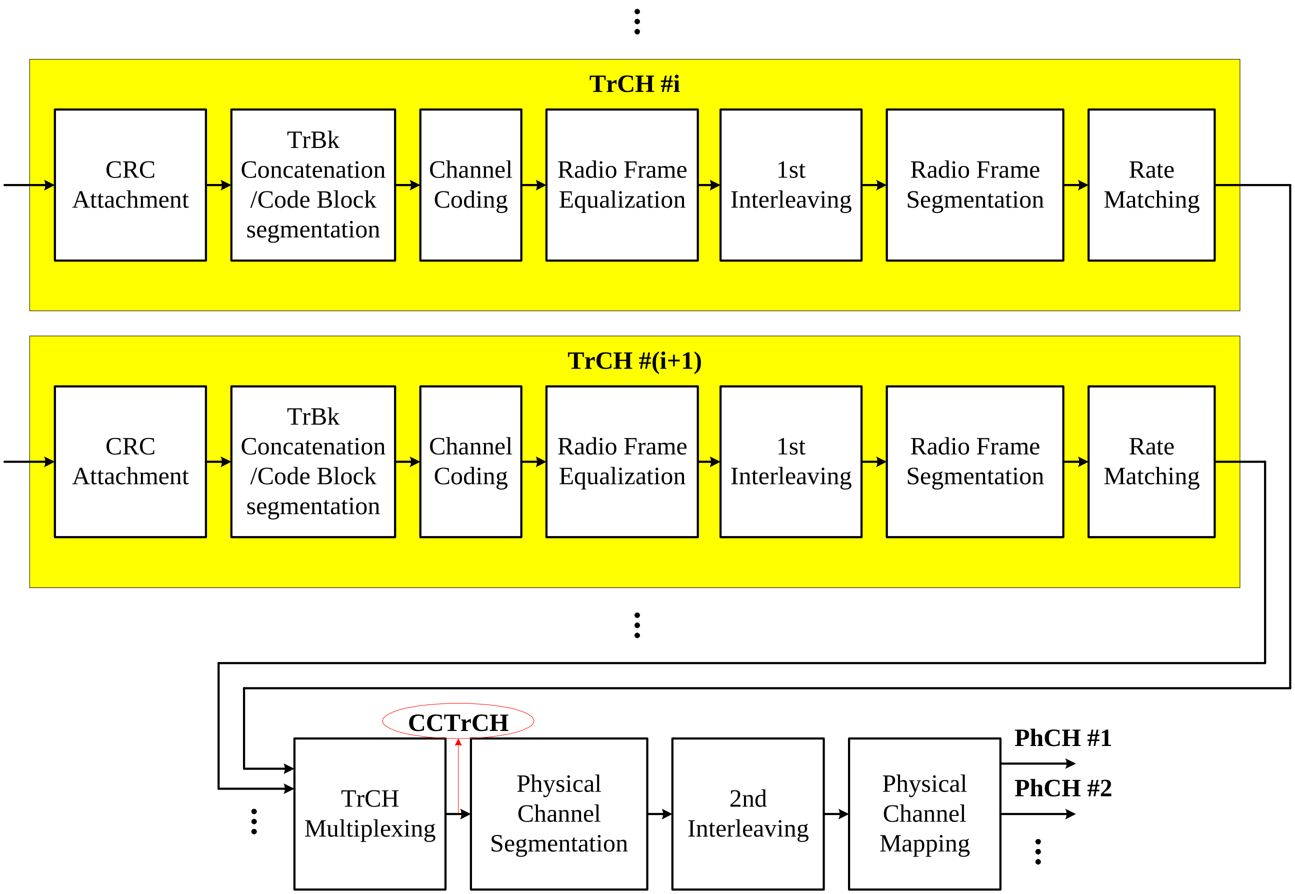
- T_{cpch} : identical to AICH_Transmission_Timing
- a1 : AP-AICH, a2 : CD/CA-ICH
- 15360 chips + 5120 chips × T_{cpch} ≤ $\tau_{p\text{-}p}$ ≤ 5120 chips × 12
- $\tau_{p\text{-}a1}$ = 7680 chips for T_{cpch} = 0 or 12800 chips for T_{cpch} = 1
- $\tau_{a1\text{-}cdp} \geq \tau_{a1\text{-}cdp,min}$ = 7680 chips
- $\tau_{p\text{-}cdp} \geq \tau_{p\text{-}cdp,min}$ = 15360 chips for T_{cpch} = 0 or
  20480 chips for T_{cpch} = 1
- $\tau_{cdp\text{-}a2}$ = 7680 chips for T_{cpch} = 0 or 12800 chips for T_{cpch} = 1
- $\tau_{cdp\text{-}pcp}$ = 15360 chips for T_{cpch} = 0 or 20480 chips for T_{cpch} = 1

Timing Relationship between PRACH/AICH



- Access slot : 5120 chips
- AICH_Transmission_Timing = 0(or 1) : parameter signaled by higher layers
  - $\tau_{p\text{-}p} \geq \tau_{p\text{-}p,min}$ = 15360 chips (or 20480 chips)
  - $\tau_{p\text{-}a}$ = 7680 chips (or 12800 chips)
  - $\tau_{p\text{-}m}$ = 15360 chips (or 20480 chips)

Coding and Multiplexing



HSDPA

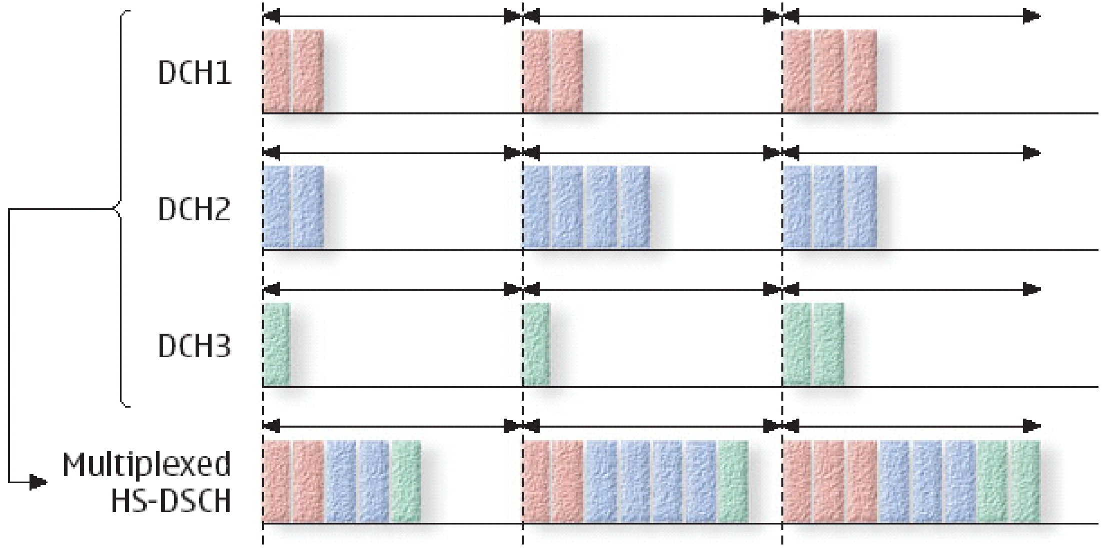
- HSDPA Concepts
- Properties of HSDPA
- Channels and Coding Process of HSDPA

HSDPA Concepts (1)

- High Speed Downlink Packet Access
  - increases downlink data rates
    - up to a theoretical peak data rate of 14.4 Mbps
    - much lower in practice and dependent on cell size
  - improves spectral efficiency for downlink packet data services
  - reduces transmission latency
  - supports multimedia services (packet based) : web browsing, movie streaming, interactive games, car navigation system, etc
- HSDPA UE and R'99 UE can share the same carrier

HSDPA Concepts (2)

- Improved DSCH(Downlink Shared Channel) for packet communication
  - HS-DSCH(High Speed-DSCH)

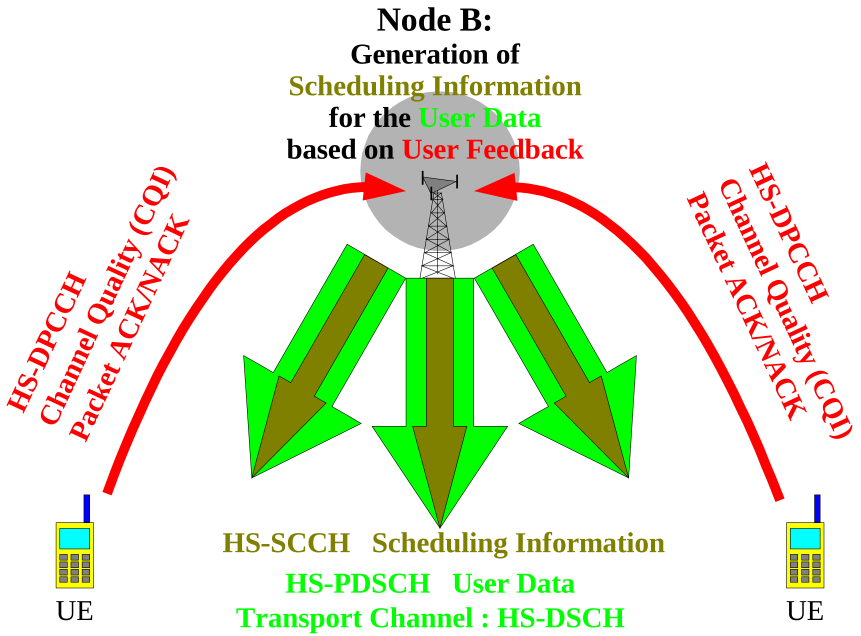


Properties of HSDPA (1)

- Overview
  - new high speed downlink channels
  - a new high speed uplink channel
  - shorter TTI (or radio subframe) of 2ms
  - code multiplexing combined with time multiplexing
  - fast Scheduling in the Node B instead of RNC
  - AMC(Adaptive Modulation and Coding)
  - HARQ(Hybrid Automatic Repeat reQuest)

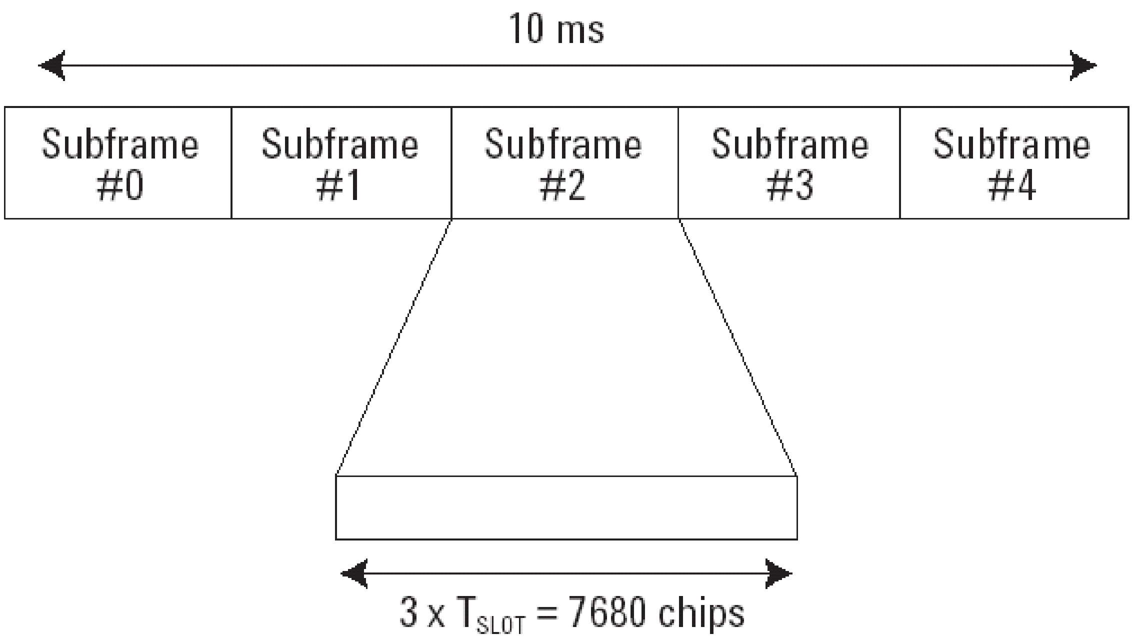
Properties of HSDPA (2)

- HSDPA Channels



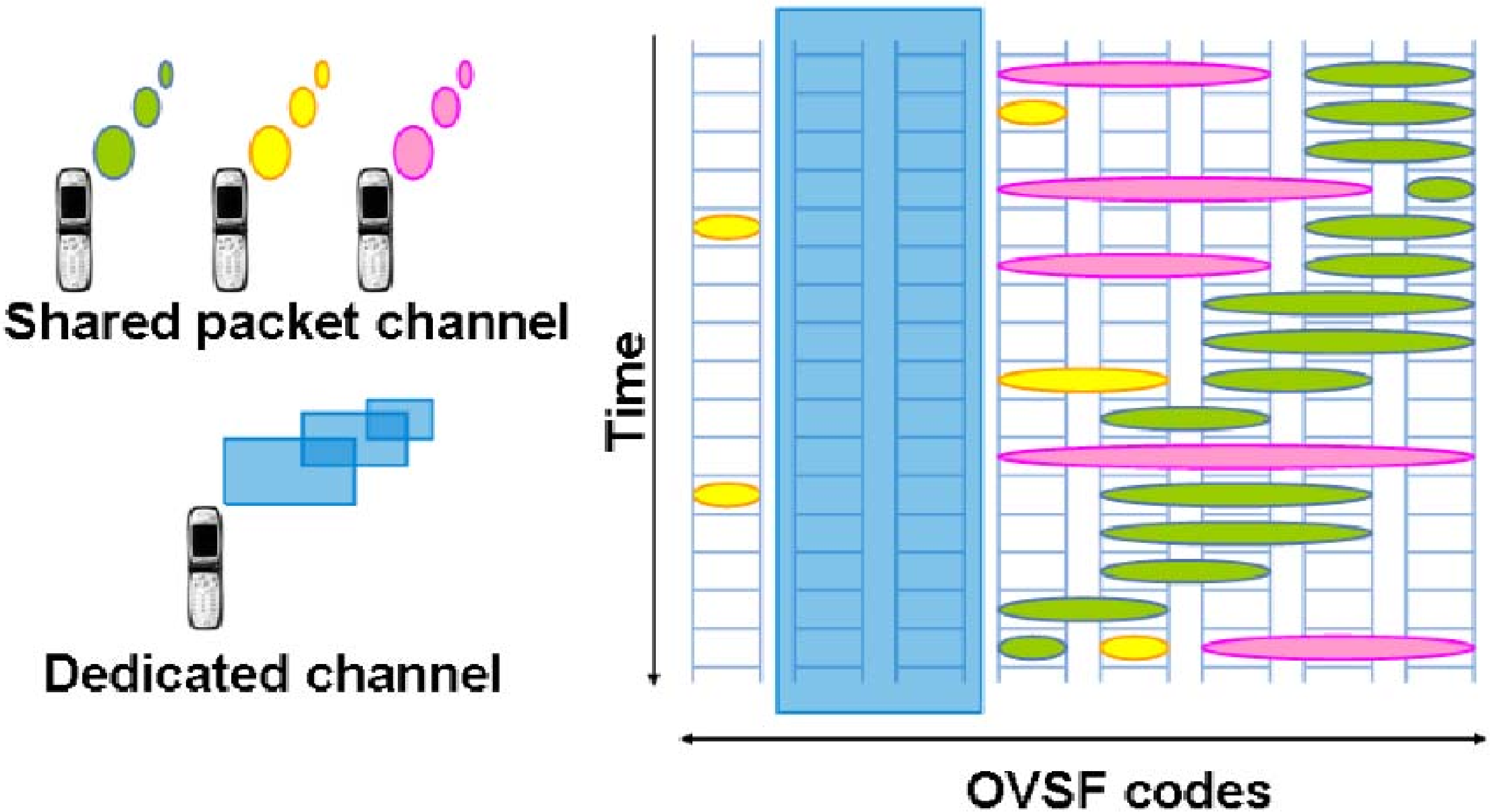
Properties of HSDPA (3)

- Shorter TTI (or radio subframe) of 2 ms



Properties of HSDPA (4)

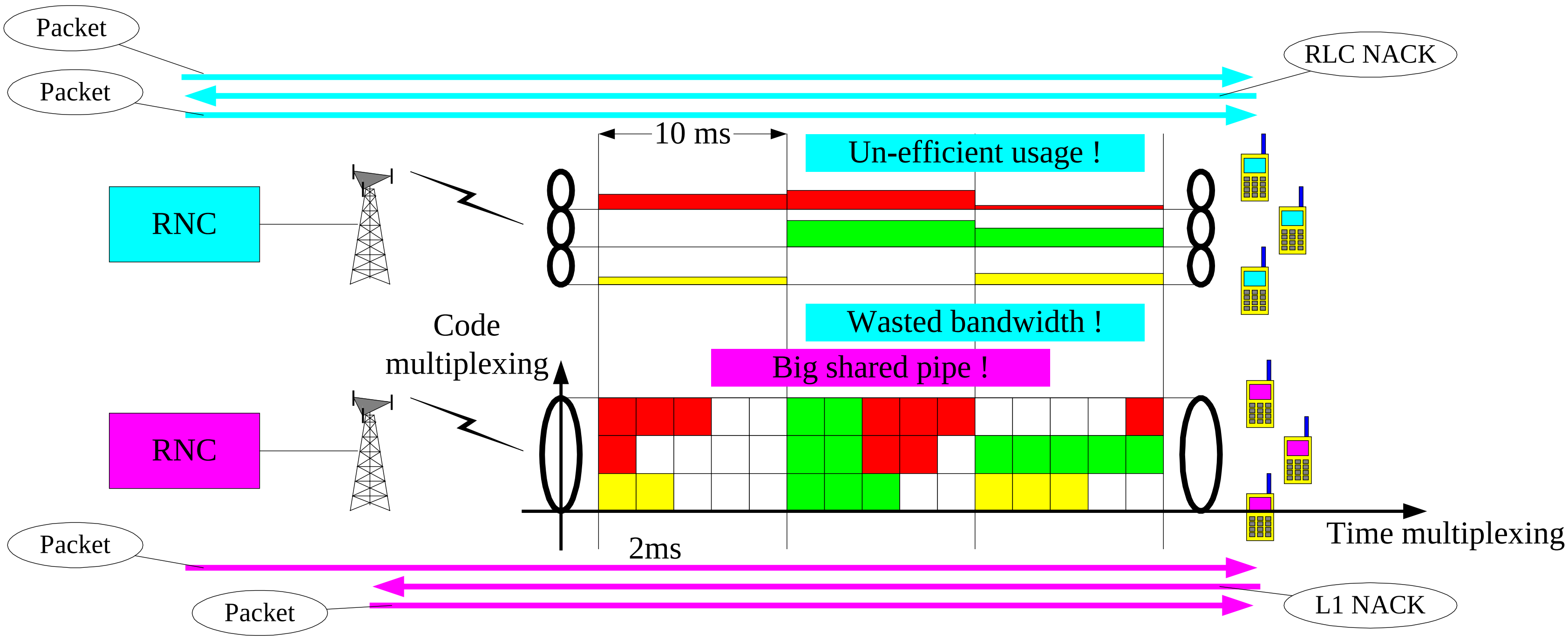
- Downlink Code/Time Multiplexing



Properties of HSDPA (5)

- MAC Layer Scheduling in Node B
  - fast scheduling possible because of functionality closer to air interface and short frame length
    - fast adaptation to channel variation (AMC)
    - fast HARQ retransmissions
  - scheduling based on channel quality, UE capability, QoS class, power/code availability

Properties of HSDPA (6)

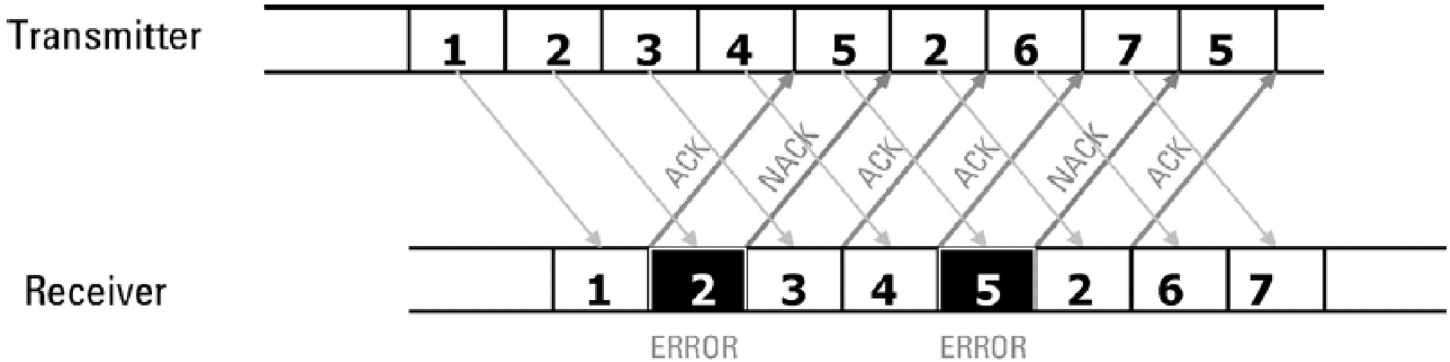


Properties of HSDPA (7)

- AMC
  - link adaptation to improve data throughput
  - DL modulation-coding scheme depending on the channel conditions for each user
    - The modulation and coding format are changed to match the current received signal quality or channel conditions at the receiver.
  - modulation
    - QPSK/16-QAM
  - coding
    - rate 1/3 turbo coding
    - different effective code rates obtained through various rate-matching parameters

Properties of HSDPA (8)

- HARQ(Hybrid Auto Repeat reQuest)
  - Forward error correction such as turbo coding
  - Backward error correction using ARQ



  - ACK/NACK control : Layer 1 (HS-DPCCH)
  - packet order scheduling : Layer 2 (MAC)

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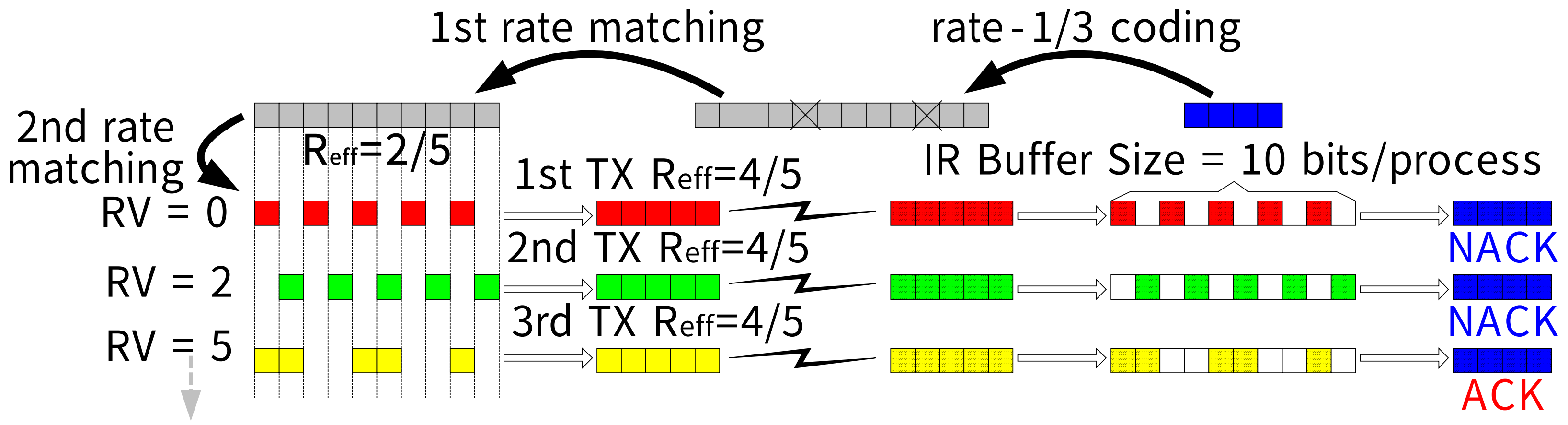
Properties of HSDPA (9)

- Soft Combining Scheme
  - minimizes the number of additional retransmission requests
  - 2 soft combining schemes
    - CC(Chase Combining)
      - involves sending an identical version of an erroneously detected packet
      - Received copies are combined by the decoder prior to decoding
    - IR (Type II and III HARQ)
      - involves sending a different set of bits incrementally to be combined with the original set, thus increasing the amount of redundant data and the likelihood of recovering from errors

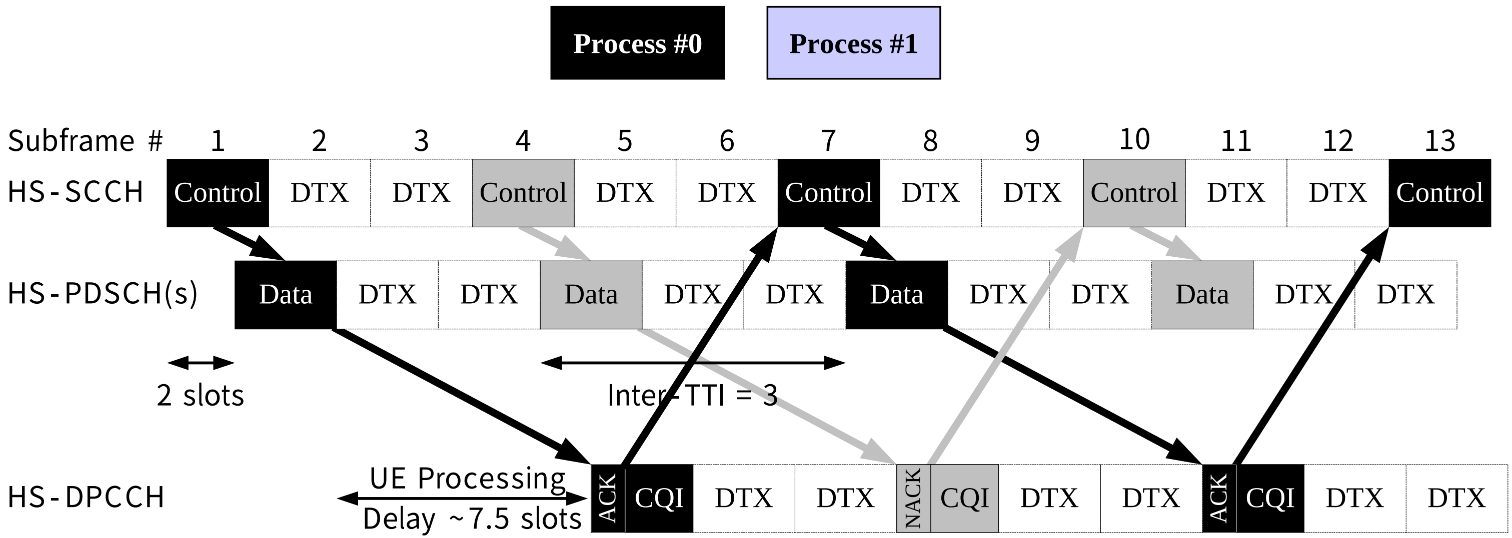
Properties of HSDPA (10)

- Incremental Redundancy



Properties of HSDPA (11)

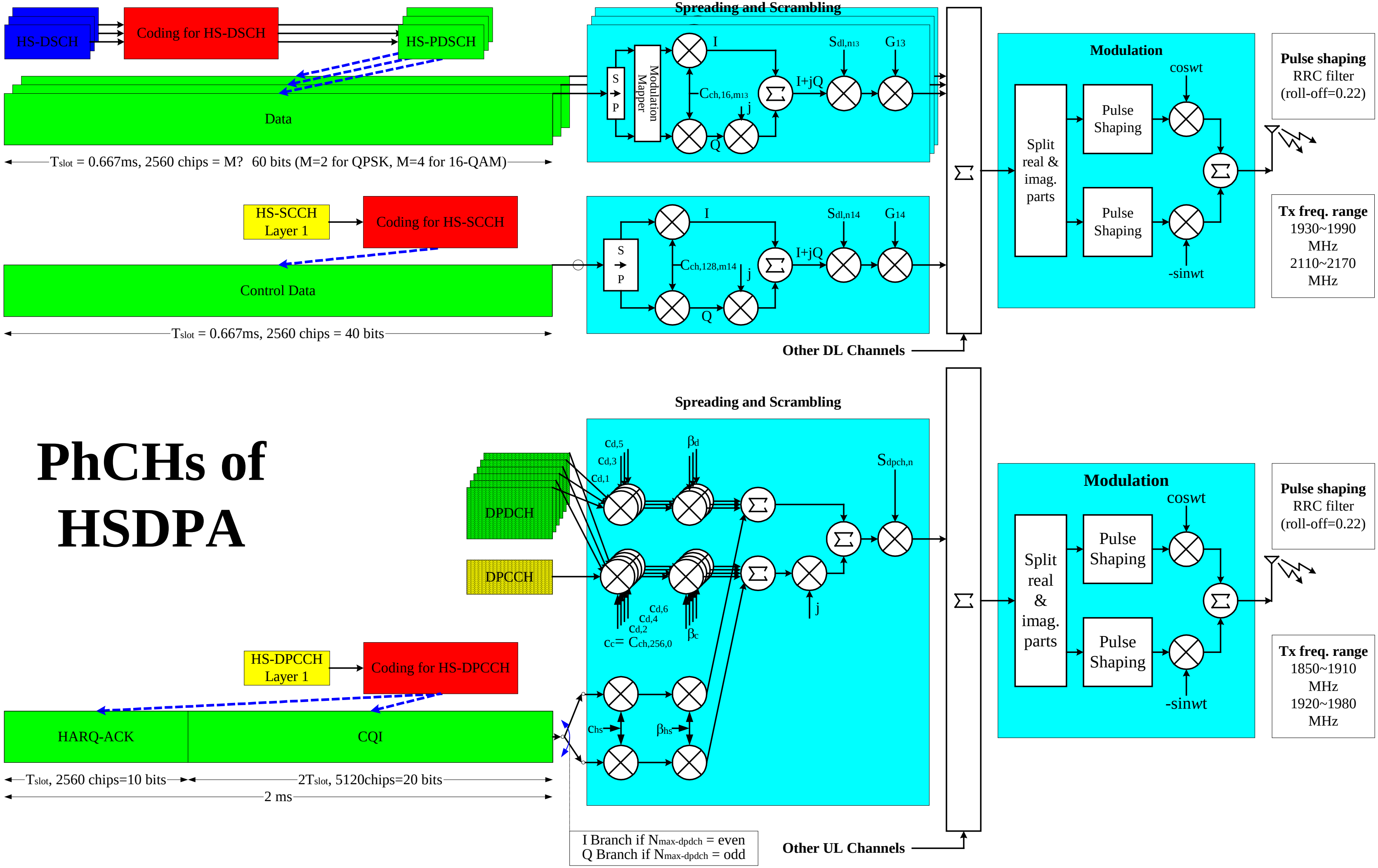
- Multiple HARQ Processes
  - Throughput can be increased by reducing the inter-TTI interval.
  - Available system capacity is not wasted.



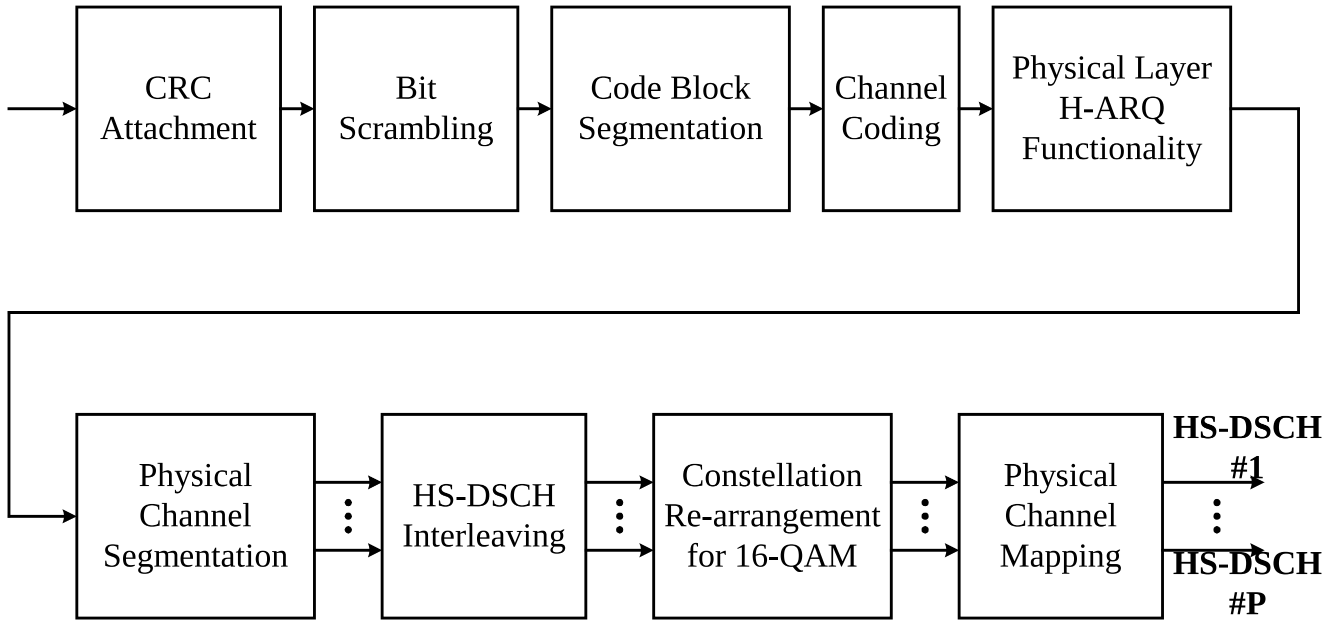
Channel Types

- New downlink channels
  - TrCH
    - HS-DSCH
  - PhCH
    - HS-PDSCH (HS-Physical DSCH) : payload data
    - HS-SCCH (HS-Shared CCH) : UE identity and HS-DSCH coding information
- New uplink physical channel
  - HS-DPCCH (HS-Dedicated Physical CCH) : ACK/NACK and CQI (Channel Quality Indicator)

PhCHs of HSDPA



Coding for HS-DSCH



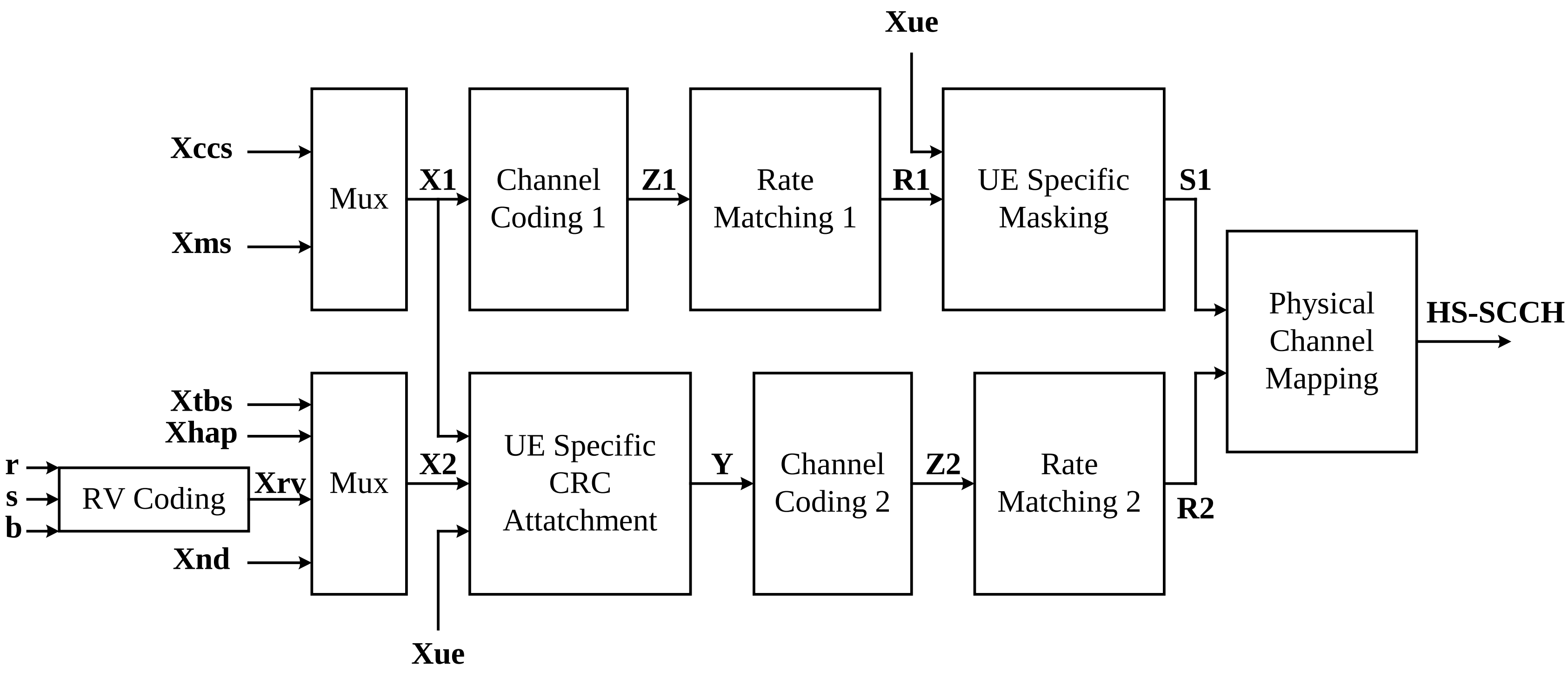
Coding Process for HS-DSCH

- 1 TrCH in HS-DSCH CCTrCH
- 1 transport block in each TTI of 2ms
- CRC length = 24 bits
- Channel coding = 1/3 rate turbo coding
- H-ARQ : 2 stage rate matching
  - 1st rate matching : matches the number of input bits to the virtual IR(Incremental Redundancy) buffer
  - 2nd rate matching : matches the number of bits after 1st rate matching stage to the number of physical channel bits available in the HS-PDSCH set in the TTI
- Mapped onto (up to 15) HS-PDSCH(s)
- Interleaving is performed separately for each PhCH
- Different 16-QAM constellations are defined.

Data Rate Categories of HSDPA

Category	Codes	Inter-TTI	TB size	Total # of soft Bits	Modulation	Data rate
1	5	3	7300	19200	QPSK/16QAM	**1.2 Mbps**
2	5	3	7300	28800	QPSK/16QAM	**1.2 Mbps**
3	5	2	7300	28800	QPSK/16QAM	**1.8 Mbps**
4	5	2	7300	38400	QPSK/16QAM	**1.8 Mbps**
5	5	1	7300	57600	QPSK/16QAM	**3.6 Mbps**
6	5	1	7300	67200	QPSK/16QAM	**3.6 Mbps**
7	10	1	14600	115200	QPSK/16QAM	**7.2 Mbps**
8	10	1	14600	134400	QPSK/16QAM	**7.2 Mbps**
9	15	1	20432	172800	QPSK/16QAM	**10.2 Mbps**
10	15	1	28776	172800	QPSK/16QAM	**14.4 Mbps**
11	5	2	3650	14400	QPSK only	**0.9 Mbps**
12	5	1	3650	28800	QPSK only	**1.8 Mbps**

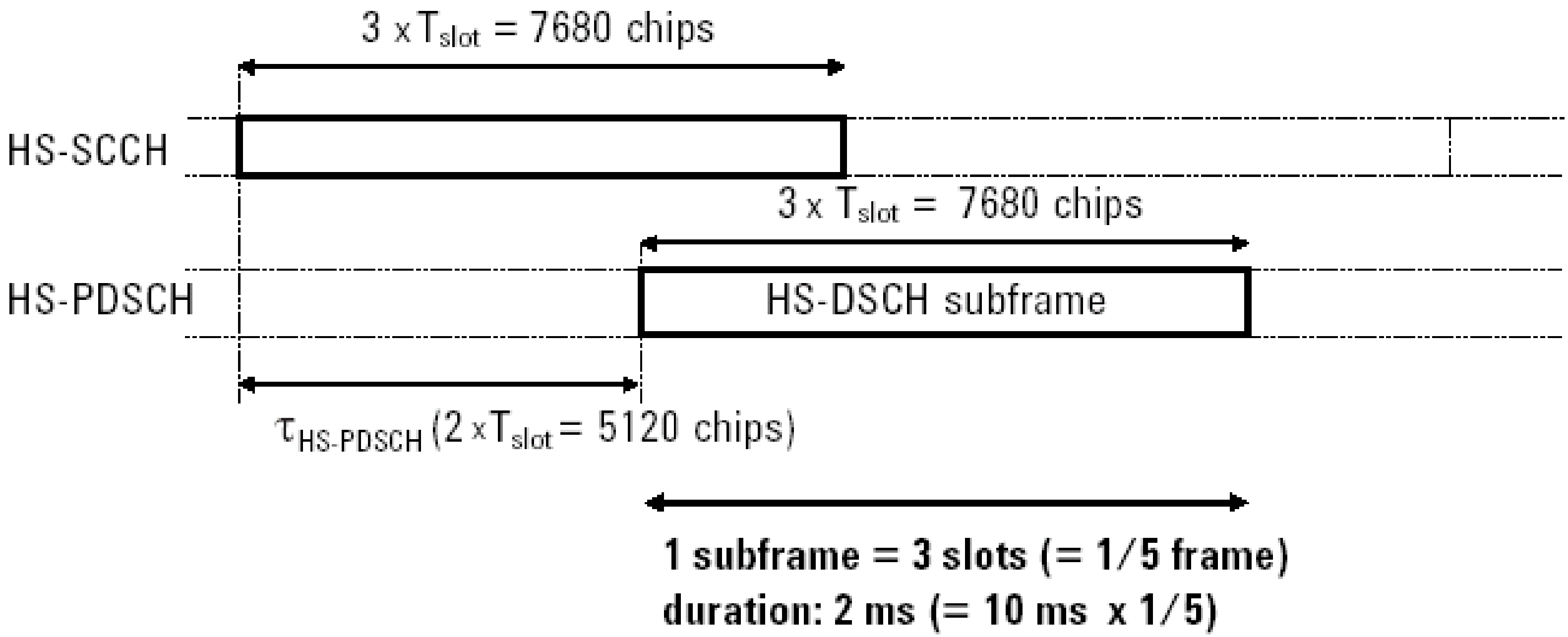
Coding for HS-SCCH



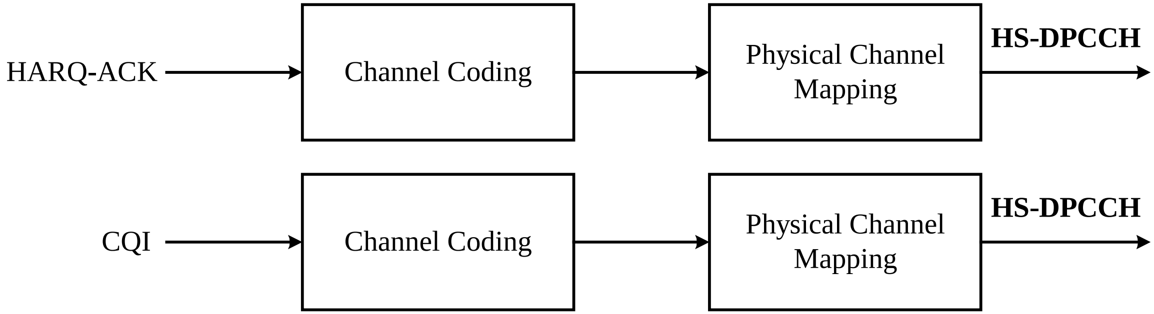
Information of HS-SCCH

- Channelization-code-set information (7 bits) : Xccs
- Modulation scheme information (1 bit) : Xms
- Transport-block size information (6 bits) : Xtbs
- H-ARQ process information (3 bits) : Xhap
- Redundancy and constellation version (3 bits) : Xrv
- New data indicator (1 bit) : Xnd
- UE identity (16 bits) : Xue

Timing Relationship between HS-SCCH and HS-PDSCH



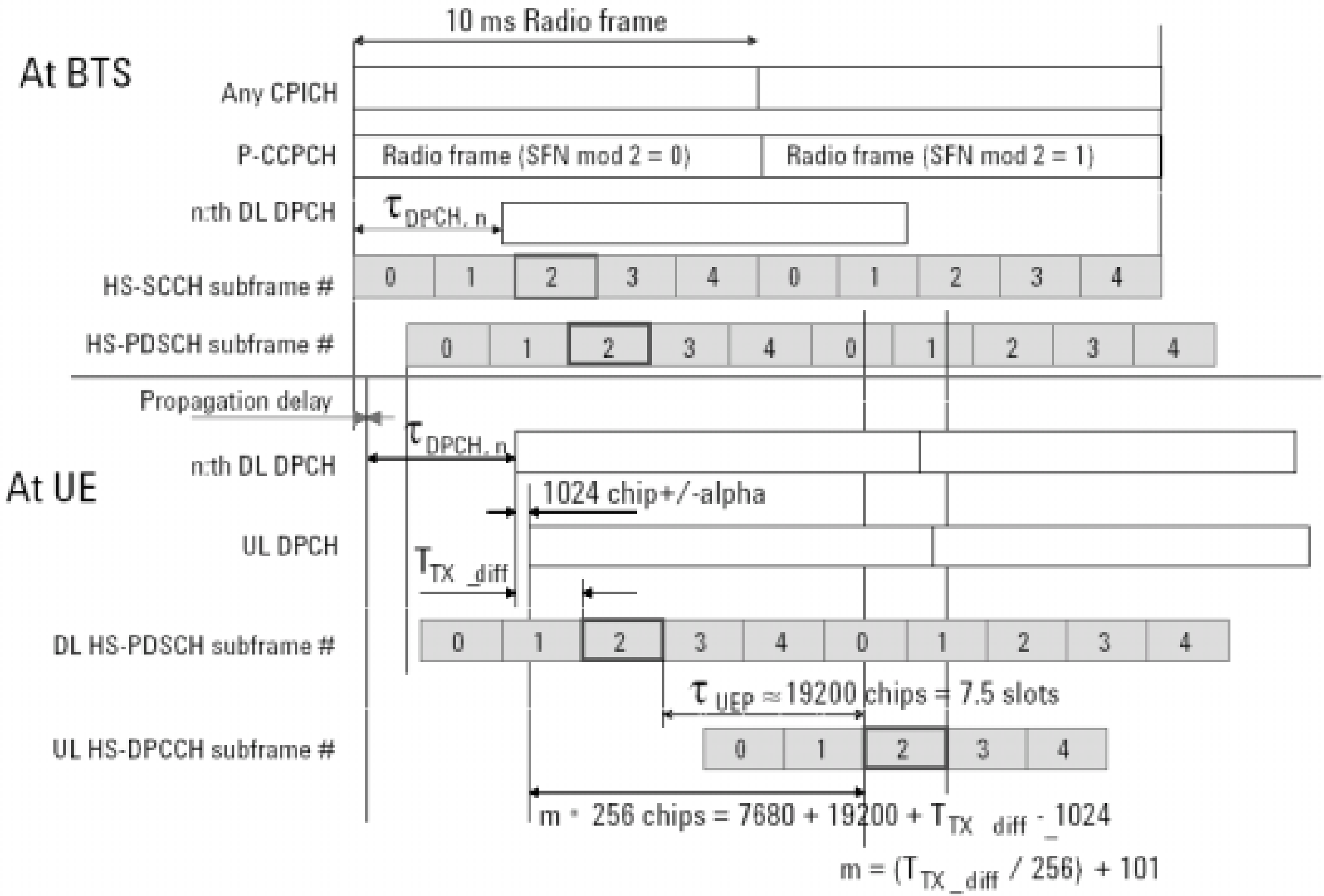
Coding for HS-DPCCH



Code Allocation for Spreading of HS-DPCCH

- Channelization code
  - if $N_{max\text{-}dpdch} = 1 \Rightarrow c_{hs} = C_{ch,256,64}$
  - if $N_{max\text{-}dpdch} = 2, 4, 6 \Rightarrow c_{hs} = C_{ch,256,1}$
  - if $N_{max\text{-}dpdch} = 3, 5 \Rightarrow c_{hs} = C_{ch,256,32}$
- Scrambling code
  - same as UL DPCH
    - $S_{dpch,n}(i) = C_{long,n}(i)$ or $C_{short,n}(i)$, $i=0,1,\ldots,38399$

Timing Relationship among DL and UL Channels



4G Cellular Communication

- Evolution of Cellular Mobile Communication
- 4G Cellular Mobile Communication

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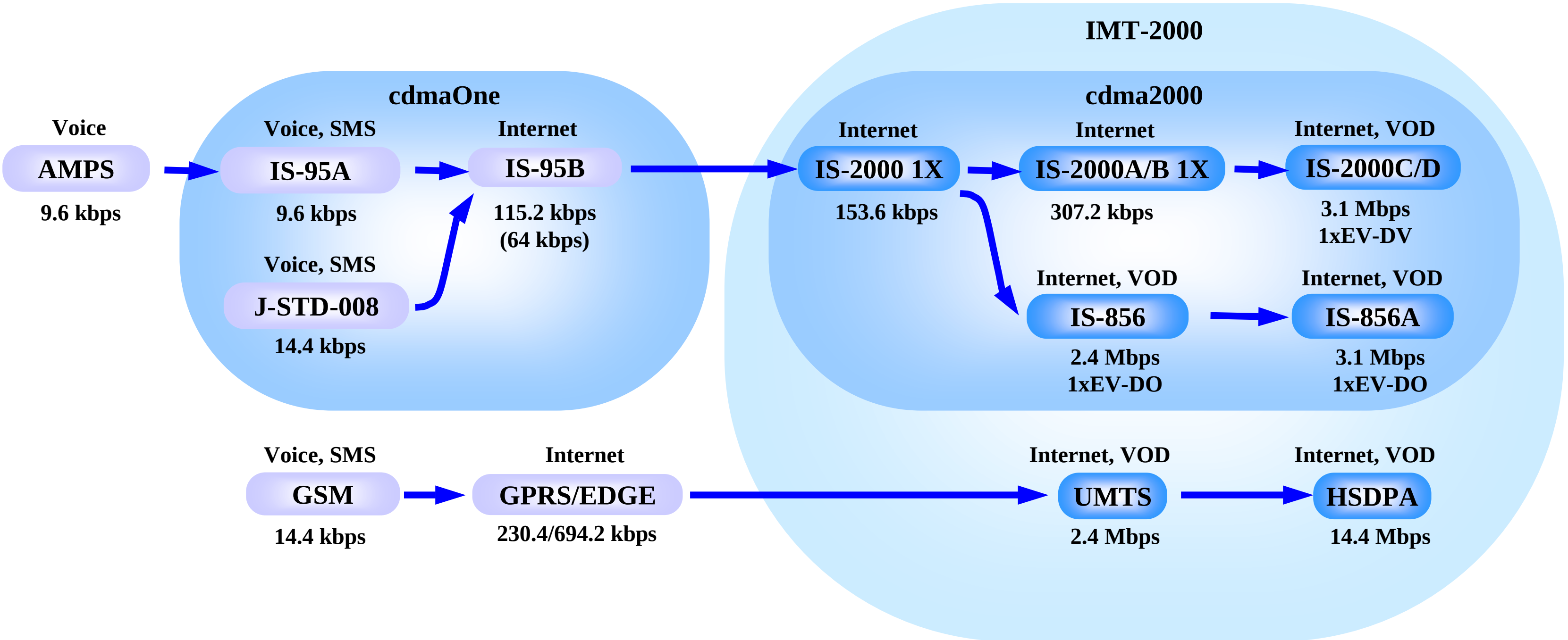
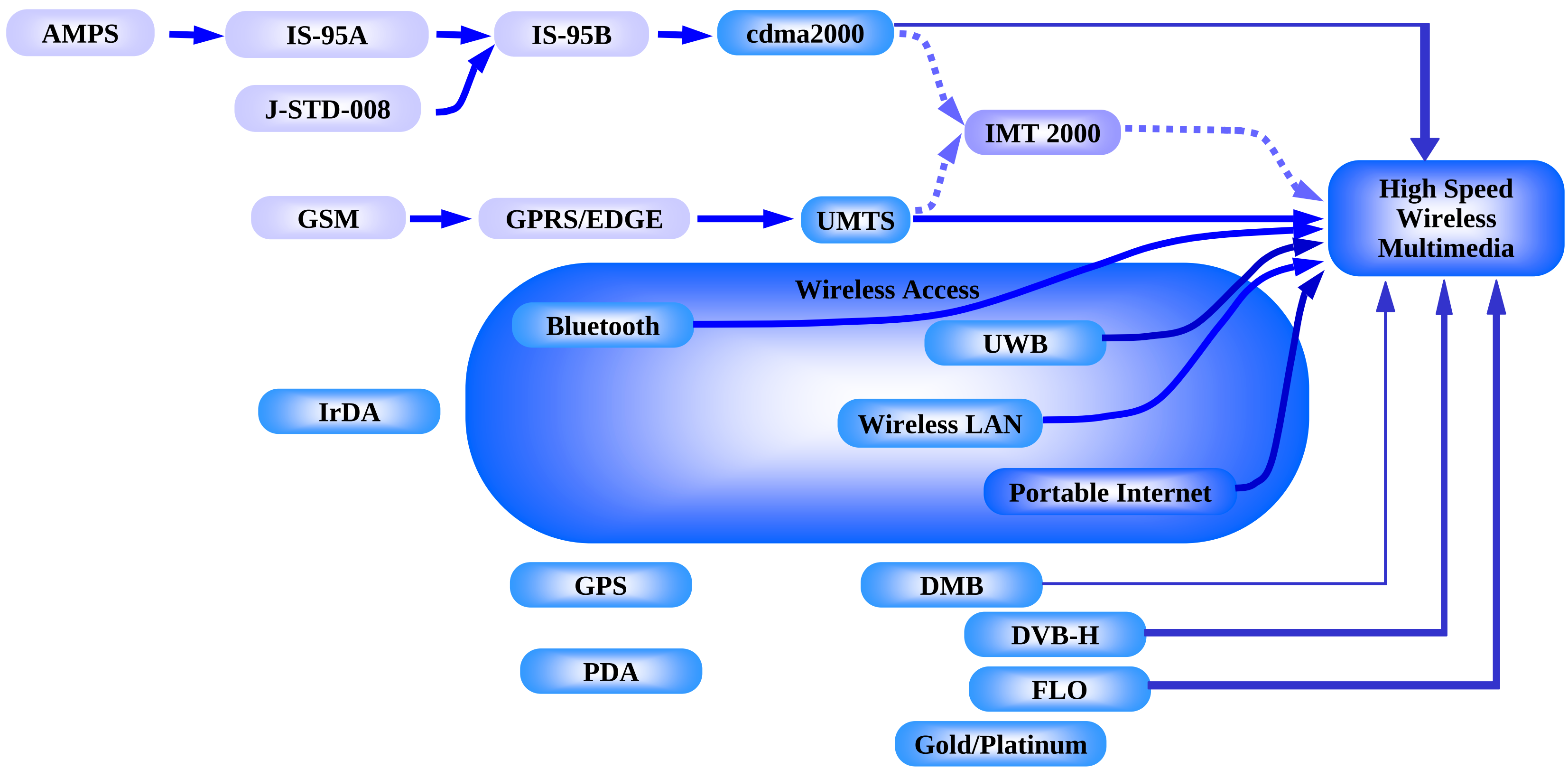
Evolution of Cellular Mobile Communication (1)

1G (1980's)	2G (1990's)	2.5G (1999~)	3G (2001~)
Analog	Digital	Data SVC	Multimedia

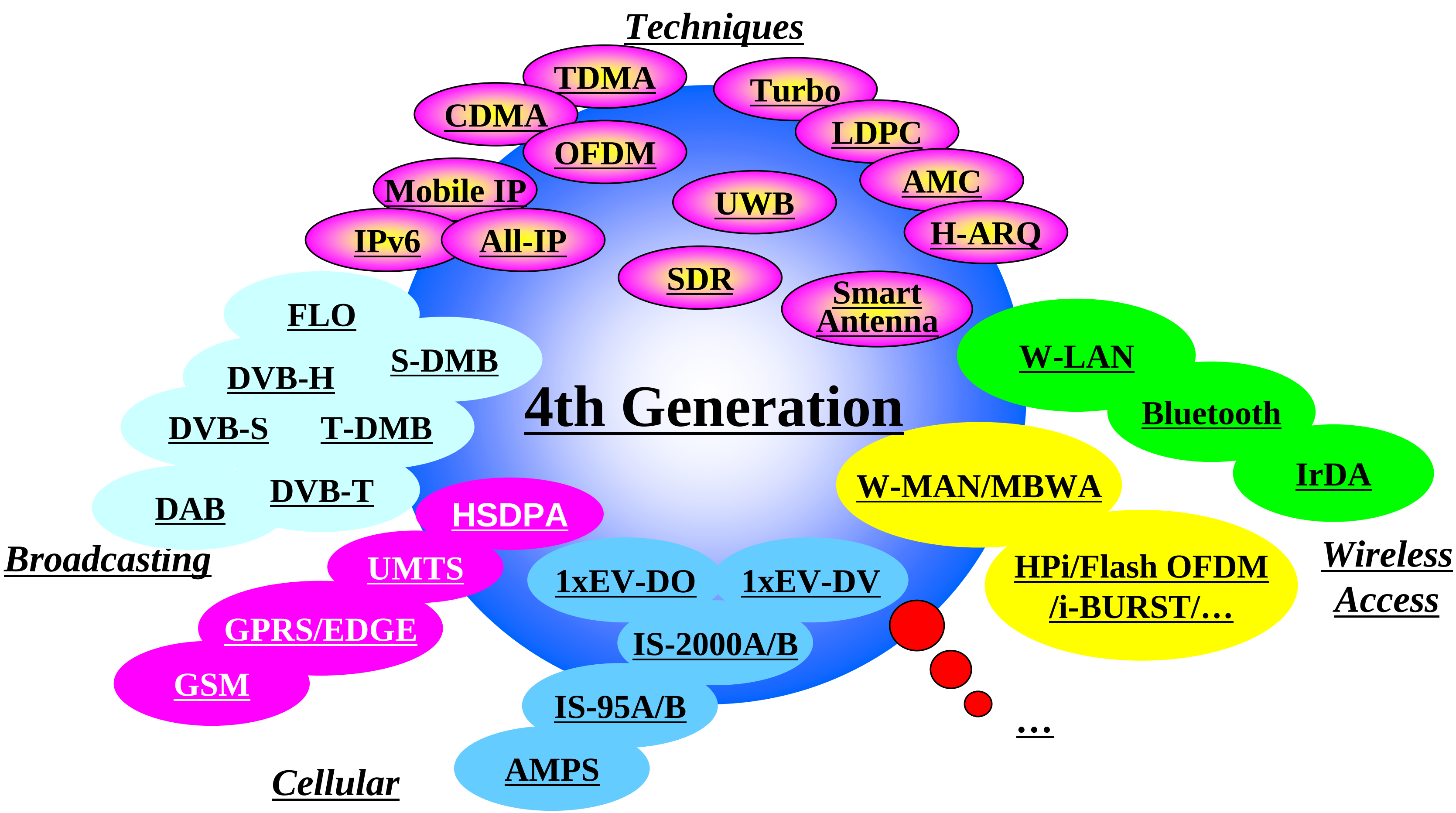


Evolution of Cellular Mobile Communication (2)

1G (1980's)	2G (1990's)	2.5G (1999~)	3G (2001~)	4G (2010~)
Analog	Digital	Data SVC	Multimedia	High Speed Multimedia



4G Cellular Mobile Communication



Q&A