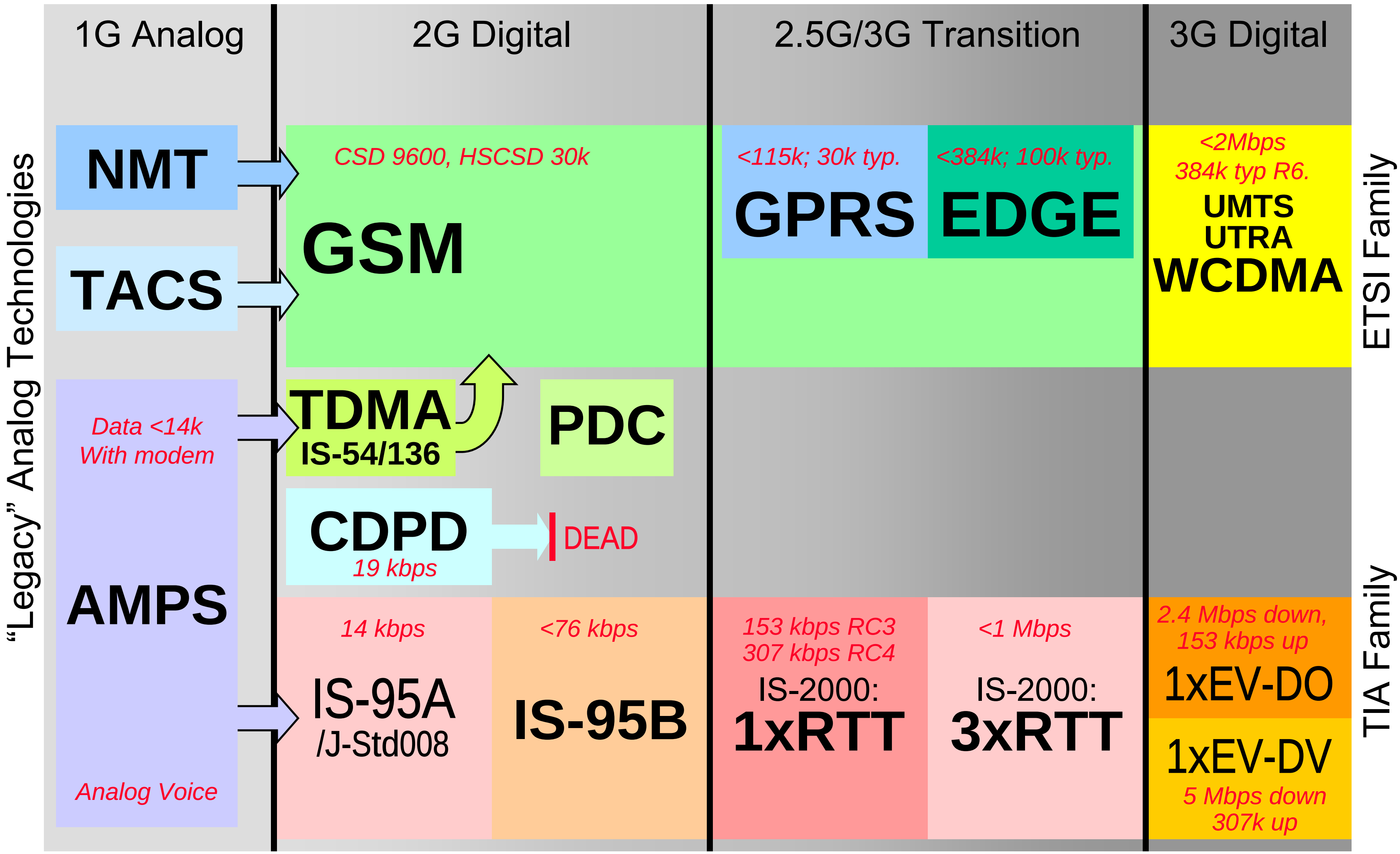
Course 441

Background and Introduction to
UMTS WCDMA Technology

Contents

Industry Survey, Update and Perspective

Competing Wireless Technology Families: Origins and Migration Paths



WCDMA Releases and Timeline

<table>
<tr><th>GSM/EDGE Release</th><th>3G Release</th><th>Abbrev name</th><th>Spec version number</th><th>Freeze date</th><th>Changes, Notes and Features</th></tr>
<tr><td>Phase 2+ Release 7 (tbd)</td><td>Release7 (TR 21.101)</td><td>Rel-7</td><td>7.x.y</td><td>tbd</td><td>User interface, Location Svcs, CS and IP sessions, encryption</td></tr>
<tr><td>Phase 2+ Release 6 (will be TR 41.101)</td><td>Release 6 (TR 21.101)</td><td>Rel-6</td><td>6.x.y</td><td>March 2004?</td><td>-800 Mhz, MMS, interfaces, UIM, security, L3 msg, AMR, IP and session issues</td></tr>
<tr><td>Phase 2+ Release 5 (TR 41.101)</td><td>Release 5 (TR 21.101)</td><td>Rel-5</td><td>5.x.y</td><td>June 2002</td><td>Numerous major revisions</td></tr>
<tr><td>Phase 2+ Release 4 (TR 41.101)</td><td>Release 4 (TR 21.101)</td><td>Rel-4</td><td>4.x.y</td><td>March 2001</td><td>Numerous major revisions</td></tr>
<tr><td>-</td><td>Release 2000</td><td rowspan="2">R00</td><td>3.x.y</td><td rowspan="2">See note 1 below</td><td rowspan="2">Numerous major revisions</td></tr>
<tr><td>Phase 2+ Release 2000</td><td>-</td><td>9.x.y</td></tr>
<tr><td>-</td><td>Release 1999 (TR 21.101)</td><td rowspan="2">R99</td><td>3.x.y</td><td rowspan="2">March 2000</td><td rowspan="2">Widely used as first commercial release</td></tr>
<tr><td>Phase 2+ Release 1999 (TR 01.01)</td><td>-</td><td>8.x.y</td></tr>
<tr><td>Phase 2+ Release 1998 (TR 01.01)</td><td>-</td><td>R98</td><td>7.x.y</td><td>early 1999</td><td>-</td></tr>
<tr><td>Phase 2+ Release 1997 (TR 01.01)</td><td>-</td><td>R97</td><td>6.x.y</td><td>early 1998</td><td>-</td></tr>
<tr><td>Phase 2+ Release 1996 (TR 01.01)</td><td>-</td><td>R96</td><td>5.x.y</td><td>early 1997</td><td>-</td></tr>
<tr><td>Phase 2 (TR 01.01)</td><td>-</td><td>Ph2</td><td>4.x.y</td><td>1995</td><td>-</td></tr>
<tr><td>Phase 1 (TR 01.01)</td><td>-</td><td>Ph1</td><td>3.x.y</td><td>1992</td><td>-</td></tr>
</table>

Note 1: The term "Release 2000" was used only temporarily and was eventually replaced by "Release 4" and "Release 5" (most elements originally in Release 2000 were renamed Release 4, but some were deferred until Release 5)..
Note 2: Specifications with a version number of 0.x.y, 1.x.y or 2.x.y indicates that it is a new, draft, specification which has not yet been approved. The anticipated release is normally shown on the cover of the document.

Current UMTS WCDMA Deployment

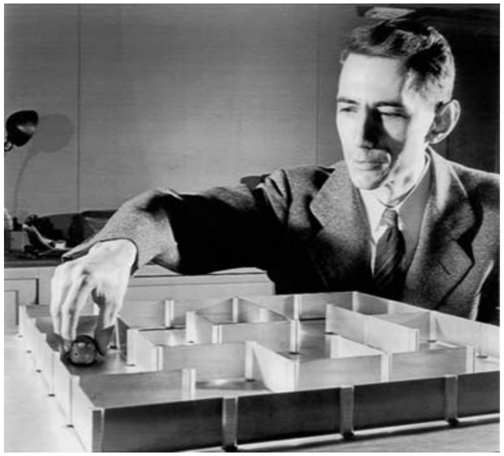
North America			
USA	Cingular + AT&T Wireless	Jun-04	Constructing
USA	T-Mobile	??	??
Europe, Middle East, Africa			
Country	**Operator**	**Date**	**Status**
Austria	3	May-03	Service Launched
Austria	mobilkom austria	Apr-03	Service Launched
Austria	T-Mobile	Dec-03	Service Launched
Belguim	Proximus	May-04	Service Launched
Croatia	VIPnet	May-03	Trial
Czech Republic	Eurotel	Feb-03	Trial
Denmark	3	Oct-03	Service Launched
Estonia	EMT	Sep-03	Trial
Finland	TeliaSonera	Dec-03	Trial
France	Orange	Feb-04	Trial
France	SFR	May-04	Service Launched
Germany	O2	Apr-04	Service Launched
Germany	Vodafone	Feb-04	Service Launched
Germany	T-Mobile	Apr-04	Service Launched
Germany	E-Plus	Jun-04	Service Launched
Greece	Telestet	Jan-04	Service Launched
Greece	COSMOTE	May-04	Service Launched
Ireland	3	Oct-03	Trial
Ireland	Vodafone	Jul-04	Service Launched
Ireland	O2	Dec-03	Trial
Isle of Man	Manx Telecom	Dec-01	Trial
Italy	3	Mar-03	Service Launched
Italy	Vodafone	Feb-04	Service Launched
Italy	TIM	May-04	Service Launched

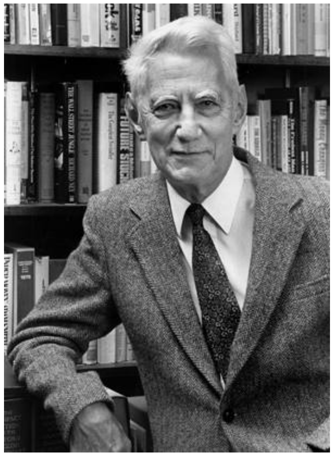
Luxembourg	P&T Luxembourg	Jun-03	Trial
Luxembourg	Tango	May-03	Trial
Monaco	Monaco Telecom	Jun-01	Trial
Netherlands	KPN Mobile	Jul-04	Service Launched
Netherlands	Vodafone	Feb-04	Service Launched
Portugal	Vodafone	Feb-04	Service Launched
Portugal	TMN	Apr-04	Service Launched
Slovenia	Mobitel	Dec-03	Service Launched
Spain	Telef´nica M´viles Espa˝a	Feb-04	Service Launched
Spain	Vodafone	Feb-04	Service Launched
Sweden	3	May-03	Service Launched
Sweden	Vodafone	Feb-04	Service Launched
Sweden	Tele2	Jun-04	Service Launched
UAE	Etisalat	Dec-03	Service Launched
UK	3	May-03	Service Launched
UK	Vodafone	Feb-04	Service Launched
UK	T-Mobile	Feb-04	Trial
UK	Orange	Jul-04	Service Launched
Asia Pacific			
Country	Operator	**Date**	**Status**
Australia	3	Apr-03	Service Launched
Hong Kong	3	Jan-04	Service Launched
Japan	NTT DoCoMo	Oct-01	Service Launched
Japan	Vodafone K.K.	Dec-02	Service Launched
Malaysia	Telekom Malaysia	Jul-03	Trial
Malaysia	Maxis	Mar-04	Trial
Singapore	SingTel	Sep-03	Trial
South Korea	KTF	Dec-03	Service Launched
South Korea	SKT	Dec-03	Service Launched

WCDMA Principles

Claude Shannon:
The Einstein of Information Theory

- The core idea that makes WCDMA possible was first explained by Claude Shannon, a Bell Labs research mathematician
- Shannon's work relates amount of information carried, channel bandwidth, signal-to-noise-ratio, and detection error probability
  - It shows the theoretical upper limit attainable





In 1948 **Claude Shannon** published his landmark paper on information theory, ***A Mathematical Theory of Communication***. He observed that "the fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point." His paper so clearly established the foundations of information theory that his framework and terminology are standard today. Shannon died Feb. 24, 2001, at age 84.

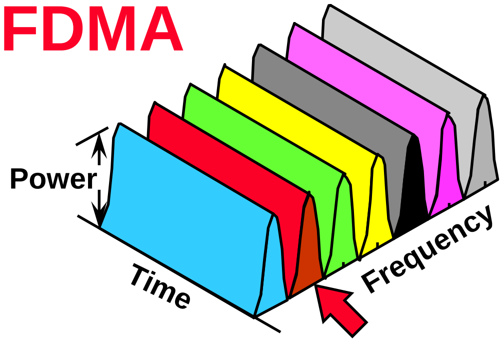
SHANNON'S CAPACITY EQUATION

$$C = B_{\omega} \log_2 \left[1 + \frac{S}{N} \right]$$

B_{ω} = bandwidth in Hertz
C = channel capacity in bits/second
S = signal power
N = noise power

Wireless Multiple Access Methods

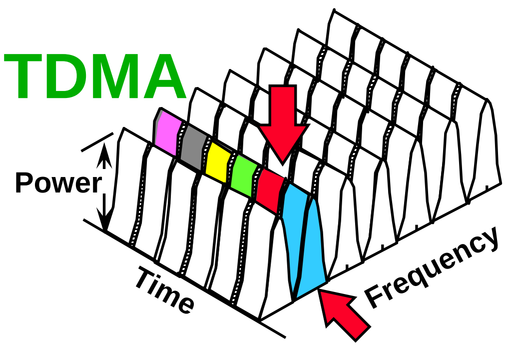
FDMA



Frequency Division Multiple Access

•A user's channel is a private frequency

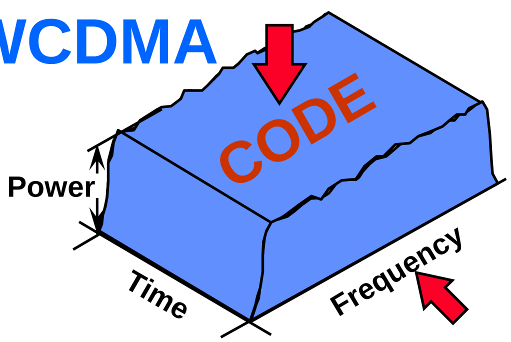
TDMA



Time Division Multiple Access

•A user's channel is a specific frequency, but it only belongs to the user during certain time slots in a repeating sequence

WCDMA



Code Division Multiple Access

•Each user's signal is a continuous unique code pattern buried within a shared signal, mingled with other users' code patterns. If a user's code pattern is known, the presence or absence of their signal can be detected, thus conveying information.

WCDMA: Using A New Dimension

- All WCDMA users occupy the same frequency at the same time! Frequency and time are not used as discriminators
- WCDMA operates by using CODING to discriminate between users
- WCDMA interference comes mainly from nearby users
- Each user is a small voice in a roaring crowd -- but with a uniquely recoverable code

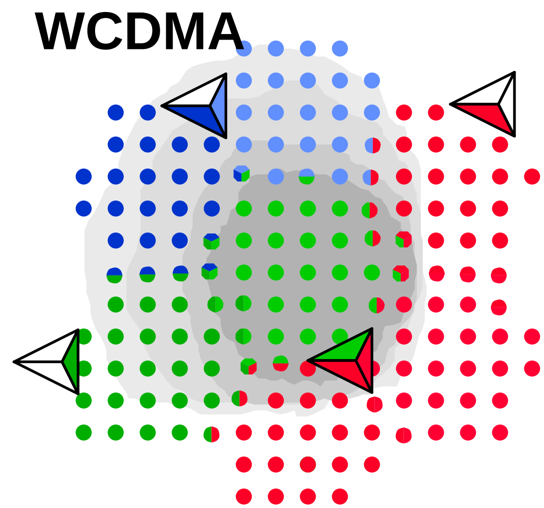


Figure of Merit: C/I
(carrier/interference ratio)
AMPS: +17 dB
TDMA: +14 to +17 dB
GSM: +7 to 9 dB.
WCDMA: -15 to -23 dB.
WCDMA: E_b/N_o ~+6 dB.

DSSS Spreading: Time-Domain View

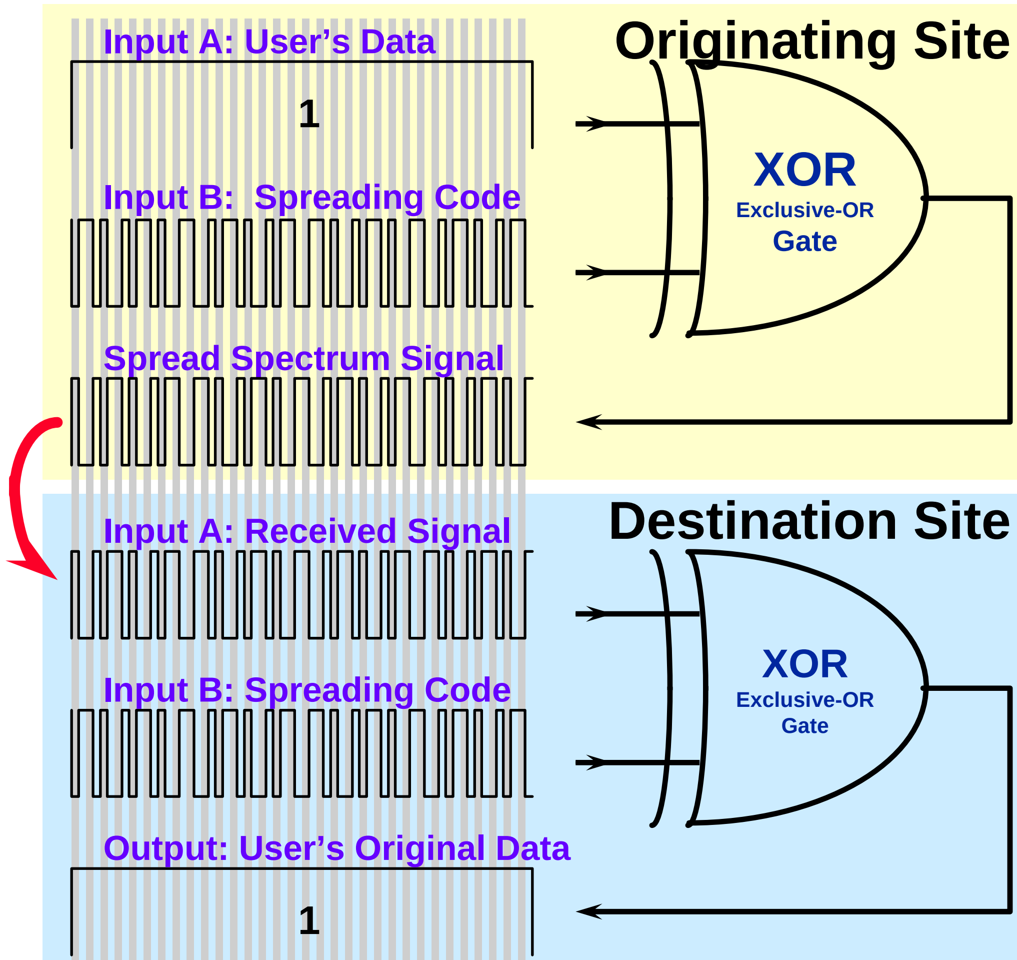
At Originating Site:

- Input A: User's Data @ 19,200 bits/second
- Input B: OVSF Code #23 @ 3.84 Mcps
- Output: Spread spectrum signal

via air interface

At Destination Site:

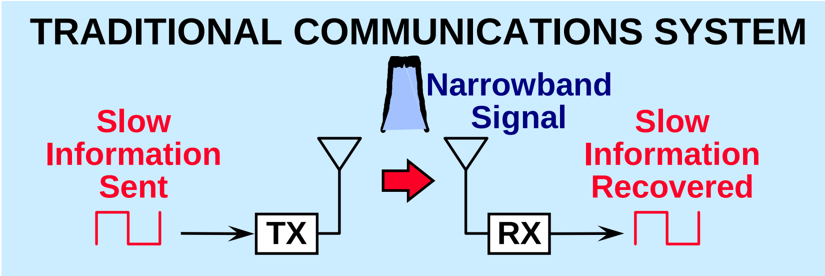
- Input A: Received spread spectrum signal
- Input B: OVSF Code #23 @ 3.84 Mcps
- Output: User's Data @ 19,200 bits/second just as originally sent

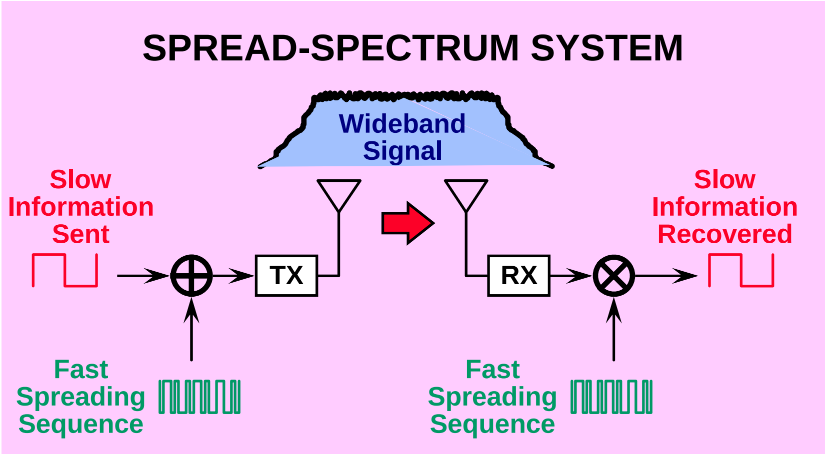


Drawn to actual scale and time alignment

Spreading from a Frequency-Domain View

- Traditional technologies try to squeeze signal into minimum required bandwidth
- WCDMA uses larger bandwidth but uses resulting processing gain to increase capacity





Spread Spectrum Payoff: Processing Gain

The WCDMA Spread Spectrum Payoff:
Take all the gain yourself, or share it with others?

- Claude Shannon's work suggests that a certain bit rate of information deserves a certain bandwidth
- If one WCDMA user is carried alone by a WCDMA signal, the processing gain is large - roughly 26 db for an 8k vocoder.
  - 3,840,000 / 9,600 = 400 power gain
  - 10 log 400 = 26.0 db
  - Each doubling of the number of users consumes 3 db of the processing gain
  - Somewhere above 100 users, the signal-to-noise ratio becomes undesirable and the ultimate capacity of the sector is reached
- Practical WCDMA systems restrict the number of users per sector to ensure processing gain remains at usable levels

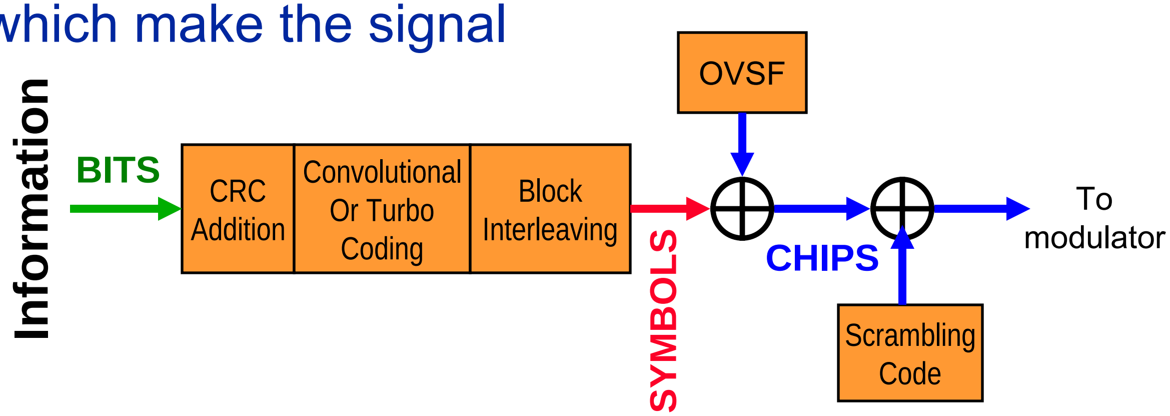
WCDMA Spreading Gain

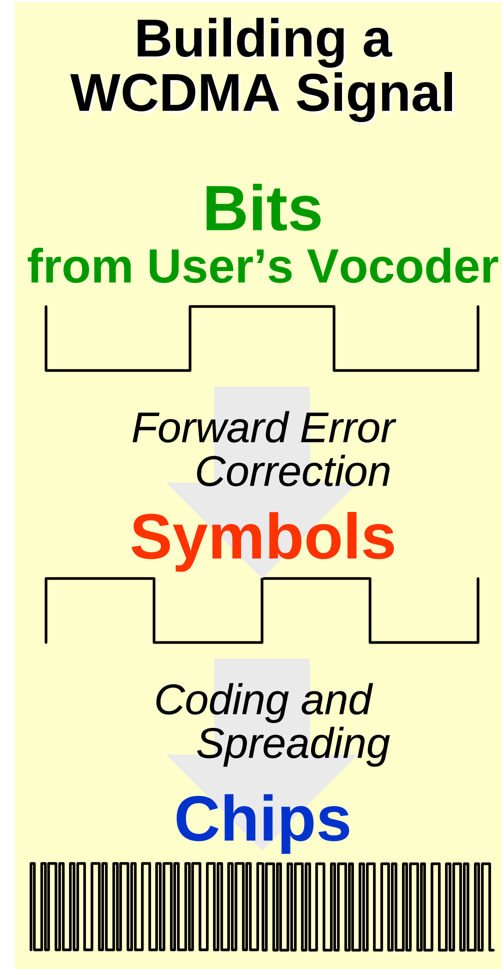
Consider a user with a 9600 bps vocoder talking on a WCDMA signal 3,840,000 hz wide. The processing gain is 3,840,000/9600 = 400, which is 26 db. What happens if additional users are added?

# Users	Processing Gain
1	26 db
2	23 db
4	20 db
8	17db
16	14 db
32	11 db
64	8 db
128	5 db
Half the wisdom of winning is knowing when to leave the game.	

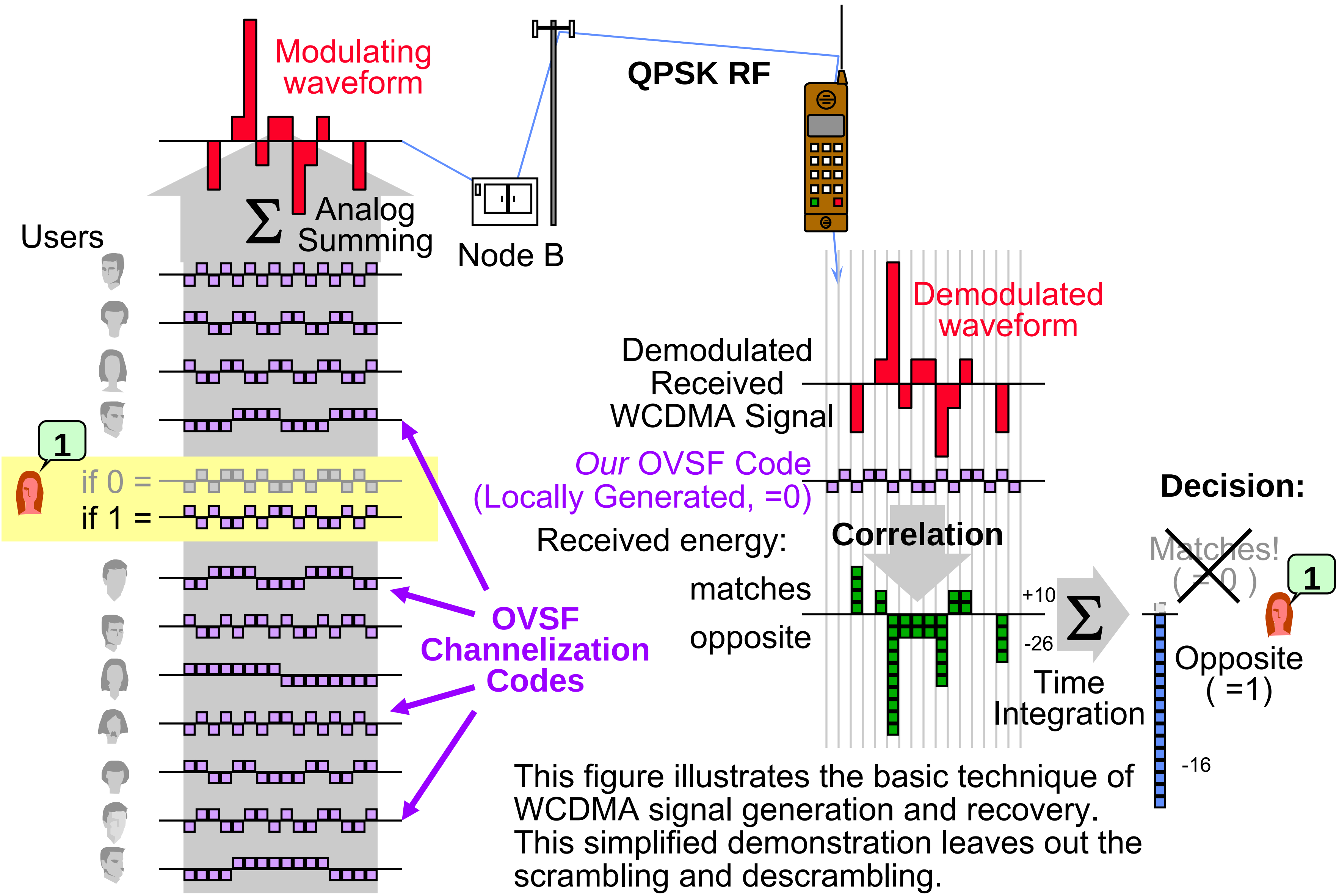
Terminology: All “Bits” Are *Not* Created Equal

- Units of information in binary form are called “bits”
- In WCDMA, there are streams of information at three distinct levels of importance; we call their individual information elements by different names
- BITS are the 1’s and 0’s in the stream of raw information to be transmitted – the “payload”
- SYMBOLS are redundantly-encoded 1’s and 0’s output from a convolutional or turbo coder
- CHIPS are the 1’s and 0’s in the fast spread spectrum signal, and the 1’s and 0’s in the codes which make the signal



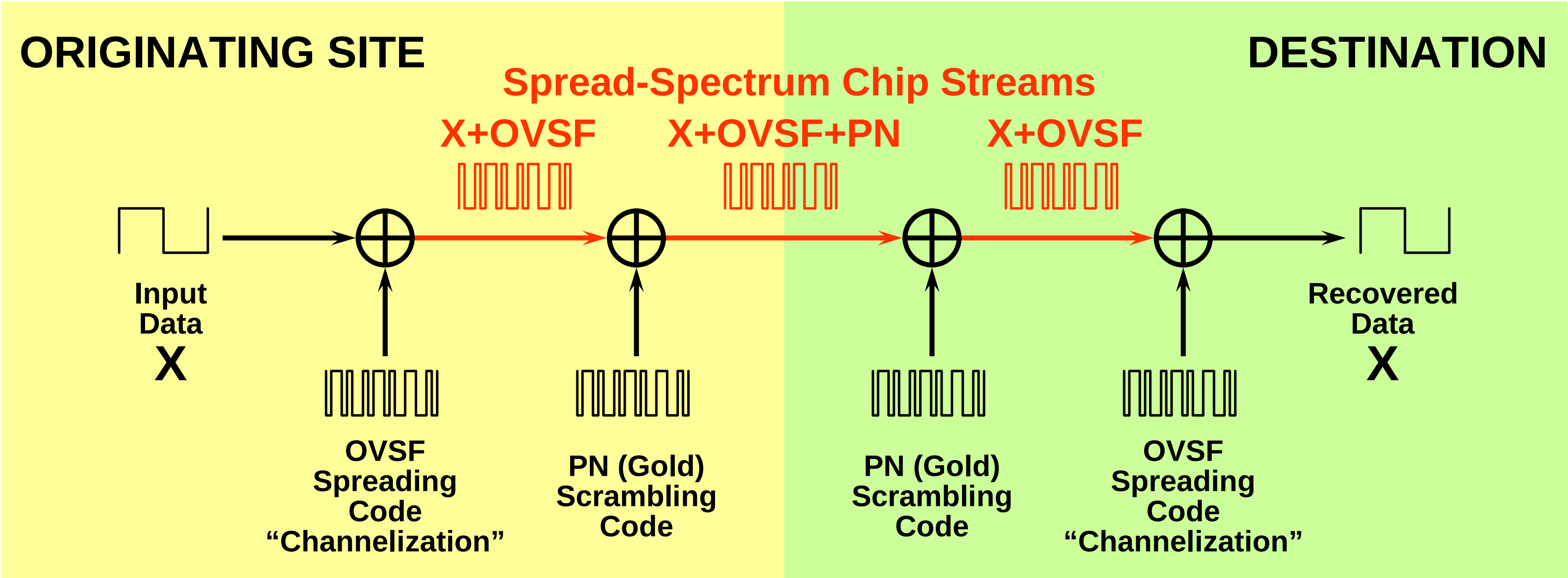


Channelization Insulates Multiple Users



This figure illustrates the basic technique of WCDMA signal generation and recovery. This simplified demonstration leaves out the scrambling and descrambling.

WCDMA's Nested Spreading Sequences



- WCDMA combines two different spreading sequences to create unique, robust channels
- The sequences are easy to generate on both sending and receiving ends of each link
- "Whatever we do, we can undo"

W-CDMA Spreading

- W-CDMA uses long spreading codes
  - One set of codes are used for cell separation on downlink
  - One set of codes are used for user separation on uplink
- Downlink
  - Gold Codes 2^{18} chips long are used
  - Truncated to same length as the 10 ms frames
  - Total number of scrambling codes is 512
  - Divided into 64 code groups with 8 codes in each group, to allow fast cell search
- Uplink
  - Short codes can be used to ease implementation of advanced multi-user receiver techniques
    - VL-Kasami Codes 256 chips long
  - Otherwise long codes are used
    - Gold sequences 2^{41} chips long, truncated to 10 ms frame length

The WCDMA Spreading and Channelization Sequence: Orthogonal Variable Spreading Factor (OVSF)

- 64 “Magic” Sequences, each 64 chips long
- Each OVSF is precisely Orthogonal with respect to all other OVSF Codes in its family
  - it’s simple to generate the codes, or
  - they’re small enough to use from ROM

Unique Properties:
Mutual Orthogonality

EXAMPLE:

Correlation of OVSF #23 with OVSF #59

```
#23   0110100101101001100101101001011001101001011010011001011010010110
#59   0110011010011001100110010110011010011001011001100110011010011001
Sum   0000111111110000000011111111000011110000000011111111000000001111
```

Correlation Results: 32 1’s, 32 0’s: Orthogonal!!

Orthogonal Variable Spreading Factor

#	---------------------------------- 64-Chip Sequence ----------------------------------
0	0000000000000000000000000000000000000000000000000000000000000000
1	0101010101010101010101010101010101010101010101010101010101010101
2	0011001100110011001100110011001100110011001100110011001100110011
3	0110011001100110011001100110011001100110011001100110011001100110
4	0000111100001111000011110000111100001111000011110000111100001111
5	0101101001011010010110100101101001011010010110100101101001011010
6	0011110000111100001111000011110000111100001111000011110000111100
7	0110100101101001011010010110100101101001011010010110100101101001
8	0000000011111111000000001111111100000000111111110000000011111111
9	0101010110101010010101011010101001010101101010100101010110101010
10	0011001111001100001100111100110000110011110011000011001111001100
11	0110011010011001011001101001100101100110100110010110011010011001
12	0000111111110000000011111111000000001111111100000000111111110000
13	0101101010100101010110101010010101011010101001010101101010100101
14	0011110011000011001111001100001100111100110000110011110011000011
15	0110100110010110011010011001011001101001100101100110100110010110
16	0000000000000000111111111111111100000000000000001111111111111111
17	0101010101010101101010101010101001010101010101011010101010101010
18	0011001100110011110011001100110000110011001100111100110011001100
19	0110011001100110100110011001100101100110011001101001100110011001
20	0000111100001111111100001111000000001111000011111111000011110000
21	0101101001011010101001011010010101011010010110101010010110100101
22	0011110000111100110000111100001100111100001111001100001111000011
23	0110100101101001100101101001011001101001011010011001011010010110
24	0000000011111111111111110000000000000000111111111111111100000000
25	0101010110101010101010100101010101010101101010101010101001010101
26	0011001111001100110011000011001100110011110011001100110000110011
27	0110011010011001100110010110011001100110100110011001100101100110
28	0000111111110000111100000000111100001111111100001111000000001111
29	0101101010100101101001010101101001011010101001011010010101011010
30	0011110011000011110000110011110000111100110000111100001100111100
31	0110100110010110100101100110100101101001100101101001011001101001
32	0000000000000000000000000000000011111111111111111111111111111111
33	0101010101010101010101010101010110101010101010101010101010101010
34	0011001100110011001100110011001111001100110011001100110011001100
35	0110011001100110011001100110011010011001100110011001100110011001
36	0000111100001111000011110000111111110000111100001111000011110000
37	0101101001011010010110100101101010100101101001011010010110100101
38	0011110000111100001111000011110011000011110000111100001111000011
39	0110100101101001011010010110100110010110100101101001011010010110
40	0000000011111111000000001111111111111111000000001111111100000000
41	0101010110101010010101011010101010101010010101011010101001010101
42	0011001111001100001100111100110011001100001100111100110000110011
43	0110011010011001011001101001100110011001011001101001100101100110
44	0000111111110000000011111111000011110000000011111111000000001111
45	0101101010100101010110101010010110100101010110101010010101011010
46	0011110011000011001111001100001111000011001111001100001100111100
47	0110100110010110011010011001011010010110011010011001011001101001
48	0000000000000000111111111111111111111111111111110000000000000000
49	0101010101010101101010101010101010101010101010100101010101010101
50	0011001100110011110011001100110011001100110011000011001100110011
51	0110011001100110100110011001100110011001100110010110011001100110
52	0000111100001111111100001111000011110000111100000000111100001111
53	0101101001011010101001011010010110100101101001010101101001011010
54	0011110000111100110000111100001111000011110000110011110000111100
55	0110100101101001100101101001011010010110100101100110100101101001
56	0000000011111111111111110000000011111111000000000000000011111111
57	0101010110101010101010100101010110101010010101010101010110101010
58	0011001111001100110011000011001111001100001100110011001111001100
59	0110011010011001100110010110011010011001011001100110011010011001
60	0000111111110000111100000000111111110000000011110000111111110000
61	0101101010100101101001010101101010100101010110100101101010100101
62	0011110011000011110000110011110011000011001111000011110011000011
63	0110100110010110100101100110100110010110011010010110100110010110

Families of OVSF

OVSF

#	1-Chip
0	0

OVSF

#	2-Chips
0	00
1	01

2x2

OVSF

#	4-Chips
0	0000
1	0101
2	0011
3	0110

4x4

OVSF

#	8-Chips
0	00000000
1	01010101
2	00110011
3	01100110
4	00001111
5	01011010
6	00111100
7	01101001

8x8

OVSF

#	---- 16-Chips -------
0	0000000000000000
1	0101010101010101
2	0011001100110011
3	0110011001100110
4	0000111100001111
5	0101101001011010
6	0011110000111100
7	0110100101101001
8	0000000011111111
9	0101010110101010
10	0011001111001100
11	0110011010011001
12	0000111111110000
13	0101101010100101
14	0011110011000011
15	0110100110010110

16x16

OVSF

#	---------- 32-Chip Sequence ------------
0	00000000000000000000000000000000
1	01010101010101010101010101010101
2	00110011001100110011001100110011
3	01100110011001100110011001100110
4	00001111000011110000111100001111
5	01011010010110100101101001011010
6	00111100001111000011110000111100
7	01101001011010010110100101101001
8	00000000111111110000000011111111
9	01010101101010100101010110101010
10	00110011110011000011001111001100
11	01100110100110010110011010011001
12	00001111111100000000111111110000
13	01011010101001010101101010100101
14	00111100110000110011110011000011
15	01101001100101100110100110010110
16	00000000000000001111111111111111
17	01010101010101011010101010101010
18	00110011001100111100110011001100
19	01100110011001101001100110011001
20	00001111000011111111000011110000
21	01011010010110101010010110100101
22	00111100001111001100001111000011
23	01101001011010011001011010010110
24	00000000111111111111111100000000
25	01010101101010101010101001010101
26	00110011110011001100110000110011
27	01100110100110011001100101100110
28	00001111111100001111000000001111
29	01011010101001011010010101011010
30	00111100110000111100001100111100
31	01101001100101101001011001101001

32x32

Orthogonal Variable Spreading Factor

#	------------------------------- 64-Chip Sequence ---------------------------------------
0	0000000000000000000000000000000000000000000000000000000000000000
1	0101010101010101010101010101010101010101010101010101010101010101
2	0011001100110011001100110011001100110011001100110011001100110011
3	0110011001100110011001100110011001100110011001100110011001100110
4	0000111100001111000011110000111100001111000011110000111100001111
5	0101101001011010010110100101101001011010010110100101101001011010
6	0011110000111100001111000011110000111100001111000011110000111100
7	0110100101101001011010010110100101101001011010010110100101101001
8	0000000011111111000000001111111100000000111111110000000011111111
9	0101010110101010010101011010101001010101101010100101010110101010
10	0011001111001100001100111100110000110011110011000011001111001100
11	0110011010011001011001101001100101100110100110010110011010011001
12	0000111111110000000011111111000000001111111100000000111111110000
13	0101101010100101010110101010010101011010101001010101101010100101
14	0011110011000011001111001100001100111100110000110011110011000011
15	0110100110010110011010011001011001101001100101100110100110010110
16	0000000000000000111111111111111100000000000000001111111111111111
17	0101010101010101101010101010101001010101010101011010101010101010
18	0011001100110011110011001100110000110011001100111100110011001100
19	0110011001100110100110011001100101100110011001101001100110011001
20	0000111100001111111100001111000000001111000011111111000011110000
21	0101101001011010101001011010010101011010010110101010010110100101
22	0011110000111100110000111100001100111100001111001100001111000011
23	0110100101101001100101101001011001101001011010011001011010010110
24	0000000011111111111111110000000000000000111111111111111100000000
25	0101010110101010101010100101010101010101101010101010101001010101
26	0011001111001100110011000011001100110011110011001100110000110011
27	0110011010011001100110010110011001100110100110011001100101100110
28	0000111111110000111100000000111100001111111100001111000000001111
29	0101101010100101101001010101101001011010101001011010010101011010
30	0011110011000011110000110011110000111100110000111100001100111100
31	0110100110010110100101100110100101101001100101101001011001101001
32	0000000000000000000000000000000011111111111111111111111111111111
33	0101010101010101010101010101010110101010101010101010101010101010
34	0011001100110011001100110011001111001100110011001100110011001100
35	0110011001100110011001100110011010011001100110011001100110011001
36	0000111100001111000011110000111111110000111100001111000011110000
37	0101101001011010010110100101101010100101101001011010010110100101
38	0011110000111100001111000011110011000011110000111100001111000011
39	0110100101101001011010010110100110010110100101101001011010010110
40	0000000011111111000000001111111111111111000000001111111100000000
41	0101010110101010010101011010101010101010010101011010101001010101
42	0011001111001100001100111100110011001100001100111100110000110011
43	0110011010011001011001101001100110011001011001101001100101100110
44	0000111111110000000011111111000011110000000011111111000000001111
45	0101101010100101010110101010010110100101010110101010010101011010
46	0011110011000011001111001100001111000011001111001100001100111100
47	0110100110010110011010011001011010010110011010011001011001101001
48	0000000000000000111111111111111111111111111111110000000000000000
49	0101010101010101101010101010101010101010101010100101010101010101
50	0011001100110011110011001100110011001100110011000011001100110011
51	0110011001100110100110011001100110011001100110010110011001100110
52	0000111100001111111100001111000011110000111100000000111100001111
53	0101101001011010101001011010010110100101101001010101101001011010
54	0011110000111100110000111100001111000011110000110011110000111100
55	0110100101101001100101101001011010010110100101100110100101101001
56	0000000011111111111111110000000011111111000000000000000011111111
57	0101010110101010101010100101010110101010010101010101010110101010
58	0011001111001100110011000011001111001100001100110011001111001100
59	0110011010011001100110010110011010011001011001100110011010011001
60	0000111111110000111100000000111111110000000011110000111111110000
61	0101101010100101101001010101101010100101010110100101101010100101
62	0011110011000011110000110011110011000011001111000011110011000011
63	0110100110010110100101100110100110010110011010010110100110010110

64x64

OVSF Names

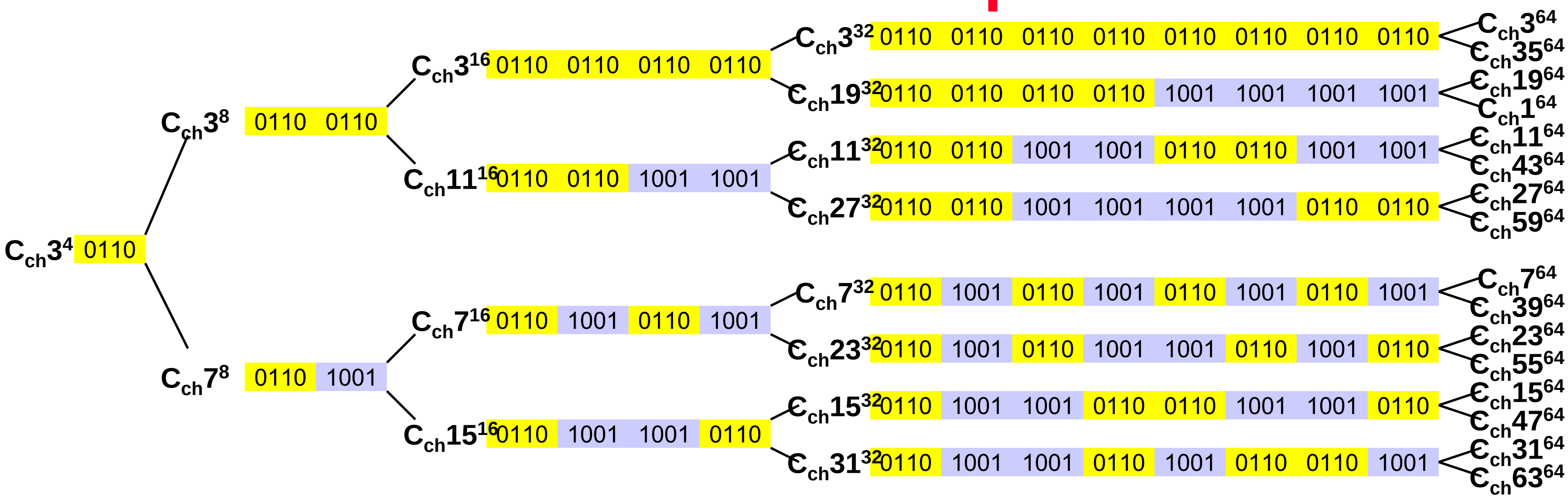
$C_{ch}12^{32}$ = "OVSF #12, 32 chips long."

OVSF Level Mapping

The OVSF shown here are in logical state values 0 and 1.
OVSF also can exist as physical bipolar signals. Logical zero is the signal value +1 and Logical 1 is the signal value -1.
Mapping: Logical 0,1 > +1, -1 Physical

- OVSF can be built to any size from a single zero by replicating and inverting
- All OVSF matrixes are square -- same number of codes and number of chips per code

OVSF Trees and Interdependencies



- Entire OVSF matrices can be built by replicating and inverting -- Individual OVSF sequences can also be expanded in the same way.
- WCDMA adds each symbol of information to one complete OVSF code
- Faster symbol rates therefore require shorter OVSF codes
- If a short OVSF is chosen to carry a fast data channel, that OVSF and all its replicative descendants are compromised and cannot be reused to carry other signals
- Therefore, the supply of available OVSF codes on a sector diminishes greatly while a fast data channel is being transmitted!

OVSF Families and Exclusions

- Consider a forward link supplemental channel being transmitted with a data rate of 307,200 symbols/second
  - Each symbol will occupy 4 chips at the 1x rate of 1,228,800 c/s.
  - A 4-chip OVSF will be used for this channel
- If OVSF #3 (4 chips) is chosen for this channel:
  - Use of $C_{ch}3^4$ will preclude other usage of the following 64-chip OVSF:
  - 3, 35, 19, 51, 11, 43, 27, 59, 7, 39, 23, 55, 15, 47, 31, 63 -- all forbidden!
  - 16 codes are tied up since the data is being sent at 16 times the rate of conventional 64-chip OVSF
- The Node B controller managing this sector must track the precluded OVSF and ensure they aren't assigned

$W3^4$ 0110

Orthogonal Variable Spreading Factor

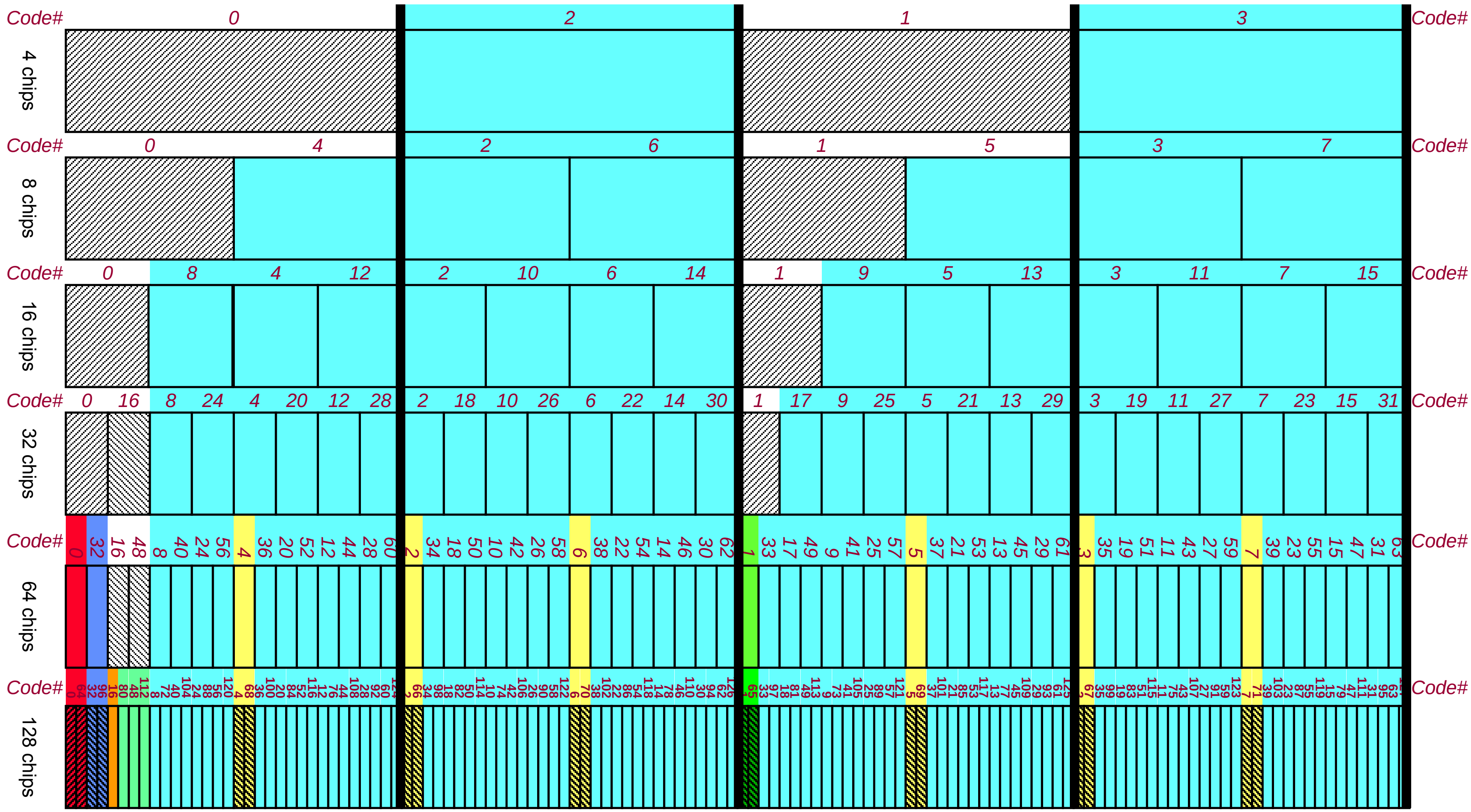
#	64-Chip Sequence
0	0000000000000000000000000000000000000000000000000000000000000000
1	0101010101010101010101010101010101010101010101010101010101010101
2	0011001100110011001100110011001100110011001100110011001100110011
~~3~~	~~0110011001100110011001100110011001100110011001100110011001100110~~
4	0000111100001111000011110000111100001111000011110000111100001111
5	0101101001011010010110100101101001011010010110100101101001011010
6	0011110000111100001111000011110000111100001111000011110000111100
~~7~~	~~0110100101101001011010010110100101101001011010010110100101101001~~
8	0000000011111111000000001111111100000000111111110000000011111111
9	0101010110101010010101011010101001010101101010100101010110101010
10	0011001111001100001100111100110000110011110011000011001111001100
~~11~~	~~0110011010011001011001101001100101100110100110010110011010011001~~
12	0000111111110000000011111111000000001111111100000000111111110000
13	0101101010100101010110101010010101011010101001010101101010100101
14	0011110011000011001111001100001100111100110000110011110011000011
~~15~~	~~0110100110010110011010011001011001101001100101100110100110010110~~
16	0000000000000000111111111111111100000000000000001111111111111111
17	0101010101010101101010101010101001010101010101011010101010101010
18	0011001100110011110011001100110000110011001100111100110011001100
~~19~~	~~0110011001100110100110011001100101100110011001101001100110011001~~
20	0000111100001111111100001111000000001111000011111111000011110000
21	0101101001011010101001011010010101011010010110101010010110100101
22	0011110000111100110000111100001100111100001111001100001111000011
~~23~~	~~0110100101101001100101101001011001101001011010011001011010010110~~
24	0000000011111111111111110000000000000000111111111111111100000000
25	0101010110101010101010100101010101010101101010101010101001010101
26	0011001111001100110011000011001100110011110011001100110000110011
~~27~~	~~0110011010011001100110010110011001100110100110011001100101100110~~
28	0000111111110000111100000000111100001111111100001111000000001111
29	0101101010100101101001010101101001011010101001011010010101011010
30	0011110011000011110000110011110000111100110000111100001100111100
~~31~~	~~0110100110010110100101100110100101101001100101101001011001101001~~
32	0000000000000000000000000000000011111111111111111111111111111111
33	0101010101010101010101010101010110101010101010101010101010101010
34	0011001100110011001100110011001111001100110011001100110011001100
~~35~~	~~0110011001100110011001100110011010011001100110011001100110011001~~
36	0000111100001111000011110000111111110000111100001111000011110000
37	0101101001011010010110100101101010100101101001011010010110100101
38	0011110000111100001111000011110011000011110000111100001111000011
~~39~~	~~0110100101101001011010010110100110010110100101101001011010010110~~
40	0000000011111111000000001111111111111111000000001111111100000000
41	0101010110101010010101011010101010101010010101011010101001010101
42	0011001111001100001100111100110011001100001100111100110000110011
~~43~~	~~0110011010011001011001101001100110011001011001101001100101100110~~
44	0000111111110000000011111111000011110000000011111111000000001111
45	0101101010100101010110101010010110100101010110101010010101011010
46	0011110011000011001111001100001111000011001111001100001100111100
~~47~~	~~0110100110010110011010011001011010010110011010011001011001101001~~
48	0000000000000000111111111111111111111111111111110000000000000000
49	0101010101010101101010101010101010101010101010100101010101010101
50	0011001100110011110011001100110011001100110011000011001100110011
~~51~~	~~0110011001100110100110011001100110011001100110010110011001100110~~
52	0000111100001111111100001111000011110000111100000000111100001111
53	0101101001011010101001011010010110100101101001010101101001011010
54	0011110000111100110000111100001111000011110000110011110000111100
~~55~~	~~0110100101101001100101101001011010010110100101100110100101101001~~
56	0000000011111111111111110000000011111111000000000000000011111111
57	0101010110101010101010100101010110101010010101010101010110101010
58	0011001111001100110011000011001111001100001100110011001111001100
~~59~~	~~0110011010011001100110010110011010011001011001100110011010011001~~
60	0000111111110000111100000000111111110000000011110000111111110000
61	0101101010100101101001010101101010100101010110100101101010100101
62	0011110011000011110000110011110011000011001111000011110011000011
~~63~~	~~0110100110010110100101100110100110010110011010010110100110010110~~

Which OVSF preclude each another?

$C_{ch}xx^{yy}$ ties up every **YY**th OVSF starting with #**XX**.

OVSF Code “Trees”

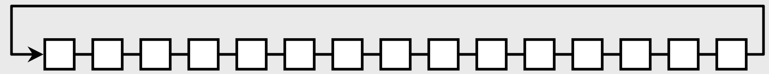
This way of displaying OVSF codes is called “bit reversal order”. It shows each OVSF code’s parents and children. Remember, we cannot use any OVSF code if another OVSF code directly above it or below it is in use.



PN M-Sequences: Generation & Properties

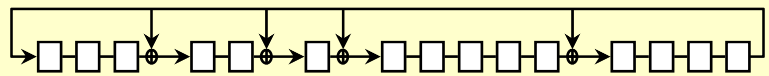
- Maximal-length sequences used in W-CDMA are generated in linear shift registers
- Simple shift register: sequence length = length of register
- Tapped shift register generates a wild, self-mutating sequence 2^N-1 chips long (N=register length)
  - Such sequences match if compared in step (no-brainer, any sequence matches itself)
  - Such sequences appear approximately orthogonal if compared with themselves not exactly matched in time
  - Cross-correlation typically <2%

An Ordinary Shift Register



Sequence repeats *every **N** chips,*
where N is number of cells in register

A Tapped, Summing Shift Register

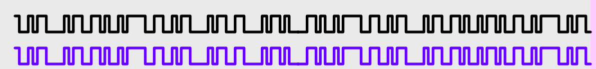


Sequence repeats *every **2^N-1** chips,*
where N is number of cells in register

A Special Characteristic of Sequences Generated in Tapped Shift Registers

Compared In-Step: Matches Itself

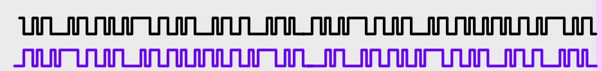
Sequence:
Self, in sync:



Sum: **Complete Correlation: All 0's**

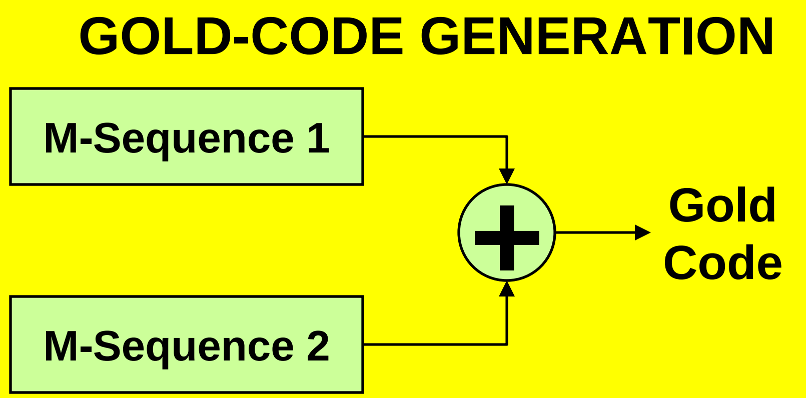
Compared Shifted: Little Correlation

Sequence:
Self, Shifted:



Sum: **Practically Orthogonal: Half 1's, Half 0's**

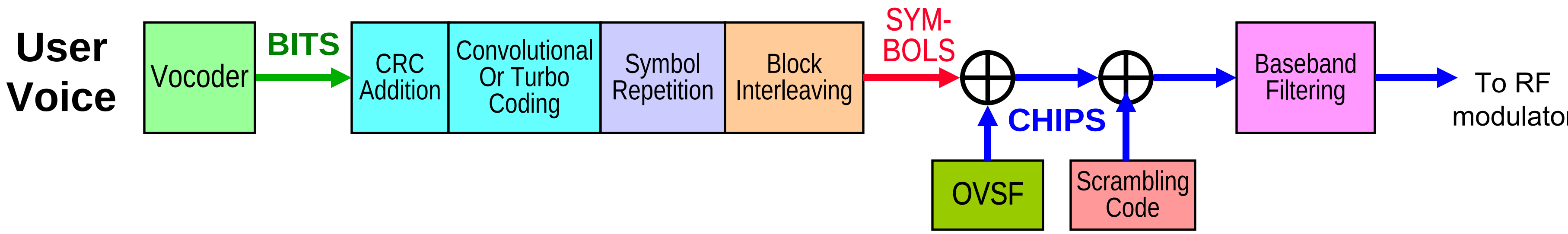
PN Sequences: Gold Codes



If the starting state for either of the M-Sequence generators is altered, a different Gold code will be produced.

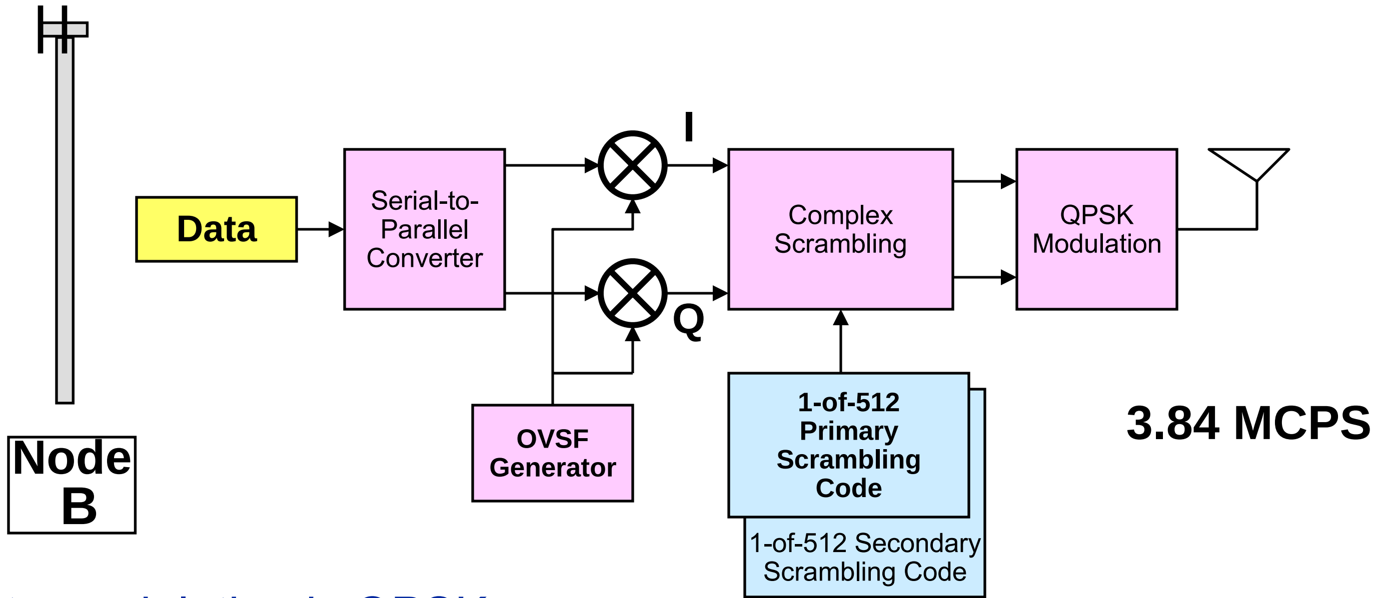
- Gold Codes were first described by R. Gold in 1967
  - Gold described a method for generating a PN sequence from a pair of primitive polynomials
- Gold Codes have defined and bounded cross-correlation
  - The cross-correlation can be much less than that achieved from M-sequences alone
- Gold Codes also provide a larger number of available codes than can be achieved using M-sequences alone

Steps in WCDMA Signal Generation



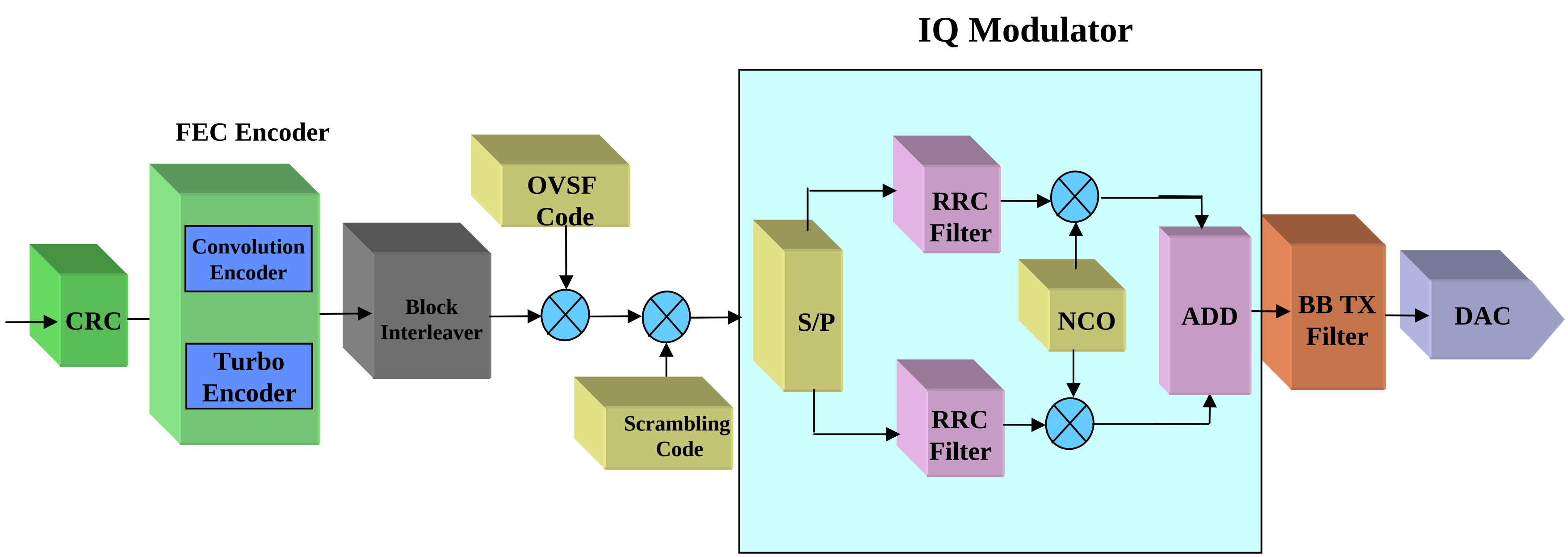
Function	What Does It Do?	Why Do We Do It?
Vocoding	**Encodes user voice or data**	For digitization and compression. The main goal is to have fewer bits to transmit, maximizing capacity..
Convolutional Coding	**Encode information bit stream before transmission**	Add calculated redundancy in the bit stream to allow error correction at reception after noisy radio link.
Symbol Repetition	**Repeat information symbols before transmission**	Increase redundancy in the bitstream even further when bit rates are low enough to allow it
Block Interleaving	**Disperse redundant bits away from each other**	Ensures symbols representing an information bit are distributed throughout the 10 ms. frame, ensuring no error burst wipes out all symbols of a specific bit..
Orthogonal Spreading	**Create a Spread-Spectrum Signal; make User channel**	Spreading user bitstream into spread-spectrum chipstream for gain advantage; the specific OVSF code is the user's "channel" in the cell
Scrambling	**Scramble user chipstreams in a cell (DL) or UE (UL)**	This makes the DL signal of each cell unique from other cells and each UE (UL) from other UEs.
Quadrature Spreading	**Add additional phase dimensions to RF signal**	Increases the bandwidth-density of transmitted information for maximum system capacity
Power Control	**Node B adjusts UE's transmit power**	So each UE transmits enough power to achieve desired S/N, without causing excessive interference
Baseband Filtering	**Restrict and shape signal bandwidth**	Eliminate outer sidebands of the baseband signal to meet bandwith requirements

Downlink Spreading and Modulation

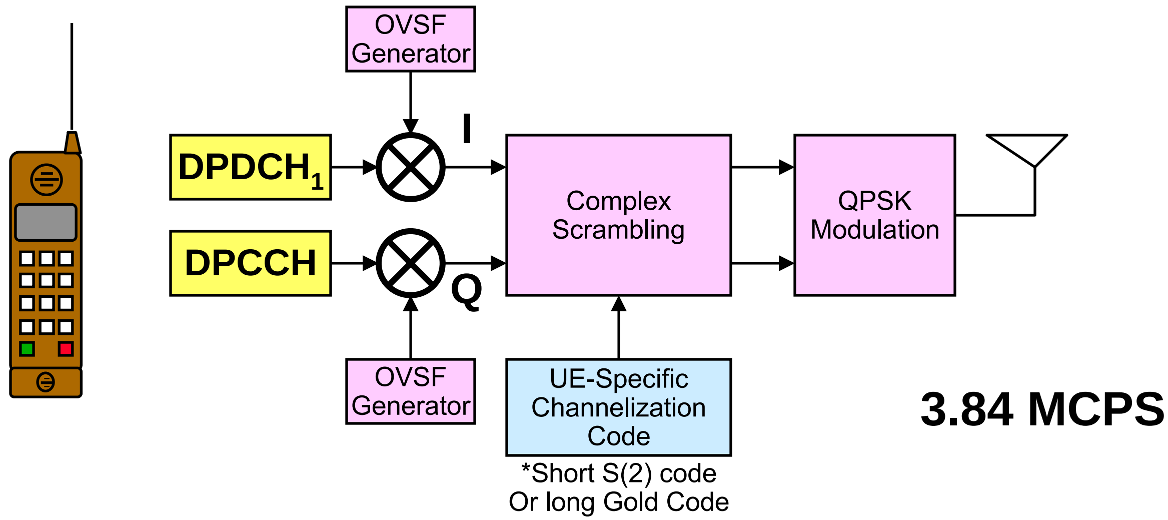


- Data modulation is QPSK
- Each pair of two bits are serial-parallel converted and mapped to the I and Q branches
  - I and Q are then spread to chip rate with an OVSF unique for the specific channel
- Complex spreading uses one of 512 primary scrambling codes
  - the primary CCPCH is scrambled this way
  - Other downlink physical channels are scrambled using the primary scrambling code or a secondary scrambling code from the set of the chosen 1-of-512 primary scrambling code

Transmitter Elements in a Node B

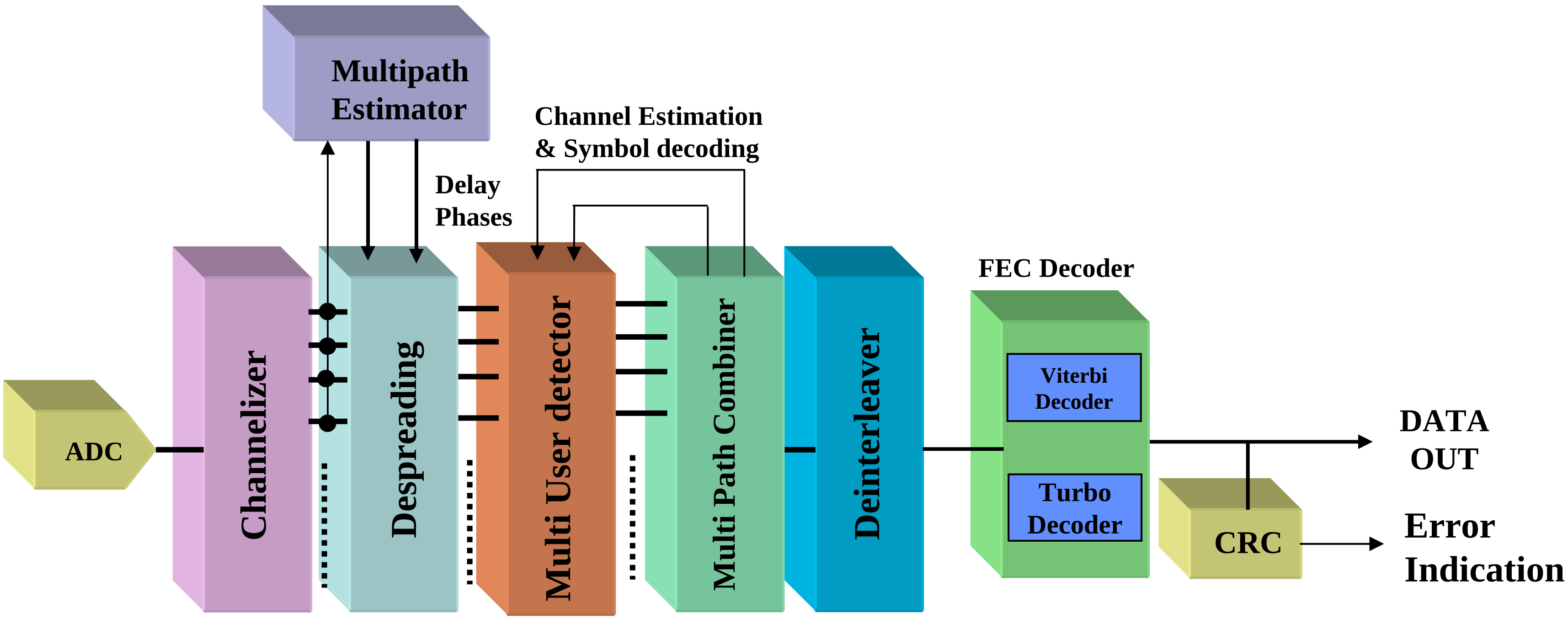


Uplink Spreading and Modulation



- Dual-channel QPSK is used
- DPCCH channel mapped to Q, first DPDCH mapped to I
  - Subsequently-mapped DPDCHs can be mapped to I or Q
- I and Q are then spread to chip rate with two different OVSF codes
- In an ordinary Node B, a 38.4K-long Gold Code is used for complex scrambling
  - If transmitting to a Node B with advanced receiver for multi-user detection, a 256 code from the S(2) family is used instead

Receiver Elements in a Node B



Differences between WCDMA and CDMA2000

Comparison of IS-2000 and W-CDMA

Parameters	3GPP2 (cdma2000)	3GPP (W-CDMA)
Multiple Access Technique and duplexing scheme	Multiple access: DS-CDMA (UL) MC-CDMA(DL) Duplexing: FDD	Multiple Access: DS-CDMA Duplexing: FDD
Chip Rate	N x 1.2288 Mchip/s (N = 1,3,6,9,12)	3.84 Mchips/s
Pilot Structure	Code-divided continuous dedicated pilot (UL) Code-divided continuous common pilot (DL) Code-divided continuous common or dedicated auxiliary pilot (DL)	Dedicated pilots (UL) Common and/or dedicated pilots (DL)
Frame Length	5, 10, 20, 40, 80 ms (usually 20)	10 ms with 15 slots
Modulation and Detection	Data modulation: UL-BPSK DL-QPSK Spreading modulation: UL-HPSK DL-QPSK Detection: pilot-aided coherent detection	Data mod:UL-dual channel QPSK; DL-QPSK Spreading modulation: QPSK Detection: pilot-aided coherent detection
Channelization Code	Walsh Codes (UL) Walsh Codes or quasi-orthogonal codes(DL)	Orthogonal variable spreading factor codes
Scrambling Code	Long code (period 2^{42}-1 chips for N=1) Short PN code (period 2^{15}-1 chips for N=1) N = spreading rate number	UL - short code (256 chips from family of S(2) codes or long code (38,400 chips, Gold-code-based) DL: Gold-code-based
Access Scheme	RsMa - flexible random access scheme Allowing three modes of access: -Basic Access -Power controlled Access -Reserved access Designated access scheme - access scheme initiated by the base station message	Acquisition-indication-based random access mechanism with power ramping on preamble followed by message
Inter-base-station operation	Synchronous, requiring GPS at each BTS for synchronization	Asynchronous, E-1 sufficient to sync. Precision Synchronous (optional)

W-CDMA Parameters

Parameters	3GPP (W-CDMA)
Carrier Spacing	5 MHz. (nominal) 4.2-5.4 MHz. On 200 kHz. raster
Downlink RF Channel Structure	Direct Spread
Chip Rate	3.84 Mcps
Roll-off factor for chip shaping	0.22
Frame Length	10 ms.
Number of slots/frame	15
Spreading modulation	Balanced QPSK (downlink) Dual channel QPSK (uplink) Complex spreading circuit
Data modulation	QPSK (downlink) BPSK (uplink)
Coherent Detection	Pilot Symbols/channel
Channel multiplexing in uplink	Control and pilot channel time multiplexed. For the data and control channels I and Q multiplexing
Multirate	Variable spreading and multicode
Spreading Factors	4-256
Power Control	Open and fast closed loop (1.5 kHz.)
Spreading (downlink)	Variable length orthogonal sequences for channel separation. Gold sequences 2^{18} for user separation (different time shifts in I and Q channel, truncated cycle 10 ms.)
Spreading (uplink)	Variable length orthogonal sequences for channel separation. Gold sequences 2^{18} for user separation (different time shifts in I and Q channel, truncated cycle 10 ms.)
Handover	Soft handover; Interfrequency Handover

WCDMA Channels

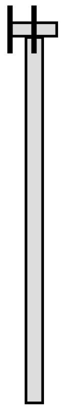
Introduction to WCDMA Channels

- Like other wireless technologies, WCDMA uses various types of channels to carry the actual information to and from users, and to manage the connections between users and the system
- The channels break down cleanly into several categories:
- In terms of ownership or control:
  - COMMON channels are public places, much like a hotel lobby
  - DEDICATED channels are private for one user, much like a guest room in a hotel
  - SHARED channels can serve several users at a time
- In terms of direction:
  - FORWARD channels are transmitted by Node B, received by UE
  - REVERSE channels are transmitted by UE, received by Node B
- In terms of purpose:
  - DATA
  - CONTROL (includes PRIMARY and SECONDARY subchannels)
  - SYNC (includes PRIMARY and SECONDARY subchannels)

Physical Channel Characteristics

- The physical channels are "carved out" of the code / frequency plane
  - On the Uplink, different information streams may be transmitted on the I and Q phase planes of the UE's signal
- A Physical channel is a specific combination of
  - carrier frequency
  - code
  - for uplink channels only, also relative phase I or Q (0 or pi /2)
- Most Physical channels are also time-multiplexed using a three-tier structure of super frames, radio frames, and time slots
  - Depending on the symbol rate of the physical channel, the configuration of radio frames or time slots varies
  - these time-patterns are shown in a following chapter

The W-CDMA Physical Channels

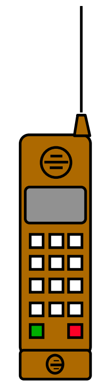


Node B

DOWNLINK CHANNELS

CPICH (P-CPICH, S-CPICH)	Common Pilot Channel
P-CCPCH	Primary Common Control Physical Channel
S-CCPCH	Secondary Common Control Physical Channel
SCH (P-SCH, S-SCH)	Synchronization Channel
PICH	Page Indication Channel
AICH	Acquisition Indication Channel
AP-AICH	Access Preamble Acquisition Indicator Channel
CSICH	CPCH Status Indicator Channel
CD/CA-ICH	Collision Detection/Channel Assignment Indicator Channel
DPDCH	Dedicated Physical Data Channel
DPCCH	Dedicated Physical Control Channel
PDSCH	Physical Downlink Shared Channel

UPLINK CHANNELS



PRACH	Physical Random Access Channel
PCPCH	Physical Common Packet Channel
DPDCH	Dedicated Physical Data Channel
DPCCH	Dedicated Physical Control Channel

Forward W-CDMA Physical Channel Functions

DOWNLINK CHANNELS

Node B

CPICH (P-CPICH, S-CPICH)	Common Pilot Channel	UEs monitor as 1) phase reference for SCH, P- CCPCH, AICH, PICH and 2) to measure signal strength for cell selection/Handover Primary is uncoded and uses main scrambling pattern of the cell. Secondary can use other scrambling pattern and beam-forming.
P-CCPCH	Primary Common Control Physical Channel	BCH cell configuration information. Same OVSF in every cell. Not transmitted in first 256 chips of every slot (90% duty factor).
S-CCPCH	Secondary Common Control Physical Channel	Contains Paging Channel PCH and Forward Access Channel FACH time-multiplexed. OVSF is announced on the P-CCPCH.
SCH (P-SCH, S-SCH)	Synchronization Channel	In PCCPCH idle period. Two subchannels, Unmodulated P-SCH gives S-SCH timing. S-SCH gives long code group.
PICH	Page Indication Channel	Idle mobiles sleep deeply to save battery power, only looking at this channel to see if they need to wake up and hear a page.
AICH	Acquisition Indication Channel	A mobile sending a random access preamble watches AICH to see when it may end the preamble and transmit its request.
AP-AICH	Access Preamble Acquisition Indicator Channel	A mobile sending a CPCH preamble watches AICH to see when it may end the preamble and transmit its request.
CSICH	CPCH Status Indicator Channel	Fixed-rate downlink channel carries CPCH status information. Paired with CPCH AP-AICH, uses same ch. and scr. codes
CD/CA-ICH	Collision Detection/Channel Assignment Indicator Channel	Fixed-rate common DL channel carries CD indicator only if CA is not active, or both CD/CA indicators if CA is active
DPDCH	Dedicated Physical Data Channel	
DPCCH	Dedicated Physical Control Channel	Carries user or control information to a UE wherever it may be in the cell.
PDSCH	Physical Downlink Shared Channel	Downlink channel used to carry fast user data (the DSCH transport channel). Much like “supplemental channel” in IS-2000.

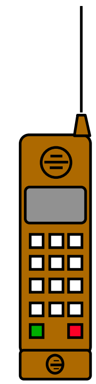
More on SCH Coding

- The Primary SCH consists of an unmodulated code 256 chips long
  - Transmitted once every slot
  - The same code is used for every base station in the system
    - Transmitted time-aligned with the slot boundary
- The Secondary SCH consists of one modulated code 256 chips long, transmitted in parallel with the Primary SCH
  - The code is one of 8, determined by the code group set to which the base station's downlink scrambling code belongs
  - S-SCH is modulated by a binary sequence 16 bits long, repeated each frame
  - The same sequence is used for each Node B and has good cyclic autocorrelation
- The SCH is transmitted intermittently (one codeword per slot)
  - Multiplexed with DPDCH/DPCCH and CCPCH after long code scrambling
  - So SCH is non-orthogonal to the other downlink physical channels

Reverse W-CDMA Physical Channel Functions

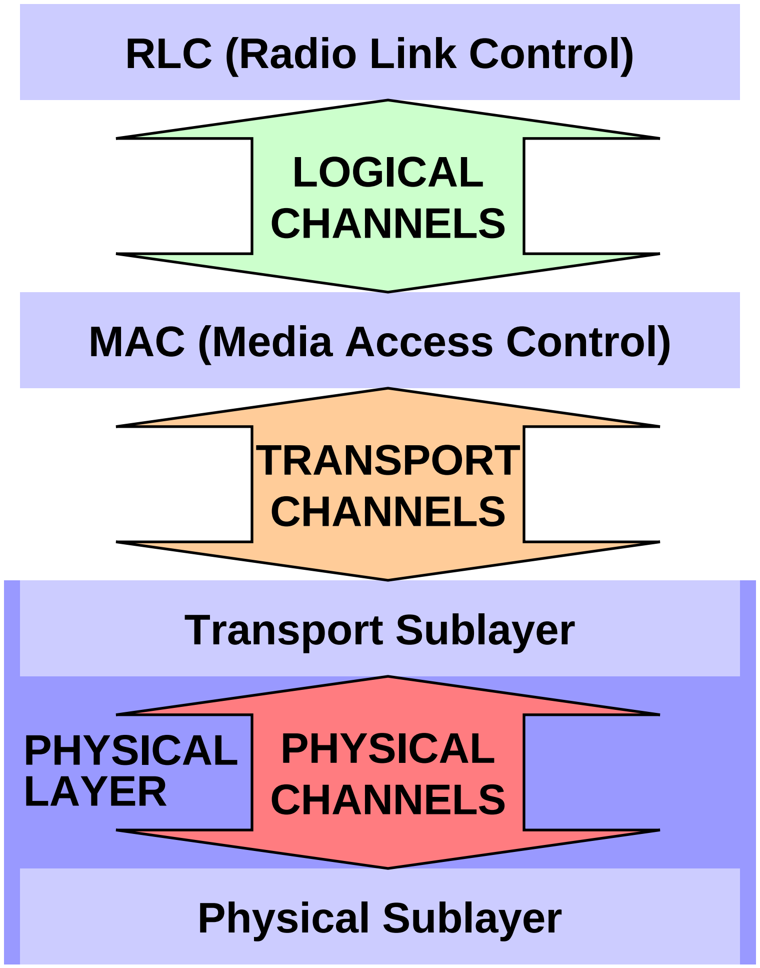
UPLINK CHANNELS

A common uplink physical channel used to carry control information or short user packets from the UE	Physical Random Access Channel	**PRACH**
A common uplink physical channel used to carry short and medium- sized user packets. It's always associated with a downlink channel for power control	Physical Common Packet Channel	**PCPCH**
Carries user data from a UE anywhere in the cell. Usually only one DPDCH allocated per connection, services interleaved on it.	Dedicated Physical Data Channel	**DPDCH**
Carries user or control information from a UE wherever it may be in the cell. Pilot symbols, Pwr ctrl bits, reverse rate indication. Can be continuous (code multiplexed) or time-multiplexed.	Dedicated Physical Control Channel	**DPCCH**



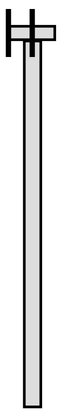
Channels at Three Functional Levels

- Thus far we've considered only channels physically identifiable in the WCDMA signal. However, the flow of information can be defined as channels at three distinct levels:
- Physical Channels
  - These are the actual, tangible channels you could receive off-air and analyze
- Transport Channels
  - These are the internally-bundled flows of information between the packet controller function in the system and the actual Node B
- Logical Channels
  - These are the aggregated broad conceptual flows of information generated by software at the signaling and application levels

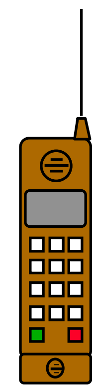


W-CDMA Logical Channels

DOWNLINK		UPLINK
BCH	**BROADCAST CONTROL CHANNEL** System Control Information for all users Configuration and Parameters	
DCCH	**DEDICATED CONTROL CHANNEL** A private channel carrying control information between one user and the network	DCCH
CCCH	**COMMON CONTROL CHANNEL** A shared channel carrying control information Between many users and the network	CCCH
PCCH	**PAGING CONTROL CHANNEL** A shared channel carrying paging information Between the network and many users	
DTCH	**DEDICATED TRAFFIC CHANNEL** A private bi-directional channel carrying traffic between one user and the network	DTCH
CTCH	**COMMON TRAFFIC CHANNEL** A shared channel carrying traffic from the network to many users or to groups of users	

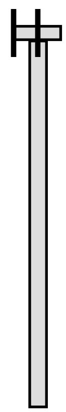


Node B

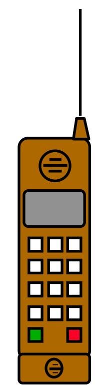


W-CDMA Transport Channels

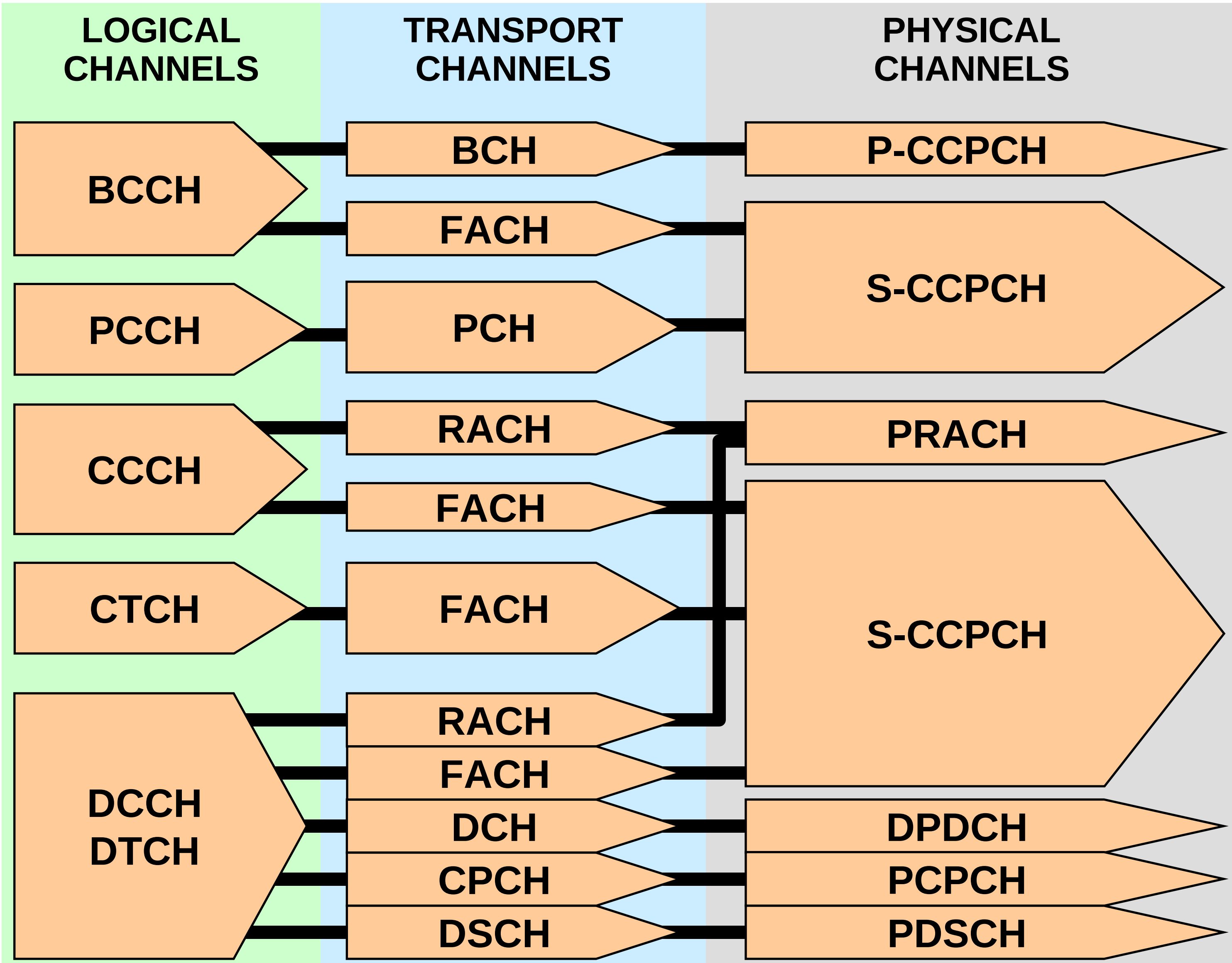
DOWNLINK		UPLINK
BCH →	**BROADCAST CHANNEL** **Low fixed bit rate, transmitted over the Entire sector coverage area**	*Configuration information*
PCH →	**PAGING CHANNEL** **Uses efficient sleep/slotted-mode procedures** **Transmitted over entire sector coverage area**	*Pages, Notifications*
Contention-based, Access, SMS	**RANDOM ACCESS CHANNEL** **Limited data fields, risk of collisions,** **Power control is open loop**	← **RACH**
FACH →	**FORWARD ACCESS CHANNEL** **Data rate can change each frame (10 ms)** **No fast power control; can use beam-forming**	*Common downlink For small bursts*
DCH →	**DEDICATED CHANNEL** **Data rate can change each frame (10 ms)** **Fast power control; can use beam-forming**	← **DCH**
Contention-based, Bursty traffic	**COMMON PACKET CHANNEL** **Change data rates fast; Open-loop ramp-up** **Fast power control; beam-forming, collision detection**	← **CPCH**
DSCH →	**DOWNLINK SHARED CHANNEL** **Fast data and fast power control;** **can use beam-forming. Paired with one DCH**	*Shared control or Bursty traffic*



Node B



Logical, Transport, Physical Channel Mapping

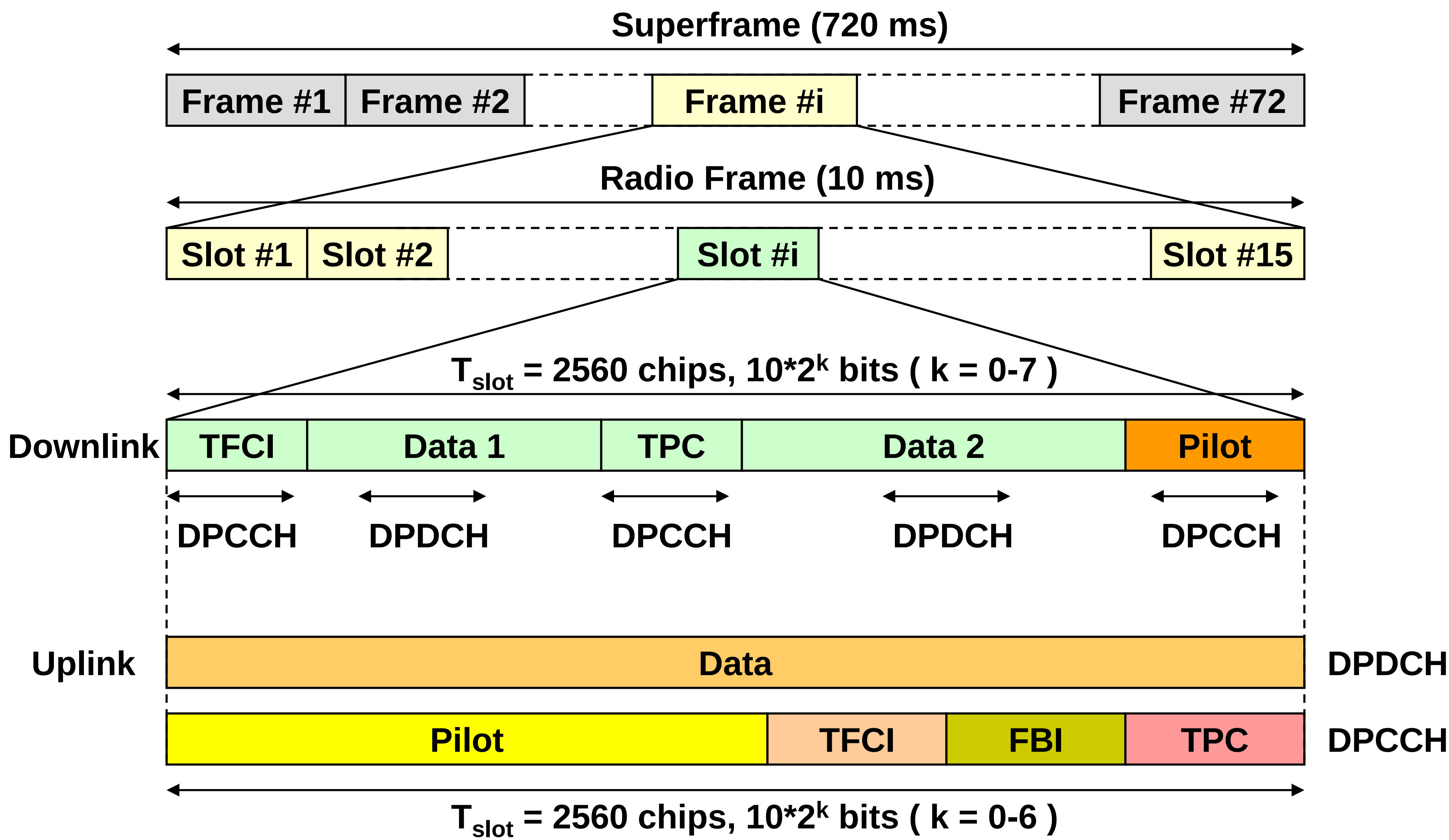


Timing Structure of WCDMA Channels

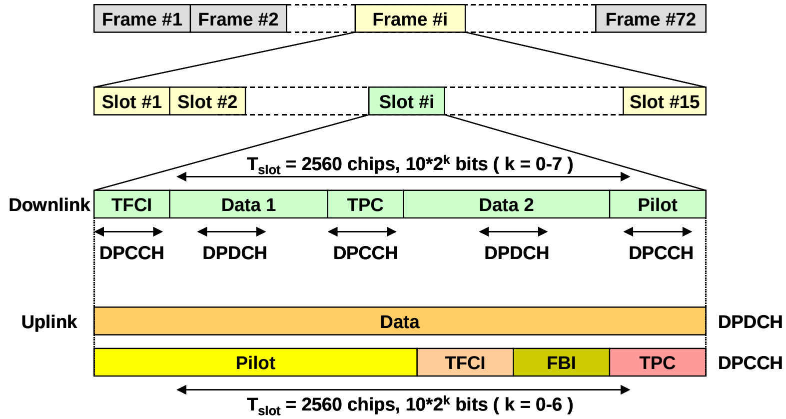
WCDMA Physical Channel Details

- A physical channel corresponds to a specific
  - Carrier frequency
  - Code
  - and in the case of uplink channels, I or Q phase (0 or pi/2)
- W-CDMA physical channels typically consist of a three-layer structure of superframes, radio frames, and time slots
  - Depending on the symbol rate of the physical channel, the configuration of the radio frames or time slots varies
- A Superframe is 720 ms. long and consists of 72 radio frames
  - boundaries are determined by its System Frame Number SFN
- A Radio Frame is a processing unit with 15 time slots
  - one slot includes 2560 chips
- A time slot is a unit containing information symbols
  - number of symbols per time slot depends on physical channel
- Uplink dedicated channels can use multicode transmission
  - up to six parallel DPDCH transmitted on different channelization codes

Dedicated Physical Channel Frame Structure

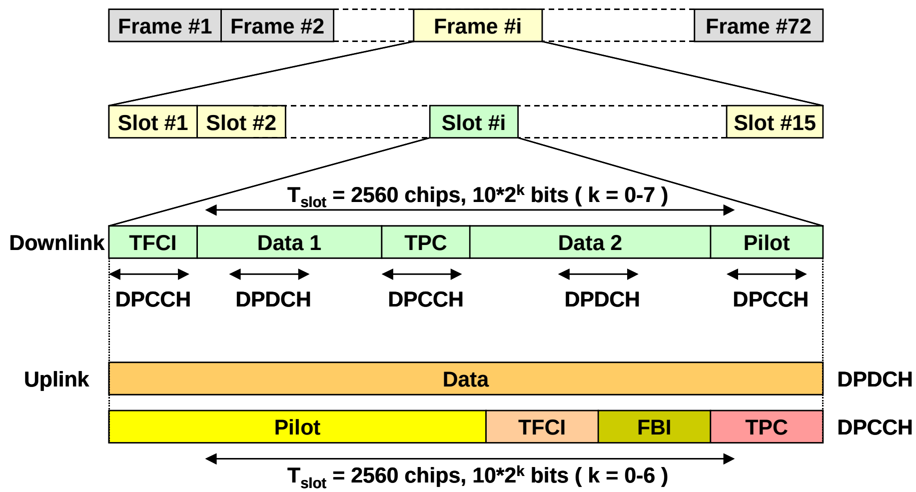


Physical Frame Structure



- Each radio frame of 10 ms is split into 15 slots
- Uplink Physical Channels DPDCH and DPCCH are I/Q multiplexed
- Downlink Physical Channels are time-multiplexed within each slot
  - DPCH, the channel on which user data is transmitted, is always associated with a DPCCH containing layer 1 information
  - The Transport Format Combination Indicator field is used to indicate the demultiplexing scheme of the data stream
  - The TFCI field does not exist for static (fixed bit rate allocations) or where blind transport format detection is used
  - The Feedback Information (FBI) field is used for transmit and site diversity functions
  - The Transmit Power Control bits are used for power control
  - On the downlink, a number of dedicated pilot bits may be included

Physical Channel Bit Rates



- Uplink
  - Max. physical channel bit rate 960 kb/s with spreading factor of 4
  - A user may use several physical channels to obtain higher bit rates
  - The channel bit rate of the DPCCH is fixed at 15 kb/s
  - The maximum uplink spreading factor is 256
- Downlink
  - Maximum channel bit rate is 1920 kb/s with a spreading factor of 4
  - The maximum downlink spreading factor is 512

Common Pilot Channel CPICH

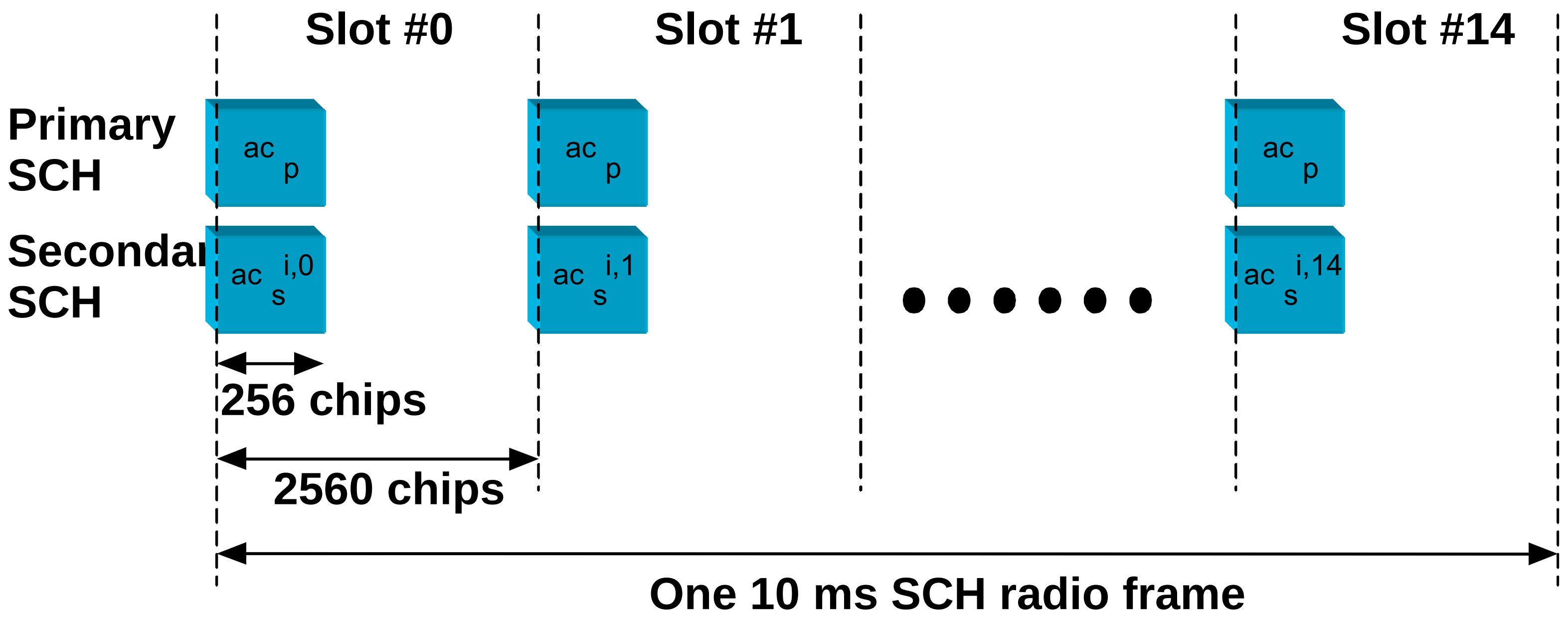
P-CPICH PRIMARY COMMON PILOT CHANNEL

- There is one and only one P-CPICH per cell
  - P-CPICH always uses same channelization code and the primary scrambling code of the cell
  - The P-CPICH is transmitted over the entire cell.
- The P-CPICH is the phase reference for the SCH, P-CCPCH, AICH, PICH AP-AICH, CD/CA-ICH, CSICH, and the S-CCPCH.
- The P-CPICH is the default phase reference for the downlink DPCH
  - upper layer signaling tells the UE if a different reference will be used

S-CPICH SECONDARY COMMON PILOT CHANNEL

- An OVSF SF=256 is arbitrarily used as the S-CPICH channelization code
- S-CPICH is scrambled by the primary OR a secondary scrambling code
- There may be zero, one, or several S-CPICH per cell;
- An S-CPICH may be transmitted over the entire cell or on a narrow beam
- S-CPICH may be the phase reference for a downlink DPCH.
  - If this occurs, the UE is informed by higher-layer signaling.
  - it is possible that an entirely different non-CPICH phase reference can be used for a downlink DPCH.

System Acquisition: the Synchronization Channel

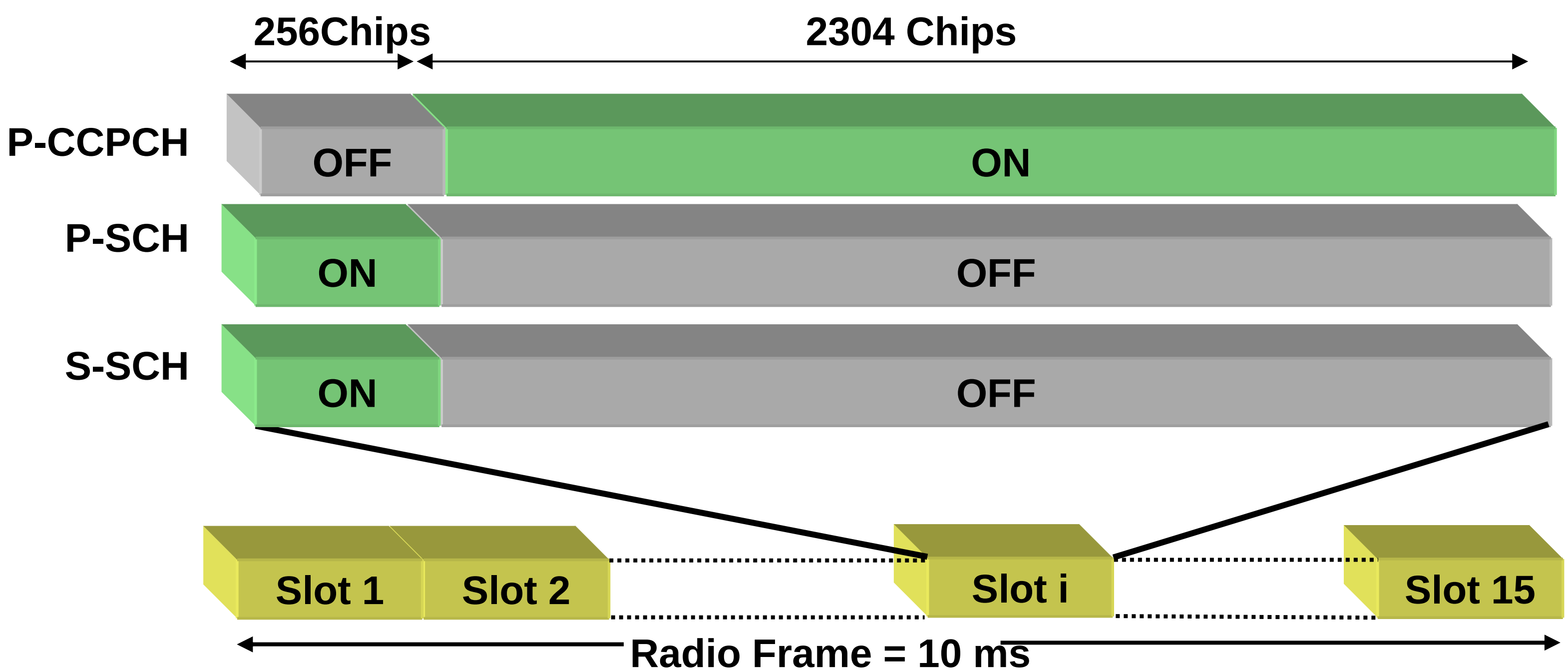


- Synchronization Channel (SCH) is a downlink signal for cell search
  - consists of two sub channels:
    - Primary SCH --- Secondary SCH
- The 10 ms radio frames of the Primary and Secondary SCH are divided into 15 slots, each 2560 chips long

The Primary SCH

- The Primary SCH consists of a modulated code of length 256 chips, the Primary Synchronization Code (PSC) denoted cp in figure , transmitted once every slot. The PSC is the same for every cell in the system.
- The Secondary SCH consists of repeatedly transmitting a length 15 sequence of modulated codes of length 256 chips, the Secondary Synchronization Codes (SSC), transmitted in parallel with the Primary SCH. The SSC is denoted cs i,k in figure, where i = 0, 1, …, 63 is the number of the scrambling code group, and k = 0, 1, …, 14 is the slot number.
- Each SSC is chosen from a set of 16 different codes of length 256. This sequence on the Secondary SCH indicates which of the code groups the cell's downlink scrambling code belongs to.

Multiplexing of SCH and P-CCPCH



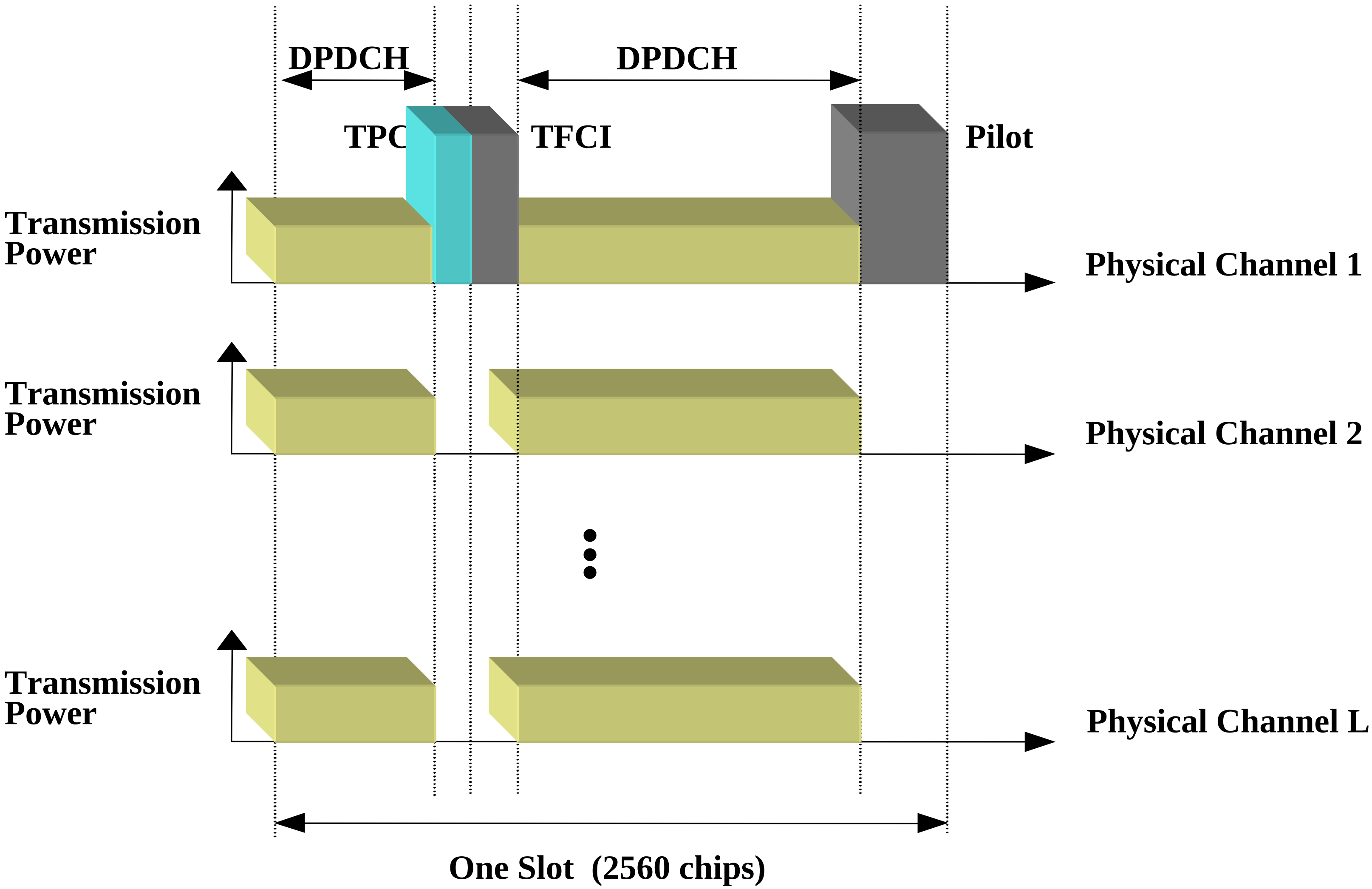
- The P-CCPCH and SCH are time multiplexed
  - the SCH gets 10% of each slot; the P-CCPCH gets the rest
- The P-SCH and S-SCH are code multiplexed

DPDCH and DPCCH Fields

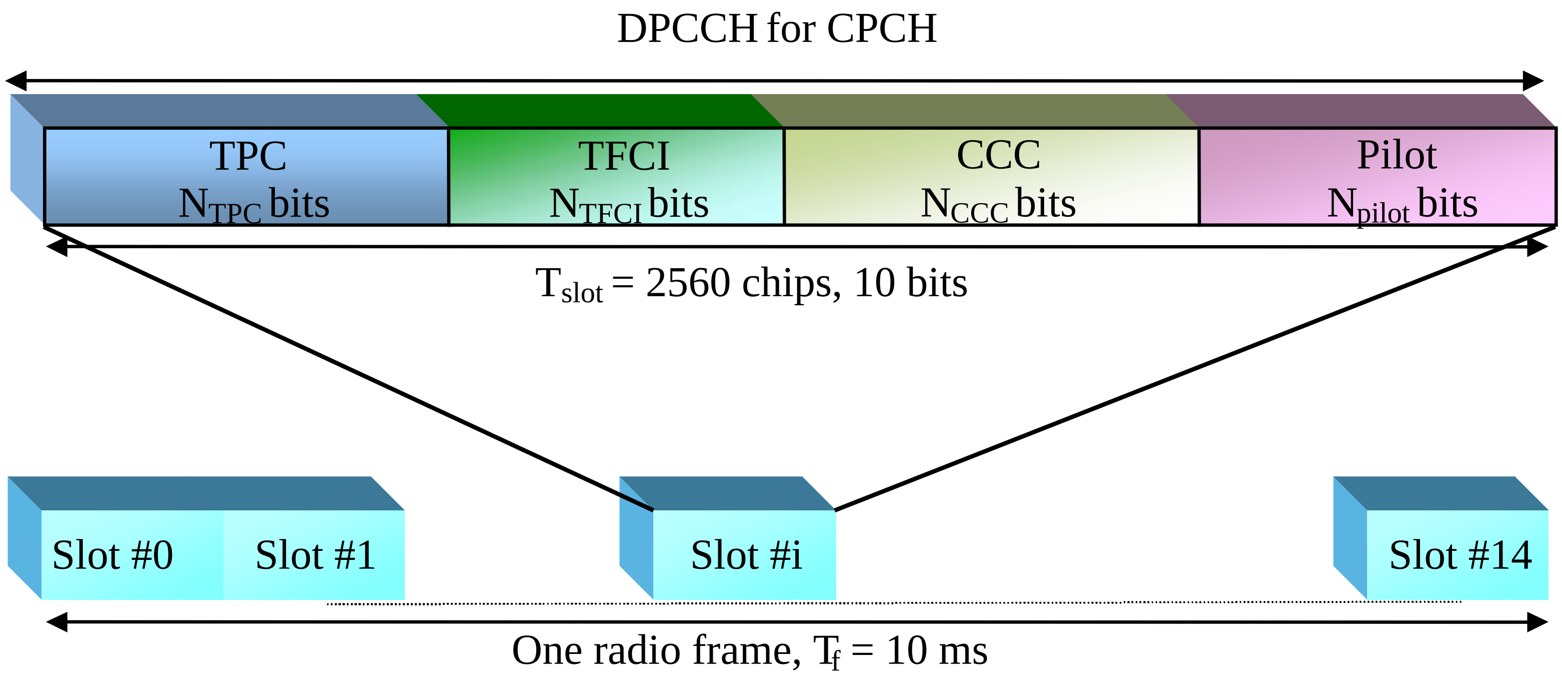
Slot Format #i	Channel Bit Rate (kbps)	Channel Symbol Rate (ksps)	SF	Bits/ Slot	DPDCH Bits/Slot		DPCCH Bits/Slot			Transmitted slots per radio frame N_{Tr}
					N_{Data1}	N_{Data2}	N_{TPC}	N_{TFCI}	N_{Pilot}	
0 the CPCH case	15	7.5	512	10	0	4	2	0	4	15
0A	15	7.5	512	10	0	4	2	0	4	8-14
0B	30	15	256	20	0	8	4	0	8	8-14
1	15	7.5	512	10	0	2	2	2	4	15
1B	30	15	256	20	0	4	4	4	8	8-14
2	30	15	256	20	2	14	2	0	2	15

Total number of slot formats = 50

Downlink Slot Format for Multi-Mode Transmission

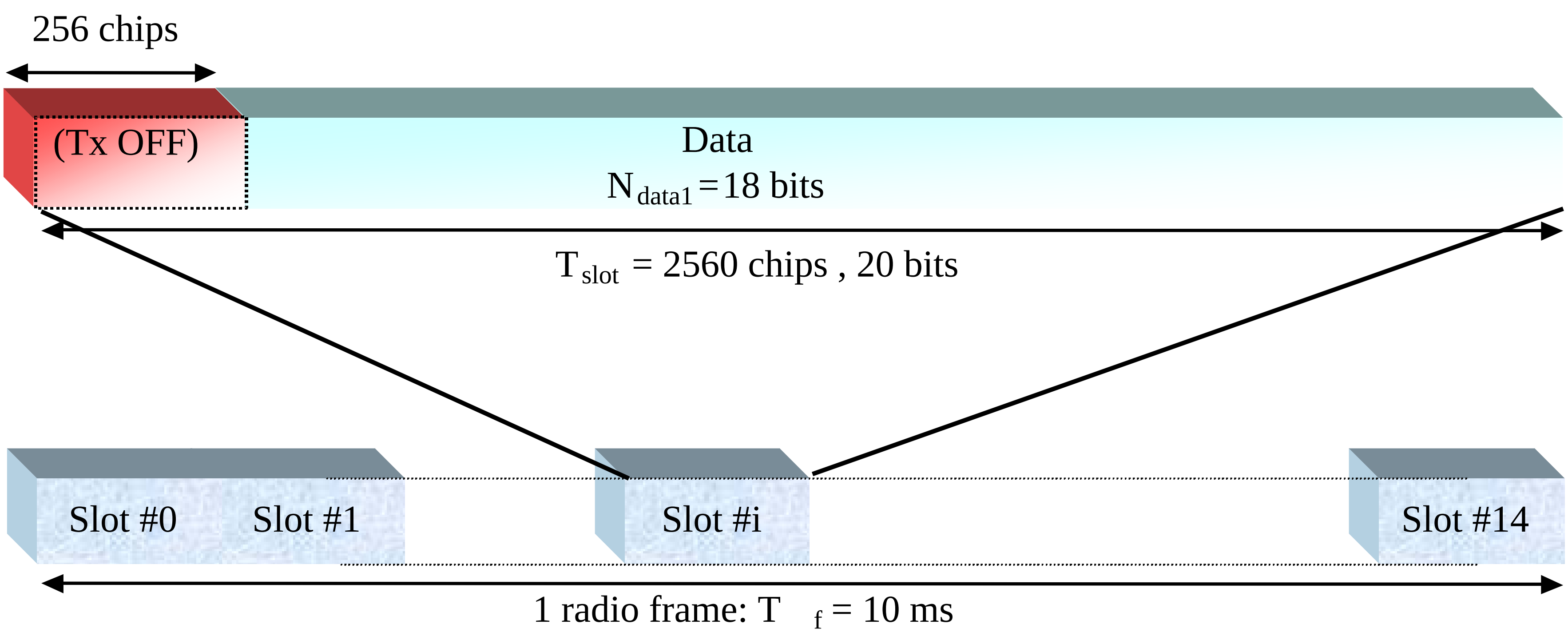


Frame Structure for Downlink DPCCH for CPCH



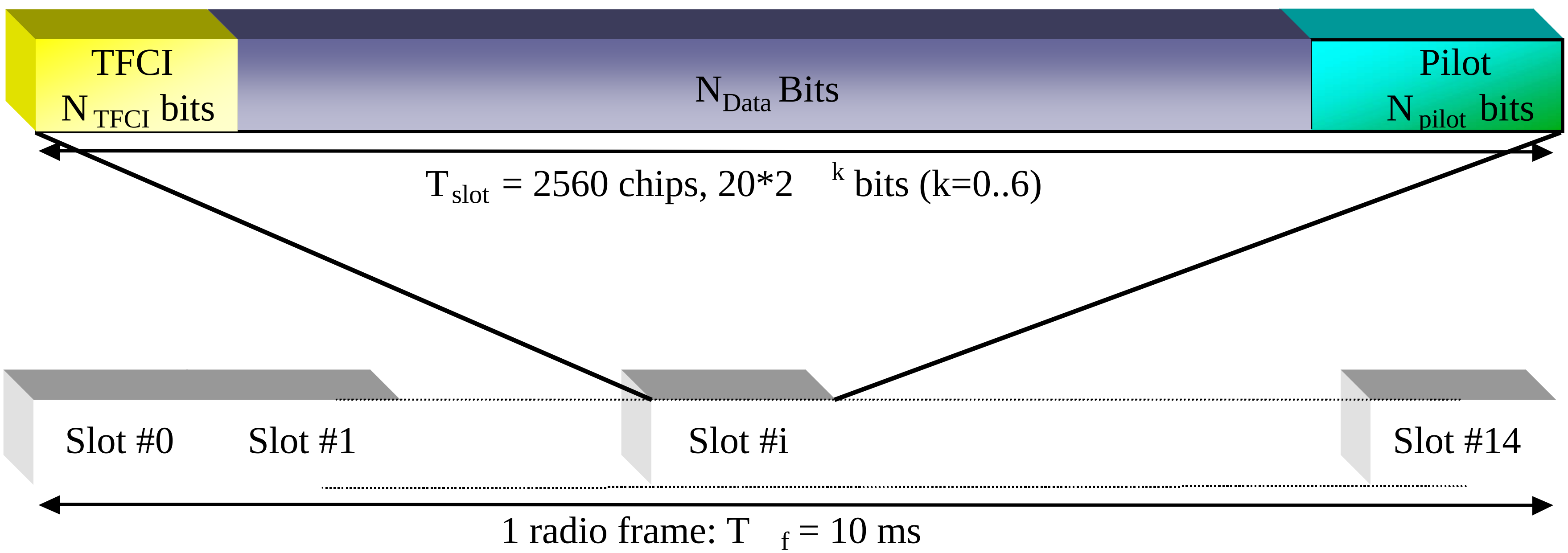
- The downlink DPCCH for CPCH is a special case:
  - downlink dedicated physical channel of format #0
  - spreading factor for the DL-DPCCH is 512.
- Two types of CPCH control commands:
  - L1 control command such as Start of Message Indicator
  - Higher layer control command - for example, Emergency Stop

Primary Common Control Physical Channel (P-CCPCH)



- It is a fixed rate (30 kbps, SF=256) DL physical channel used to carry the BCH transport channel.
- The Primary CCPCH is not transmitted during the first 256 chips of each slot.

Secondary Common Control Physical Channel (S-CCPCH)



- It is used to carry the FACH and PCH. There are two types of Secondary CCPCH: those that include TFCI and those that do not include TFCI. It is the UTRAN that determines if a TFCI should be transmitted, hence making it mandatory for all UEs to support the use of TFCI.

Secondary CPCCH Fields

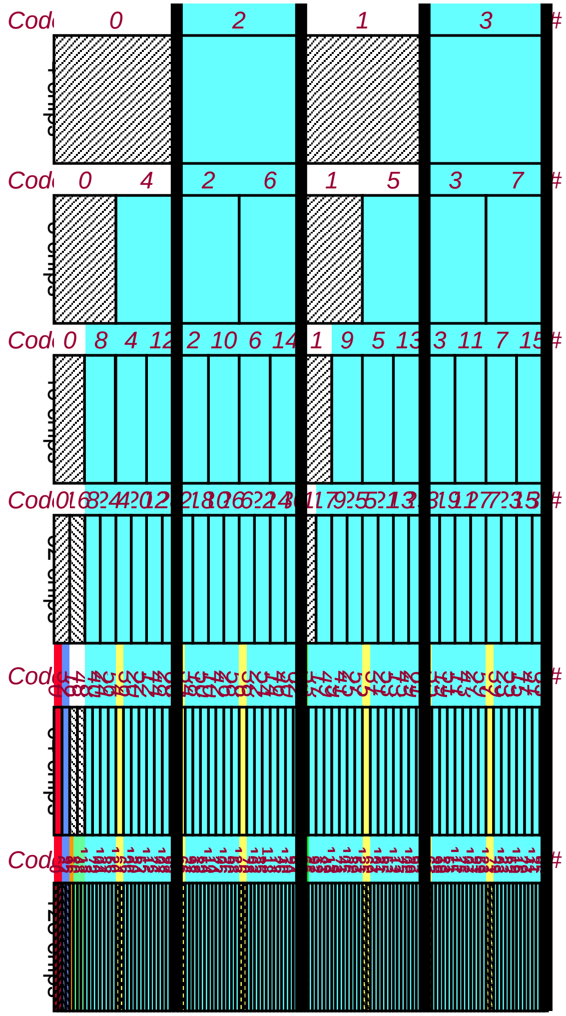
Slot Format #i	Channel Bit Rate (kbps)	Channel Symbol Rate (ksps)	SF	Bits/ Frame	Bits / Slot	N_{data1}	N_{pilot}	N_{TFCI}
0	30	15	256	300	20	20	0	0
1	30	15	256	300	20	12	8	0
2	30	15	256	300	20	18	0	2
3	30	15	256	300	20	10	8	2
4	60	30	128	600	40	40	0	0
5	60	30	128	600	40	32	8	0
6	60	30	128	600	40	38	0	2
7	60	30	128	600	40	30	8	2
8	120	60	64	1200	80	72	0	8*
9	120	60	64	1200	80	64	8	8*
10	240	120	32	2400	160	152	0	8*
11	240	120	32	2400	160	144	8	8*
12	480	240	16	4800	320	312	0	8*
13	480	240	16	4800	320	296	16	8*
14	960	480	8	9600	640	632	0	8*
15	960	480	8	9600	640	616	16	8*
16	1920	960	4	19200	1280	1272	0	8*
17	1920	960	4	19200	1280	1256	16	8*

Differences between Primary and Secondary CCPCH

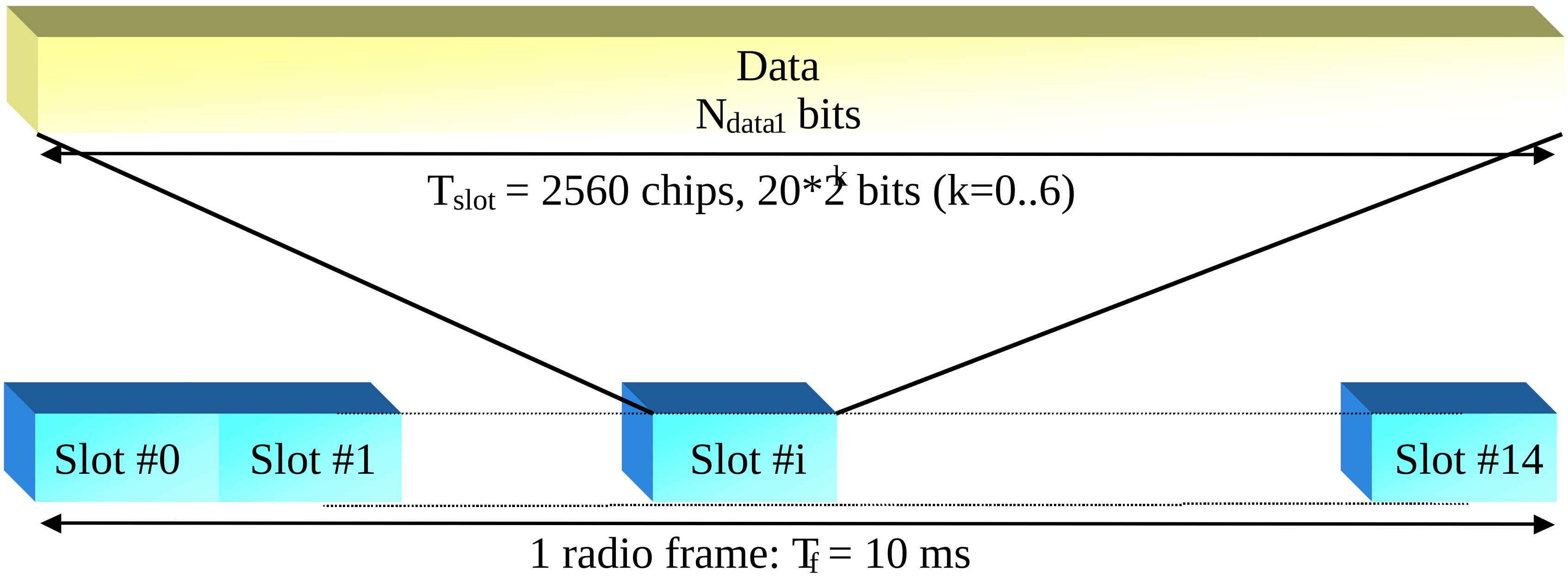
- P-CCPCH Primary
  - transport channel can use only a fixed predefined transport format combination
  - is transmitted over the entire cell
- S-CCPCH Secondary
  - can support multiple transport format combinations using TFCI
  - can be transmitted over the entire cell or on narrow beams if desired
    - this is only valid for an S-CCPCH carrying the FACH

Physical Downlink Shared Channel (PDSCH)

- The Physical Downlink Shared Channel (PDSCH) is used to carry the Downlink Shared Channel (DSCH)
  - it is a fast data channel assigned frame-by-frame to no more than one UE at a time
- A PDSCH uses a channelization code derived from a PDSCH root channelization code
  - the PDSCH code must not conflict with other codes in use in the cell
- Within one radio frame, UTRAN may allocate different PDSCHs under the same PDSCH root channelization code to different UEs so long as they do not interfere
- Within the same radio frame, multiple parallel PDSCHs, with the same spreading factor, may be allocated to a single UE. This is a special case of multicode transmission.
- All the PDSCHs under the same PDSCH root channelization code are operated with radio frame synchronization.
- PDSCHs allocated to the same UE on different radio frames may have different spreading factors.

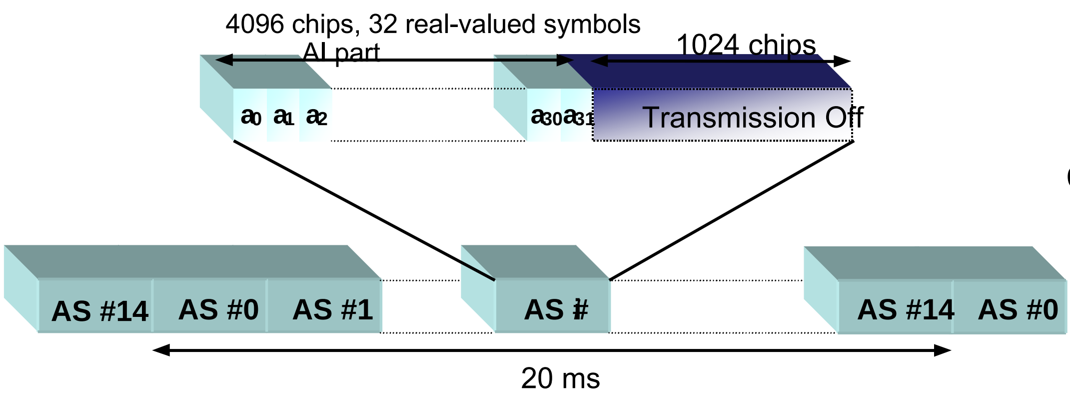


Physical Downlink Shared Channel (PDSCH)



- Frame by frame, each PDSCH is associated with one downlink DPCH
  - The PDSCH and associated DPCH do not necessarily have the same spreading factors and are not necessarily frame aligned
- All relevant Layer 1 control information is transmitted on the DPCCH part of the associated DPCH
  - the PDSCH does not carry Layer 1 information
  - The TFCI field of the associated DPCH is used to indicate for UE that there is data to decode on the DSCH

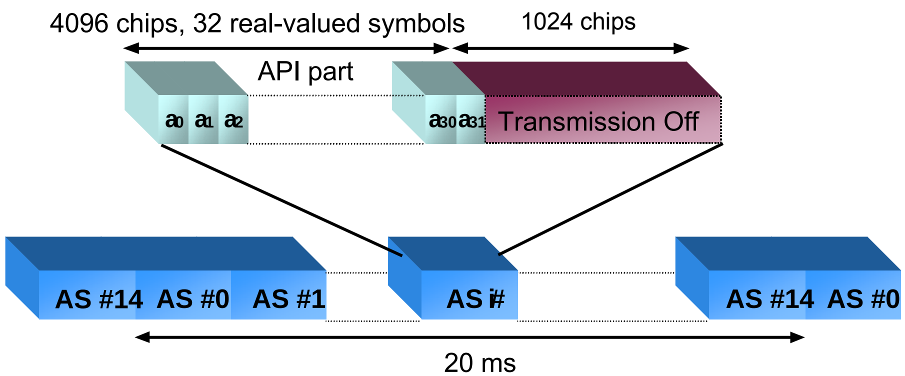
Acquisition Indicator Channel (AICH)



$$a_j = \sum_{s=0}^{15} AI_s b_{s,j}$$

- The Acquisition Indicator channel (AICH) is a fixed rate (SF=256) physical channel used to carry Acquisition Indicators (AI).
- Acquisition Indicator AI_s correspond to signatures on the PRACH
- The real-valued symbols a0, a1, …, a31 in figure are given by the equation where AI_s is the acquisition indicator corresponding to signature s and the sequence b_s,0,…, b_s,31.
  - AI_s can take on the values +1, -1, or 0 as appropriate,
- If the signature s is not a member of the set of available signatures for all the Access Service Class (ASC) for the corresponding PRACH , then AI_s shall be set to 0.

CPCH Access Preamble Acquisition Indicator Channel (AP-AICH)



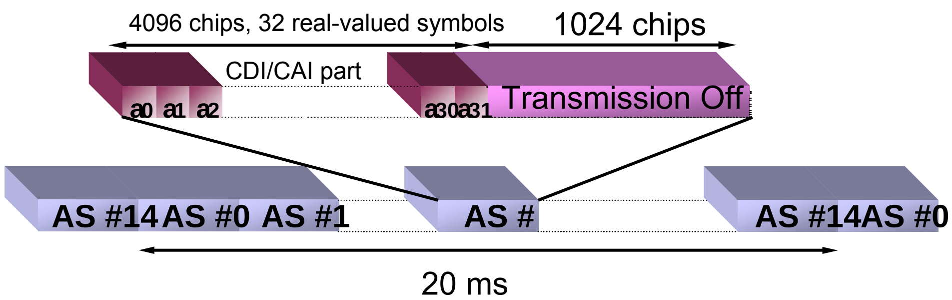
$$a_j = \sum_{s=0}^{15} API_s \times b_{s,j}$$

- The Access Preamble Acquisition Indicator channel (AP-AICH) is a fixed rate (SF=256) physical channel carrying AP acquisition indicators (API) of CPCH.
- AP acquisition indicator API_s corresponds to signatures transmitted by UE.
- The real-valued symbols a_0, a_1, …, a_{31} in figure are given by the equation where API_s, taking on values +1, -1, or 0, is the AP acquisition indicator corresponding to Access Preamble signature s transmitted by UE and the sequence b_s,0, …, b_s,31.
- If the signature s is not a member of the set of UL Access Preamble signatures for the corresponding PCPCH then API_s shall be set to 0.

AICH and AP-AICH signature patterns

s	$b_{s,0}, b_{s,1}, \dots, b_{s,31}$																														
0	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	-1
2	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
3	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
4	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
5	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
6	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
7	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
8	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
9	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
10	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
11	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
12	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
13	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
14	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
15	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

CPCH Collision Detection/Channel Assignment Indicator Channel (CD/CA-ICH)

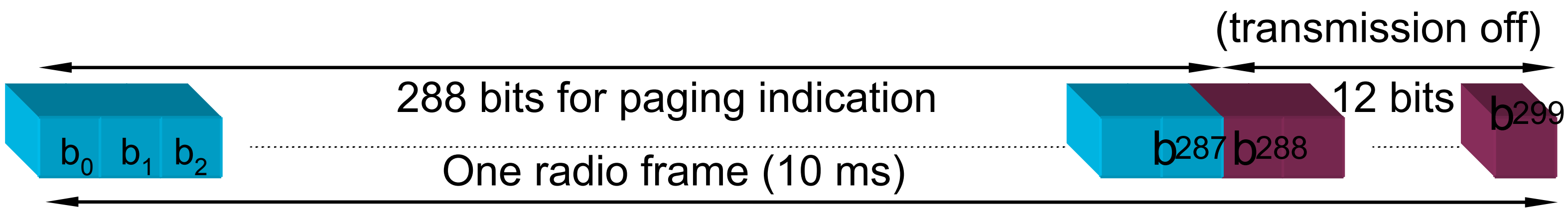


$$a_j = \sum_{i=0}^{15} CDI_i \times b_{s_i,j} + \sum_{k=0}^{15} CAI_k \times b_{s_k,j}$$

$$a_j = \sum_{s=0}^{15} CDI_s \times b_{s,j}$$

- In case CA is active, the real-valued symbols a_0, a_1, …, a_{31} are as shown in the upper expression where CDI_i, taking the values +1/0 or -1/0, is the CD indicator corresponding to the CD preamble i transmitted by the UE, and CAI_k, taking the values +1/0 or -1/0, is the CA indicator corresponding to the assigned channel index k
- In case CA is not active, the real-valued symbols a_0, a_1, …, a_{31} are as shown in the lower expression where CDI_s, taking the values +1, and 0, is the CDI indicator corresponding to CD preamble signature s transmitted by UE and the sequence b_s,0, …, b_s,31

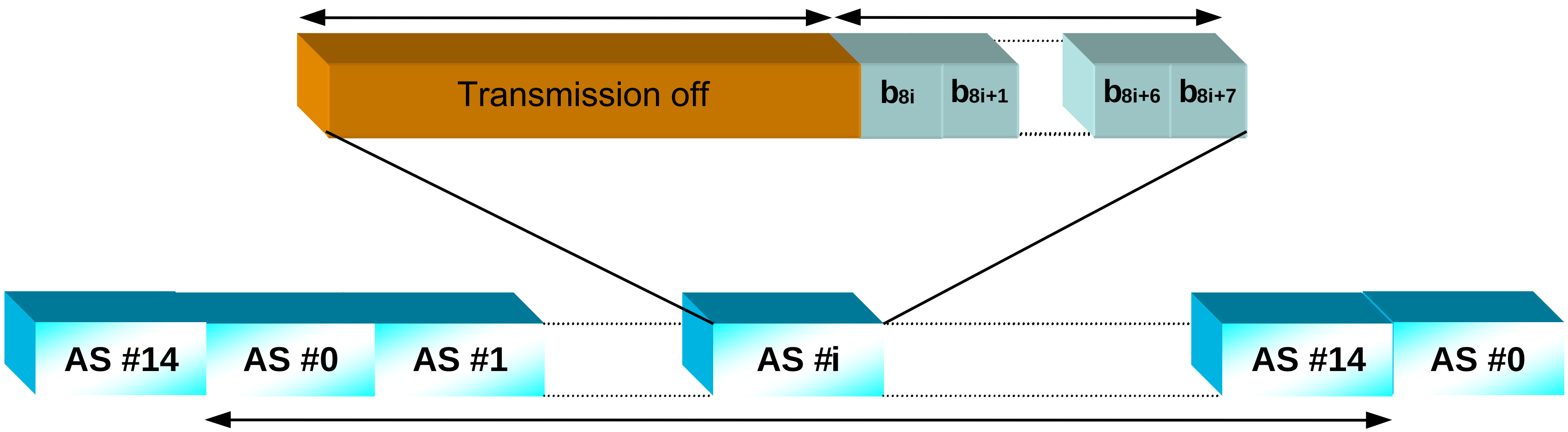
Paging Indicator Channel (PICH)



- The Paging Indicator Channel (PICH) runs at a fixed rate, SF256
  - The PICH is always paired with an S-CCPCH carrying a PCH
- One 10 ms PICH radio frame includes 300 bits (b0,b1,…, b299)
  - Bits 0-287 carry paging indicators; the other 12 aren’t transmitted.
  - The period with no transmission is reserved for possible future use.
- In each PICH frame, Np paging indicators {P0, …, PNp-1} are transmitted, where Np=18, 36, 72, or 144.
- The PI calculated by higher layers for use for a certain UE, is associated with the paging indicator Pq, where q is computed as a function of the PI computed by higher layers, the SFN of the P-CCPCH radio frame during which the start of the PICH radio frame occurs, and the number of paging indicators per frame (Np), by the following expression:

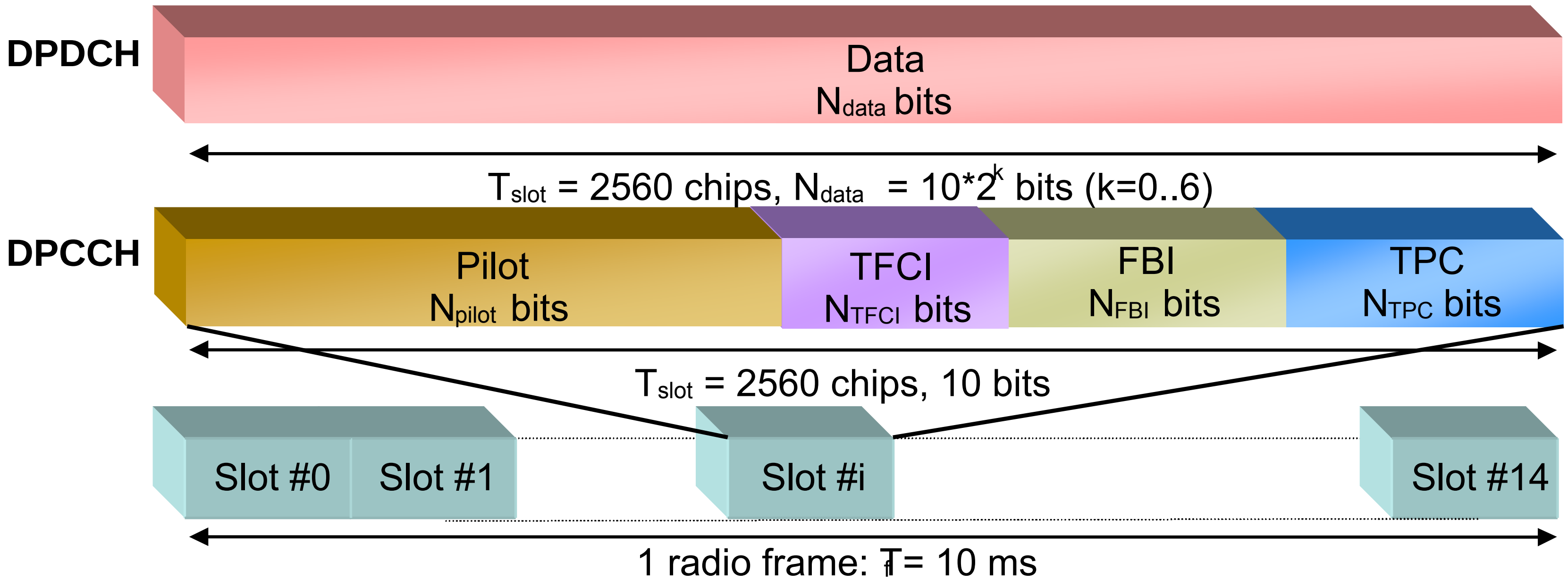
$$p = \left\{ PI + \left\lfloor \left(\left(18 \times \left(SFN + \left\lfloor \frac{SFN}{8} \right\rfloor + \left\lfloor \frac{SFN}{64} \right\rfloor + \left\lfloor \frac{SFN}{512} \right\rfloor \right) \right) \bmod 144 \right) \times \frac{Np}{144} \right\rfloor \right\} \bmod Np$$

CPCH Status Indicator Channel (CSICH)



- The CPCH Status Indicator Channel (CSICH) is a fixed rate (SF=256) physical channel used to carry CPCH status information.
- The CSICH frame includes 15 consecutive access slots (AS), each 40 bits long and divided into two parts.
  - The first part has 4096 chips with no transmission, and is not formally a functioning part of the CSICH. This part is reserved for use by AICH, AP-AICH or CD/CA-ICH.
  - The second part is a Status Indicator (SI) consisting of 8 bits b8i,….b8i+7, where i is the access slot number.

Uplink Physical Channels: Dedicated Uplink Physical Channel



- The two types of uplink dedicated physical channels, DPDCH and DPCCH, are I/Q code multiplexed within each radio frame
- The uplink DPCCH carries Layer 1 control information
  - known pilot bits to support channel estimation for coherent detection, transmit power-control (TPC) commands, feedback information (FBI), and an optional transport-format combination indicator (TFCI).
- The uplink DPDCH carries the DCH transport channel.
- There is always one and only one uplink DPCCH on each radio link.
- There may be zero, one, or several uplink DPDCHs on each radio link.

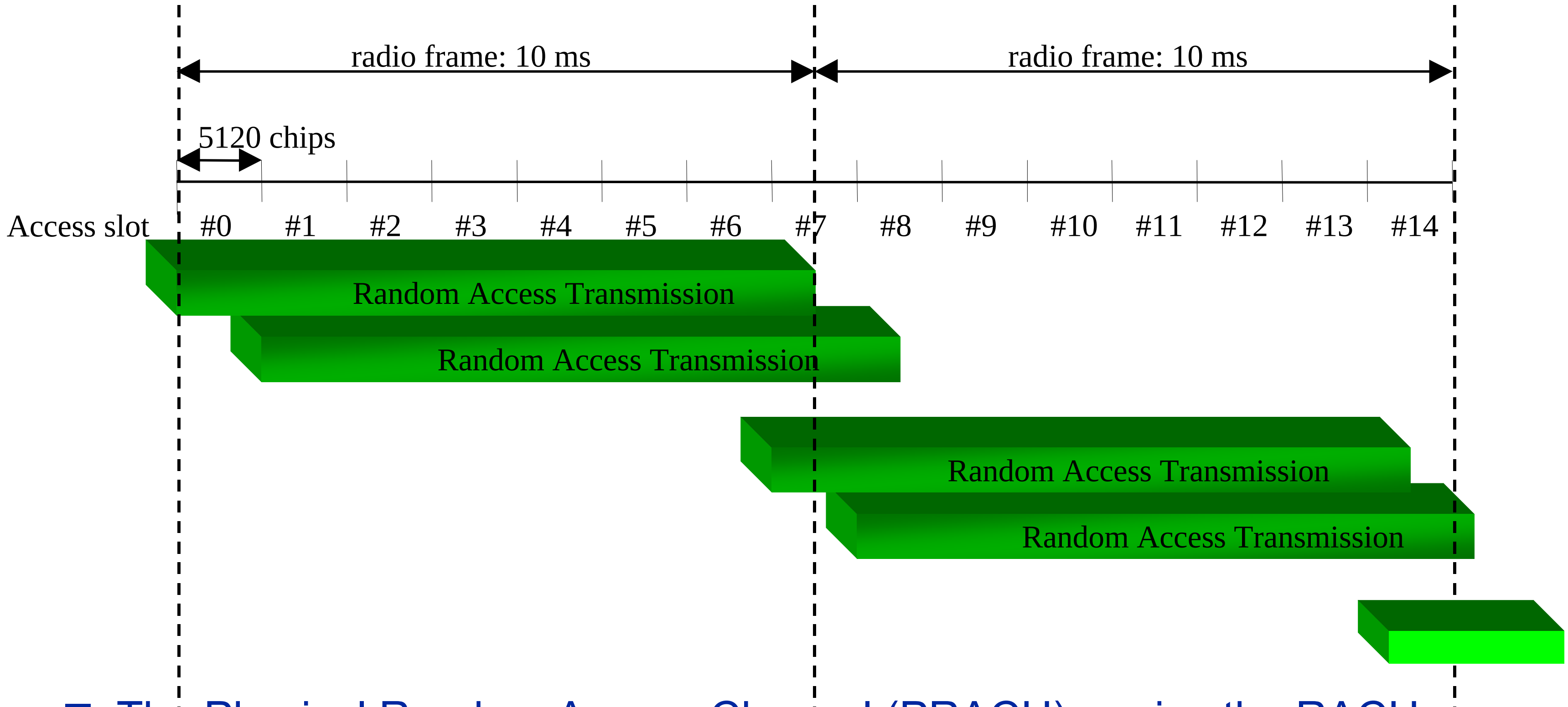
DPDCH fields

Slot Forma t #i	Channel Bit Rate (kbps)	Channel Symbol Rate (ksps)	SF	Bits/ Frame	Bits/ Slot	N_{data}
0	15	15	256	150	10	10
1	30	30	128	300	20	20
2	60	60	64	600	40	40
3	120	120	32	1200	80	80
4	240	240	16	2400	160	160
5	480	480	8	4800	320	320
6	960	960	4	9600	640	640

DPCCH fields

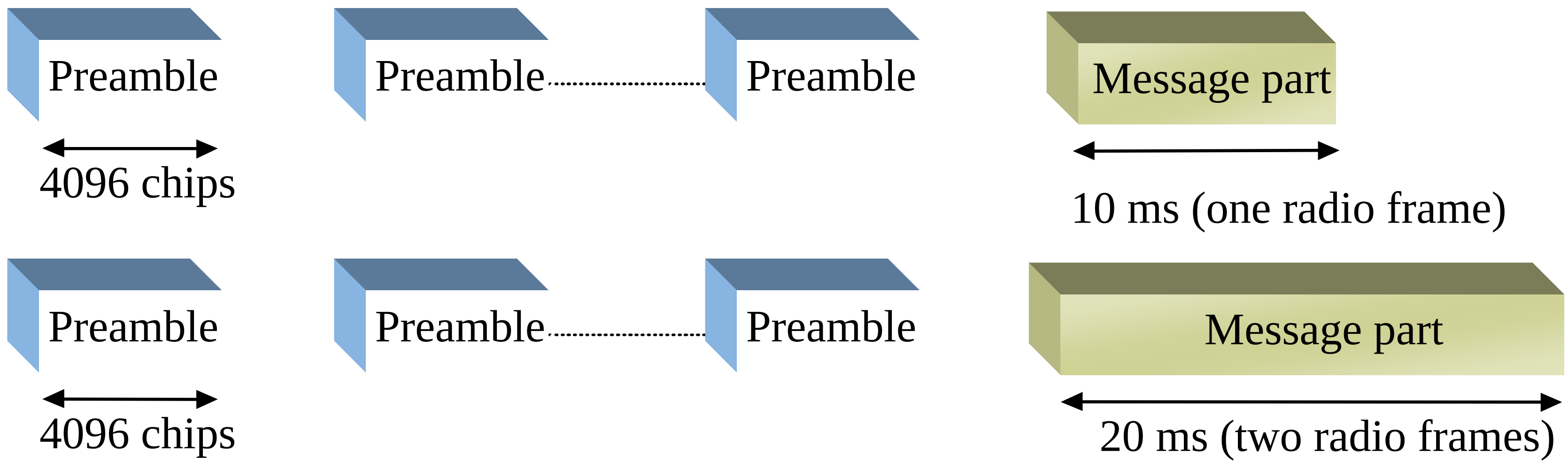
Slot Format #i	Channel Bit Rate (kbps)	Channel Symbol Rate (ksps)	SF	Bits/ Frame	Bits / Slot	N_{pilot}	N_{TPC}	N_{TFCI}	N_{FBI}	Transmitted slots per radio frame
0	15	15	256	150	10	6	2	2	0	15
0A	15	15	256	150	10	5	2	3	0	10-14
0B	15	15	256	150	10	4	2	4	0	8-9
1	15	15	256	150	10	8	2	0	0	8-15
2	15	15	256	150	10	5	2	2	1	15
2A	15	15	256	150	10	4	2	3	1	10-14
2B	15	15	256	150	10	3	2	4	1	8-9
3	15	15	256	150	10	7	2	0	1	8-15
4	15	15	256	150	10	6	2	0	2	8-15
5	15	15	256	150	10	5	1	2	2	15
5A	15	15	256	150	10	4	1	3	2	10-14
5B	15	15	256	150	10	3	1	4	2	8-9

Common uplink physical channels - PRACH



- The Physical Random Access Channel (PRACH) carries the RACH
- The random-access process uses Slotted ALOHA protocol
  - augmented with a fast acquisition indication
  - The UE can start the random-access transmission at any of many time boundaries called access slots
  - There are 15 access slots in two frames, spaced 5120 chips apart.
- Higher layers dictate what access slots are available for random access transmission, and the other parameters of the process

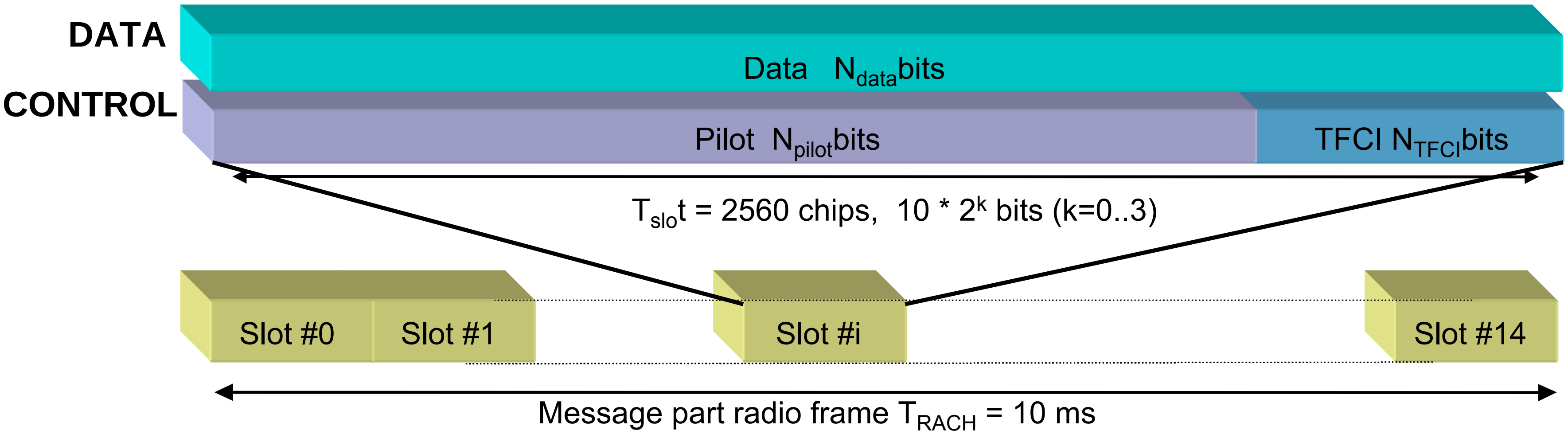
Structure of the Random-Access Transmission



RACH Preamble Part

- Each preamble is of length 4096 chips and consists of 256
- repetitions of a signature of length 16 chips. There are a
- maximum of 16 available signatures

Random-Access Transmission: RACH Message Part



- The 10 ms message-part radio frame has 15 slots, each 2560 chips long
- Each slot consists of two parts
  - a data part (RACH transport channel) 10*2 k bits long, with k=0,1,2,3
  - a control part : 8 known pilot bits for channel estimation and coherent detection, and 2 TFCI bits
- The data and control parts are transmitted in parallel
  - A 10 ms message-part is one radio frame
  - A 20 ms message-part is two consecutive 10 ms radio frames
- The message part length is the Transmission Time Interval (TTI) of the RACH Transport channel in use
  - This TTI length is configured by higher layers.

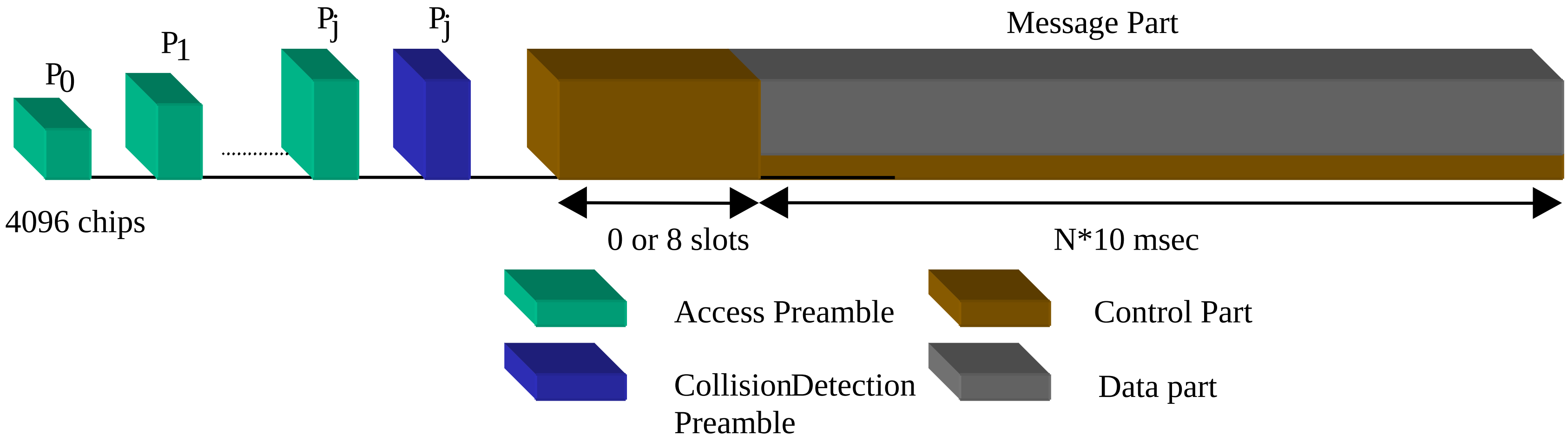
RACH Message Data Fields

Slot Format #i	Channel Bit Rate (kbps)	Channel Symbol Rate (ksps)	SF	Bits/ Frame	Bits/ Slot	N_{data}
0	15	15	256	150	10	10
1	30	30	128	300	20	20
2	60	60	64	600	40	40
3	120	120	32	1200	80	80

Random Access Message Control Fields

Slot Format #i	Channel Bit Rate (kbps)	Channel Symbol Rate (ksps)	SF	Bits/ Frame	Bits/ Slot	N_{pilot}	N_{TFCI}
0	15	15	256	150	10	8	2

Physical Common Packet Channel (PCPCH)



- The Physical Common Packet Channel (PCPCH) carries the CPCH and:
  - Longer message duration (up to 640 ms vs. 10 or 20 ms on RACH)
  - Power controlled (commands provided in the DPCCH in the downlink)
  - Status indication provided in the downlink to avoid collisions
- CPCH transmission uses DSMA-CD with fast acquisition indication
  - The UE can start transmission at the beginning of any of several defined time-intervals, relative to the frame boundary of the received BCH of the current cell.

PCPCH – Physical Common Packet Channel

- A PCPCH access transmission includes:
  - one or several Access Preambles [A-P] of length 4096 chips
  - one Collision Detection Preamble (CD-P) of length 4096 chips
  - DPCCH Power Control Preamble (PC-P) either 0 slots or 8 slots long
  - message of variable length Nx10 ms.

CPCH ACCESS PREAMBLE PART

- 4096 chips long: 256 repetitions of one of 16 signatures 16-chips long
- RACH preamble signature sequences are used.

CPCH COLLISION DETECTION PREAMBLE PART

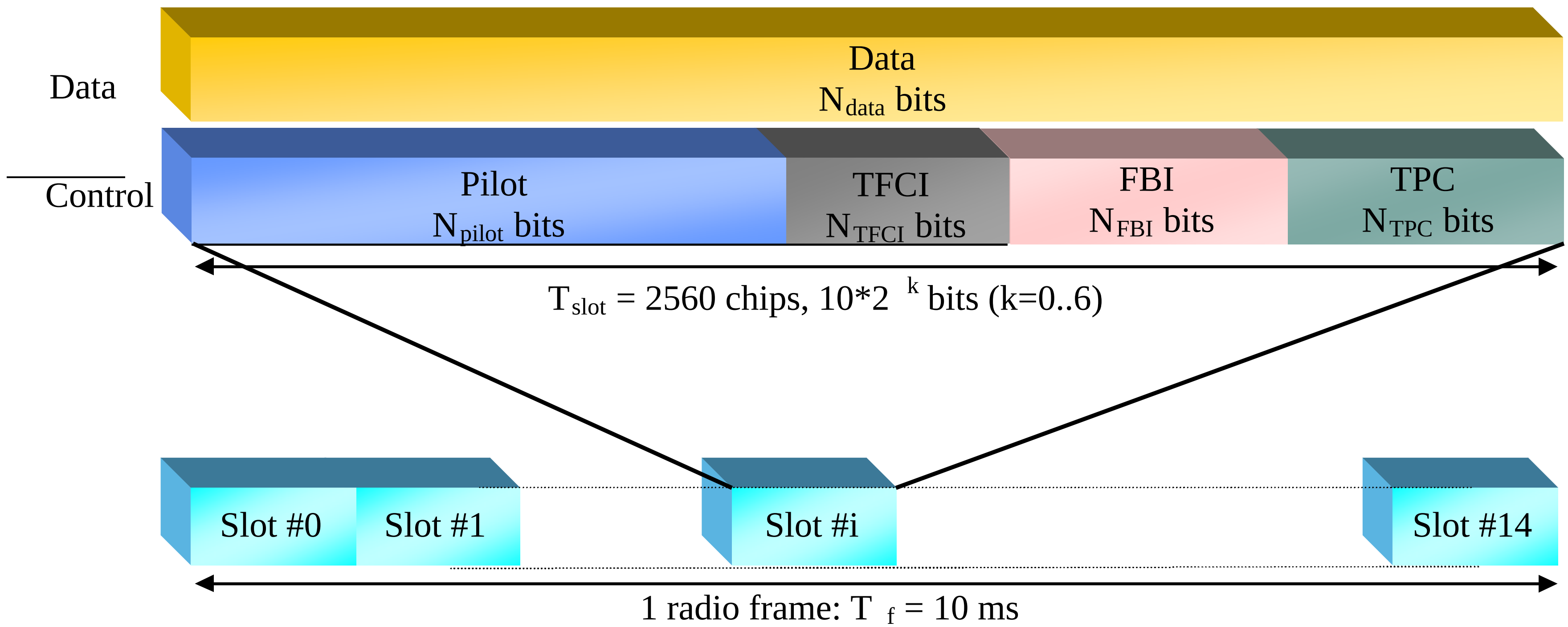
- Scrambling code is chosen to be a different code segment of the Gold code than for the RACH or CPCH preambles.
- The RACH preamble signature sequences are used.

CPCH POWER CONTROL PREAMBLE PART

- The slot format for CPCH PC-P part is same as for the message part
- PC-P length is upper-layer parameter Lpc-preamble. Value: 0 or 8 slots
  - When Lpc-preamble > 0, pilot bits extend from:
  - slot# (15-Lpc-preamble) to slot #14

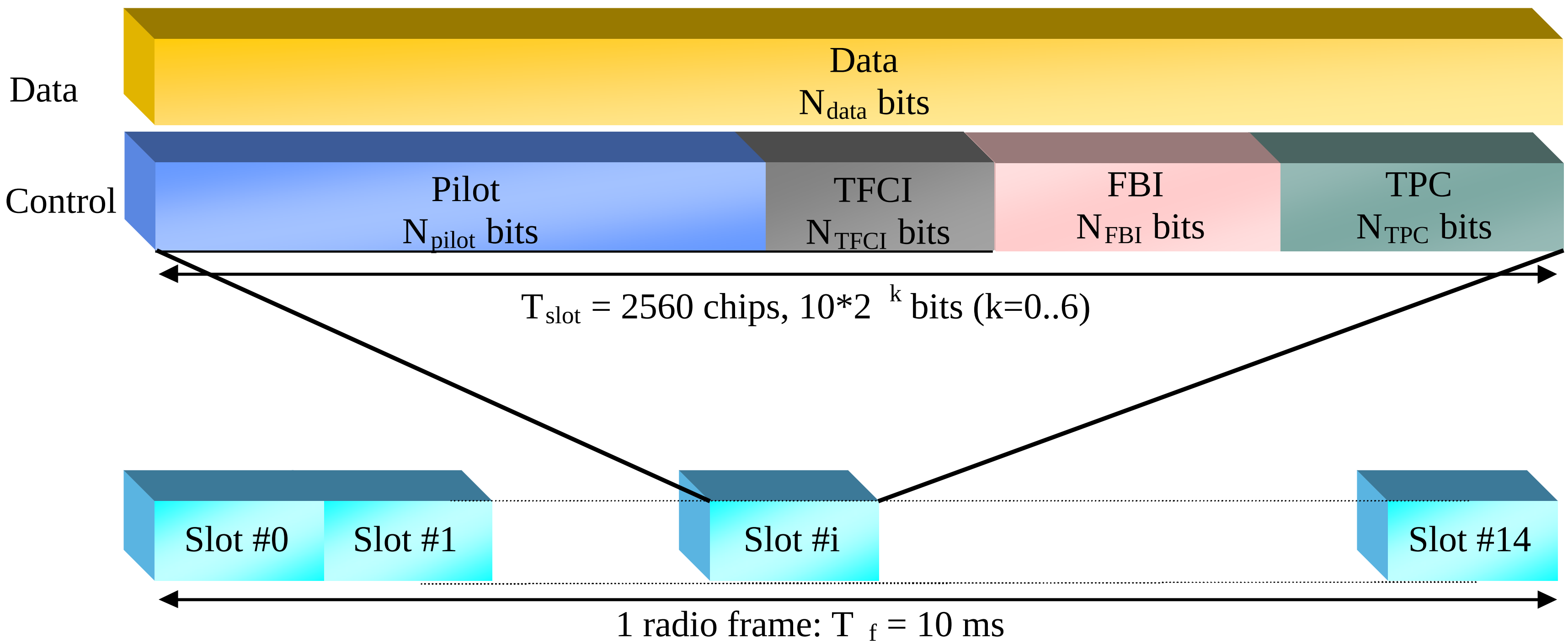
CPCH message part

Each message consists of up to N_Max_frames 10 ms frames. N_Max_frames is a higher layer parameter. Each 10 ms frame is split into 15 slots, each of length Tslot = 2560 chips. Each slot consists of two parts, a data part that carries higher layer information and a control part that carries Layer 1 control information.



The data and control parts are transmitted in parallel.

CPCH message part



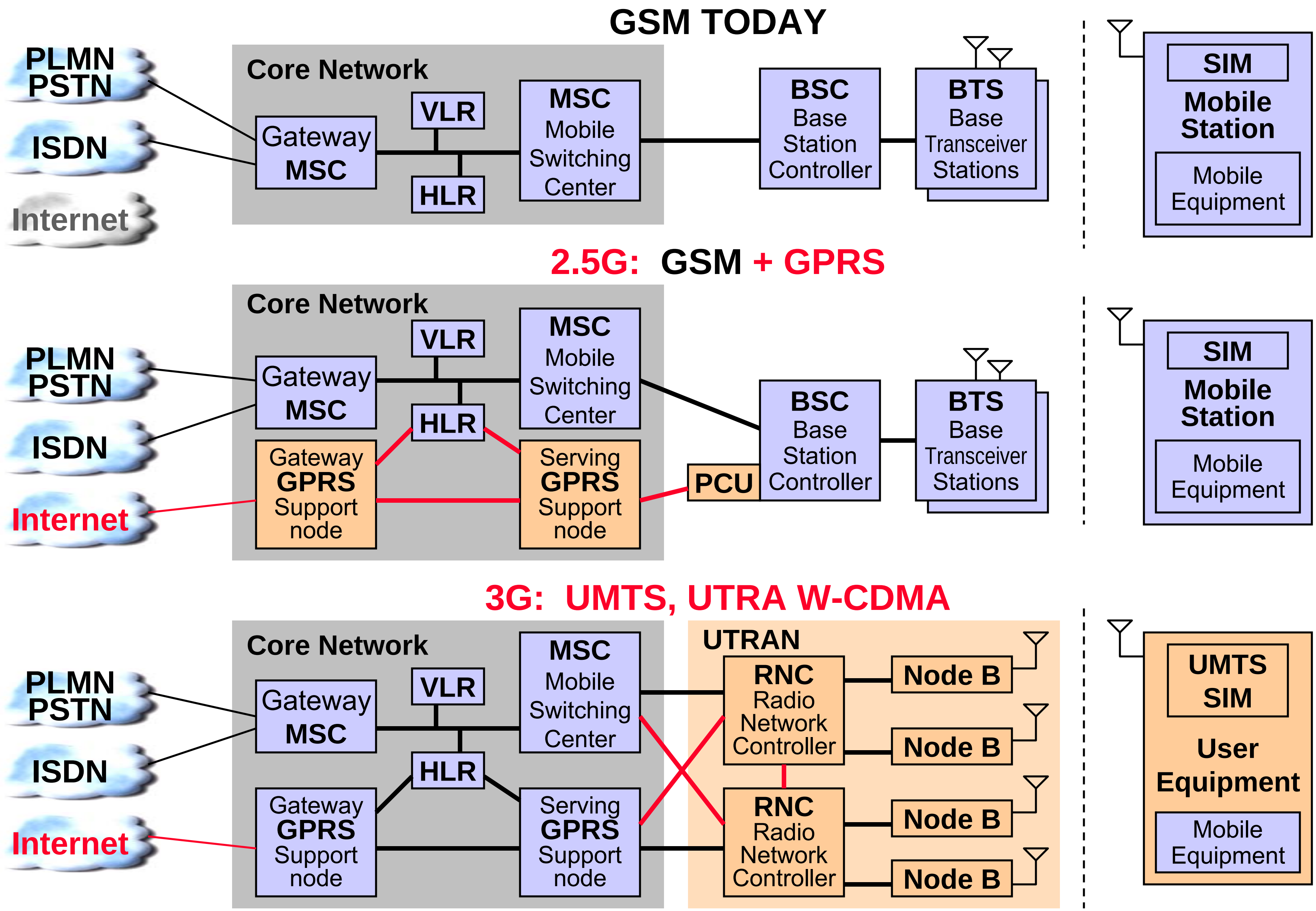
- Each message includes up to N_Max_frames 10 ms frames.
  - N_Max_frames is a higher layer parameter.
- Each 10 ms frame has15 slots 2560 chips long
- Each slot has a data part carrying higher layer information and a control part carrying Layer 1 control information.
- The data and control parts are transmitted in parallel.

Slot Format of the Control Part of CPCH Message Part

Slot Format #i	Channel Bit Rate (kbps)	Channel Symbol Rate (ksps)	SF	Bits/ Frame	Bits/ Slot	N_{pilot}	N_{TPC}	N_{TFCI}	N_{FBI}
0	15	15	256	150	10	6	2	2	0
1	15	15	256	150	10	5	2	2	1
2	15	15	256	150	10	5	1	2	2

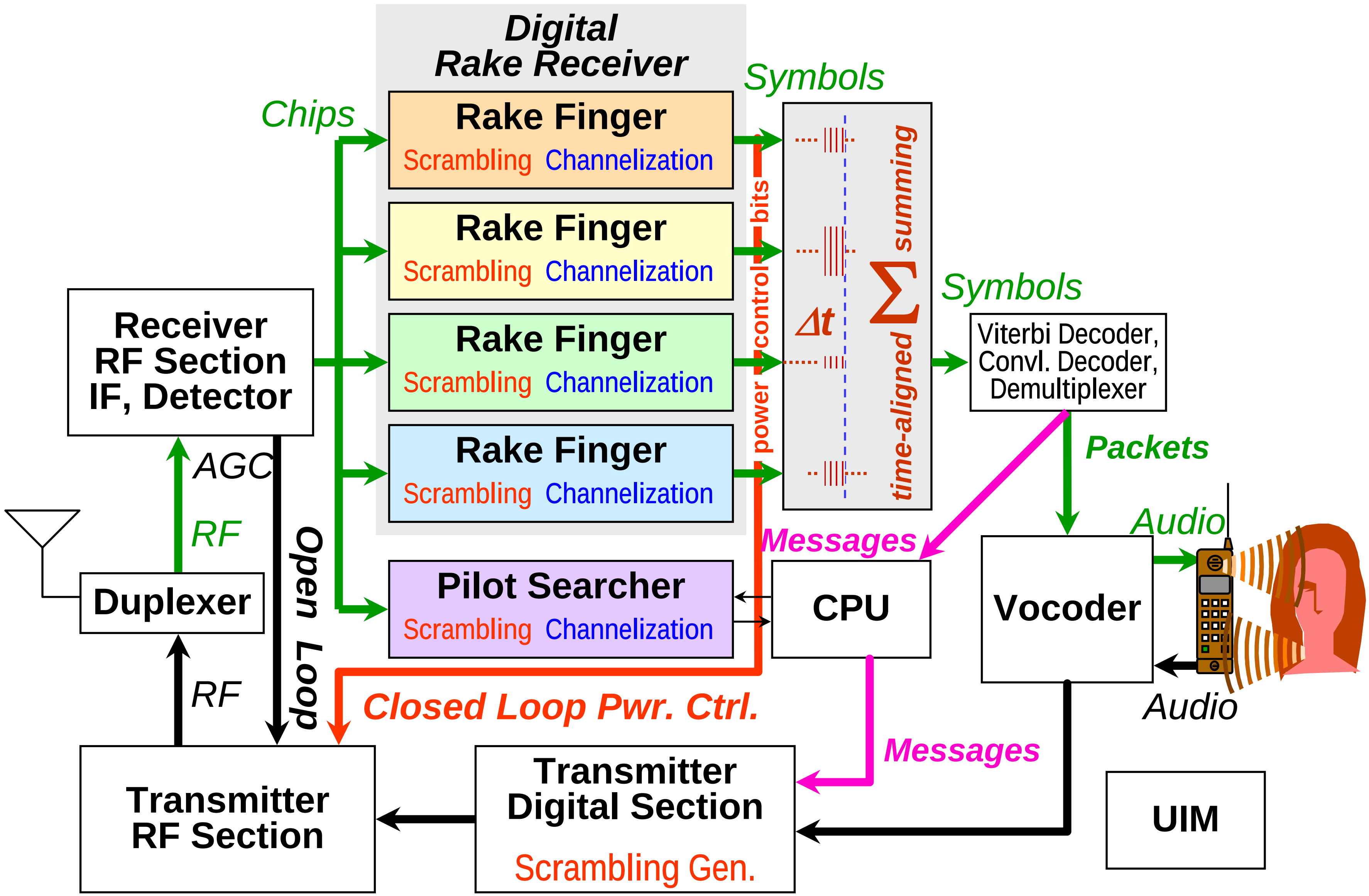
Network Architecture

3 Steps to 3G: GSM Transition to W-CDMA



User Equipment Architecture

What's In a WCDMA UE?



Power Control

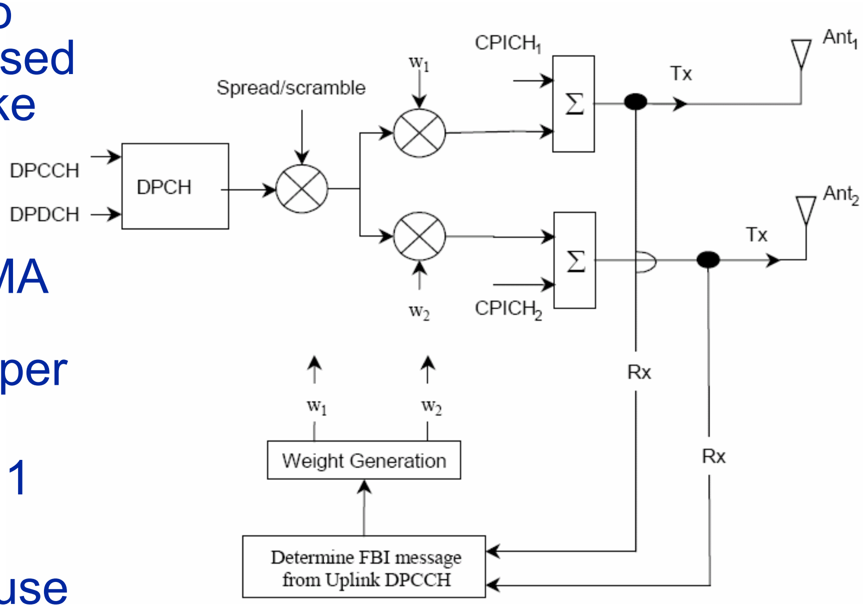
WCDMA POWER CONTROL

OPEN LOOP

- When coming from an idle state into an access transmission, the mobile uses open loop power control
  - mobile initial transmit power adjusted inversely to receive power
  - Open loop control is used only to set the initial power, and is not used during further transmission (unlike IS-95/IS-2000)

WCDMA FAST CLOSED LOOP

- During a call or data session, WCDMA applies power control to both Uplink and Downlink with 1500 corrections per second
  - correction step size is nominally 1 db but can be adjusted
  - up/down decisions on each link use SIR at the receiver



Basic Call Processing

Cell Search Procedure

- Background:
  - each cell uses the same 256-chip primary synchronization code
- 1. The UE searches the 256-chip primary synchronization code
  - the detected correlation peak corresponds to the slot boundary
  - chip, symbol, and slot synchronization are obtained
- 2. Using the peaks detected in 1, the UE seeks the largest peak from the Secondary SCH code word
  - there are 64 possible values for this code word
  - the UE must check all 15 possible delay positions since the frame boundary isn't available until this word is found
  - from the strongest Secondary SCH code word, Frame synchronization and the code group of the cell can be obtained
- 3. The UE now has the Secondary SCH code word and frame timing is known
  - The UE now seeks the primary scrambling codes belonging to this code group
    - each group has 8 primary scrambling codes which must be tested but only at the starting position of relative timing -- the starting point is known already
  - Scrambling code of the cell is then obtained

Handovers in WCDMA

Types of Handovers in WCDMA

- Intra-Mode
  - soft handover
  - softer handover
  - hard handover
- Inter-Mode
  - UMTS WCDMA to/from UTRA TDD mode
- Inter-system Handover
  - UMTS WCDMA to GSM
  - UMTS WCDMA to CDMA2000

Soft Handover

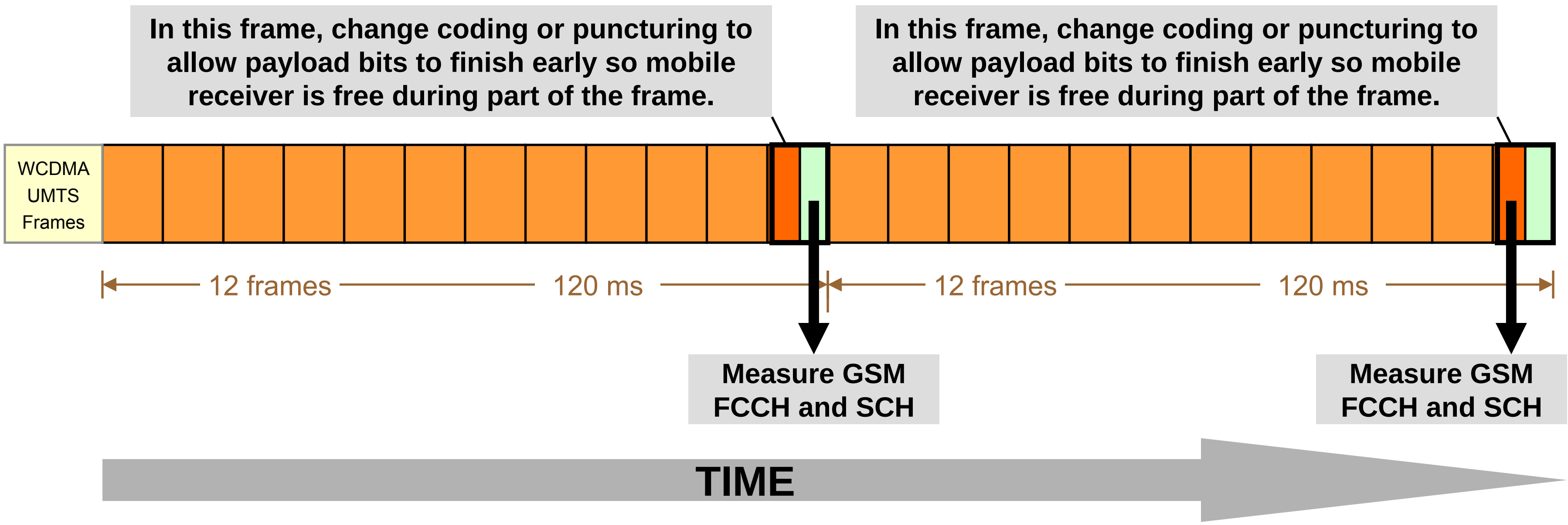
- Before entering soft handover, the mobile
  - Measures the observed timing differences of the downlink SCHs from the involved base stations
  - Reports the timing differences back to the serving base station
- Trigger Parameters
  - RSCP Received Signal Code Power
  - RSSI Received Signal Strength Indicator
  - Ec/No = RSCP/RSSI
  - other parameters are being discussed
- The timing of the new downlink soft handover connection is adjusted with a resolution of one symbol
  - This enables the rake receiver in the mobile to collect the macrodiversity energy from the two base stations
  - Timing adjustments of dedicated downlink channels is carried out with a resolution of one symbol without losing orthogonality of the downlink codes

Interfrequency Handovers

- Interfrequency handovers arise during utilization of heirarchical cell structures (macro, micro, indoor cells)
  - Several carriers and interfrequency handovers may also be used for taking care of high capacity needs in hot spots
  - Interfrequency handovers are also needed to second-generation systems such as GSM or IS-95
  - An efficient method is needed for making measurements on other frequencies while still having the connection running on the current frequency
- Two methods are available to do interfrequency measurements in WCDMA: Dual Receiver and Slotted Mode
  - Dual receiver is considered feasible especially if the mobile uses antenna diversity
    - One receiver branch can be switched to the other frequency
  - Slotted Mode is necessary if the receiver has no diversity
    - The information transmitted during a 10 ms frame is compressed by puncturing or changing the FEC rate and the mobile is free to make a quick measurement on the other frequency

WCDMA-GSM Handovers Measurement Process

- Since GSM use is so widespread, W-CDMA--GSM handovers are quite important
  - The GSM compatible multiframe structure allows similar timing for intersystem measurements as in the GSM system itself
  - The needed measurement interval is not as frequent as for GSM terminals operating in a GSM system



Special Topics

Multirate

- Multiple services of the same connection are multiplexed on one DPDCH
  - After service multiplexing and channel coding, the multiservice data stream is mapped to one DPDCH
  - If the total rate exceeds the upper limit for single code transmission, several DPDCHs are allocated
- A second alternative for service multiplexing is to map parallel services to different DPDCHs in a multicode fashion with separate channel coding and interleaving
  - This allows independent control of the power and quality of each service
  - For BER 10^{-3} services, convolutional coding of 1/3 is used
  - For high bit rates, a code rate of 1/2 can be used
  - For higher quality service classes, parallel concatenated convolutional code is used
- Retransmission can be used to guarantee service quality

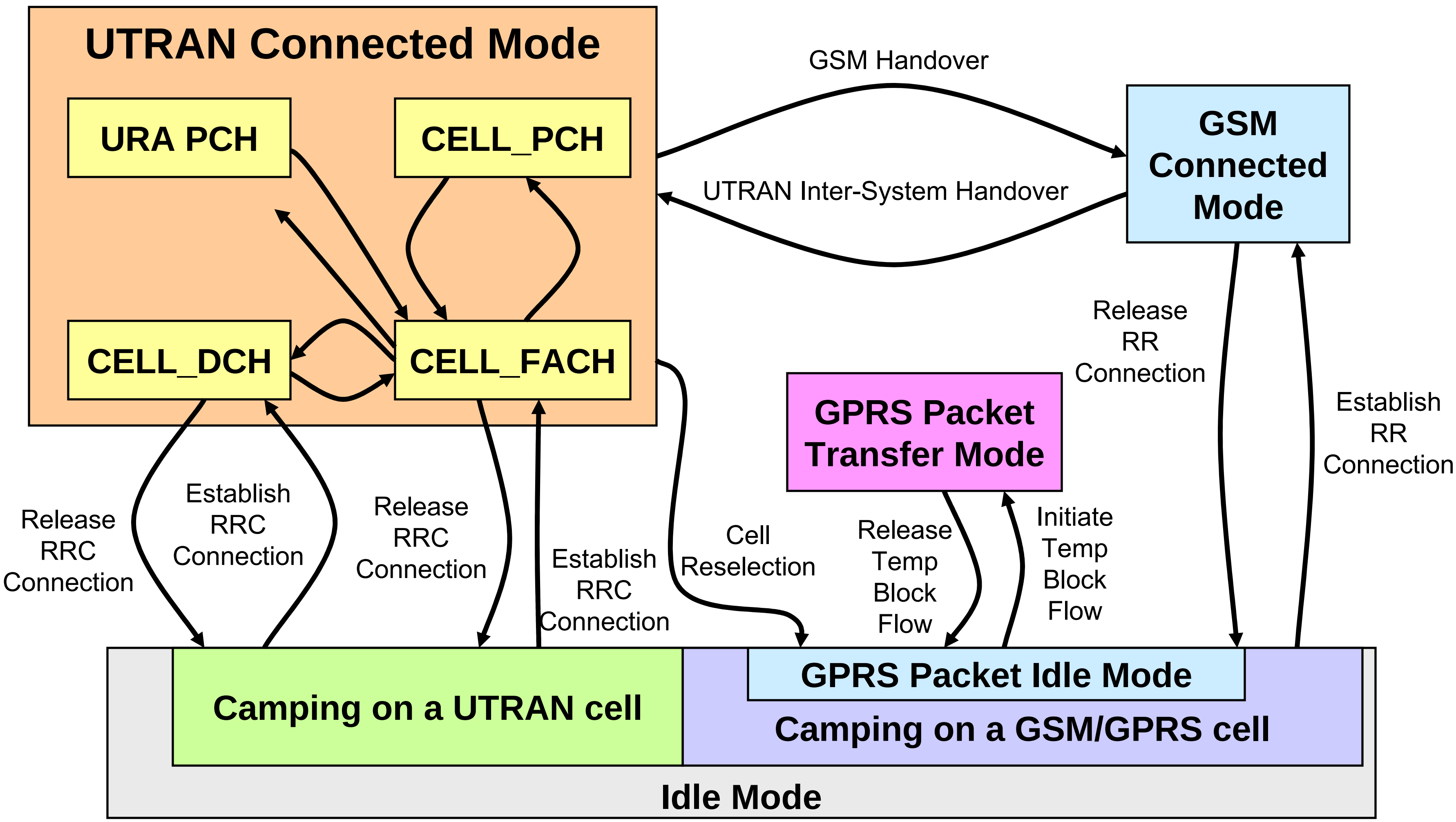
Rate Matching

- After channel coding and service multiplexing, the total bit rate can appear quite arbitrary!
  - The rate matching adapts this rate to the limited set of possible bit rates of a DPDCH
    - Repetition or puncturing is used to match the coded bit stream to the channel gross rate
- For Uplink, rate matching to the closest uplink DPDCH rate is always based on unequal repetition or code puncturing
  - Puncturing is chosen for bit rates less than 20% above
  - In all other cases, unequal repetition is performed
- For Downlink, rate matching to the closest DPDCH rate, using unequal repetition or code puncturing, is only made for the highest rate of a variable rate connection

Packet Data

- W-CDMA has two types of Packet Data transmission modes
- Common Channel Packet Transmission
  - Short Data Packets can be appended directly to a random access burst
  - Used for short infrequent packets, where link maintenance to set up a dedicated channel would cause unacceptable overhead
- Dedicated Channel Packet Transmission
  - Larger or more frequent packets are transmitted on a dedicated channel
  - A large single packet is transmitted using a scheme where the channel is released immediately after the packet has been transmitted
  - In a multipacket scheme, the dedicated channel is maintained by transmitting power control and synchronization information between subsequent packets

Modes and States - RRC Modes



Base Station (Node B) Performance

Node-B Performance Measurements

The following characteristics and parameters, the required performance levels, and methods for test of base stations are all provided in standards documents. For in-class discussion......

Transmitter:

- Maximum output power, total power dynamic range
- Frequency, Code Power and Transmit Modulation
- Power control steps and power control dynamic range
- Out of band emission
- Transmit intermodulation
- Time alignment error in TX Diversity

Receiver:

- Reference sensitivity level
- Dynamic range
- Adjacent Channel Selectivity (ACS)
- Blocking characteristics
- Intermodulation characteristics
- Receiver spurious emission

References

- 3GPP: 3GPP Specifications - Release contents and functionality, 2002-10-01 <http://www.3gpp.org/specs/releasescontents.htm>
- 3GPP: TS 23.002 Network Architecture, Release 1999, V3.6.0 2002-09
- 3GPP: TS 23.002 Network Architecture, Release 4, V4.6.0 2002-12
- 3GPP: TS 23.002 Network Architecture, Release 5, V5.6.0 2002-12
- 3GPP: TS 23.228 IP Multimedia Subsystem (IMS), Stage 2, Release 5, V5.7.0, 2002-12
- Holma Harri, Toskala Antti: WCDMA for UMTS: Radio Access for Third Generation Mobile Communications, 07 March, 2001, ISBN: 0471486876
- Halonen Timo, etc.: GSM, GPRS and EDGE Performance, John Wiley & Sons, Ltd, England, 2002, ISBN 0470 84457 4
- Kaaranen Heikki, etc.: UMTS Networks Architecture, Mobility and Services, John Wiley & Sons, Ltd, England, 2001, ISBN 0471 48654 X
- UMTS Forum: <http://www.umts-forum.org/servlet/dycon/ztumts/umts/Live/en/umts/Home>
- UMTS World: <http://www.umtsworld.com/>