IEEE 802.16-2004

Silicon DSP Corporation

WirelessMAN-OFDM PHY Layer

Silicon DSP Corporation

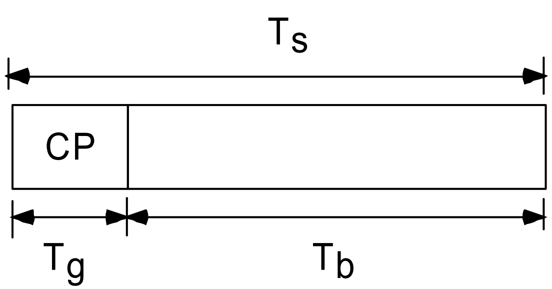
OFDM Raw Bit Rates at 20 MHz

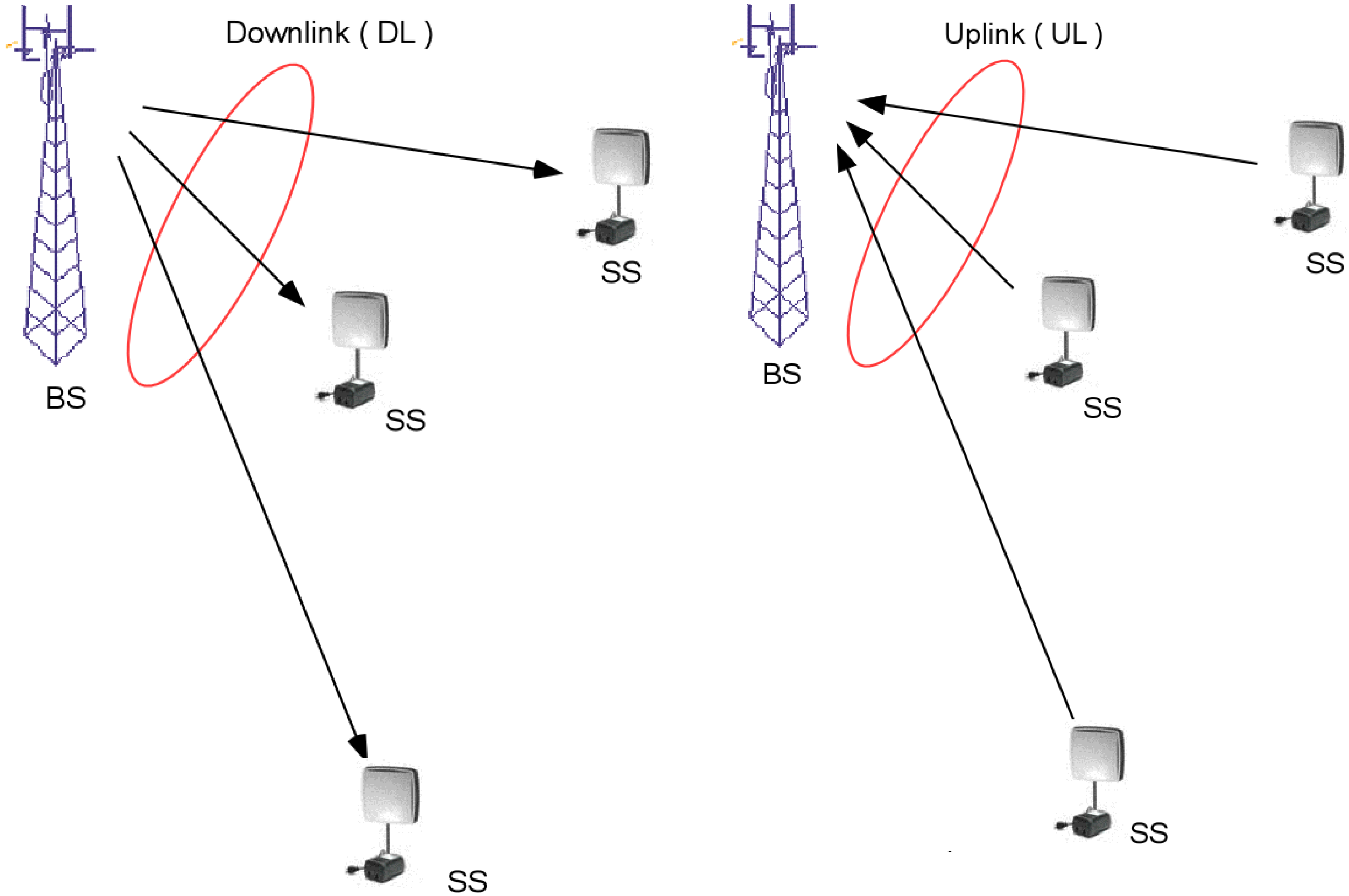
BW (MHz)	T_g	QPSK 1/2	QPSK 3/4	16-QAM 1/2	16-QAM 3/4	64-QAM 2/3	64-QAM 3/4
OFDM 256-FFT							
20 MHz (U-NII)	$T_b/16$	16.13	24.20	32.27	48.40	64.54	72.61
	$T_b/8$	15.24	22.86	30.48	45.71	60.95	68.57
	$T_b/4$	13.71	20.57	27.43	41.14	54.86	61.71

$$\text{DataRate} = \frac{N_{Data} b_m c_r}{T_s}$$

b_m is the number of bits per modulation symbol

c_r is the coding rate

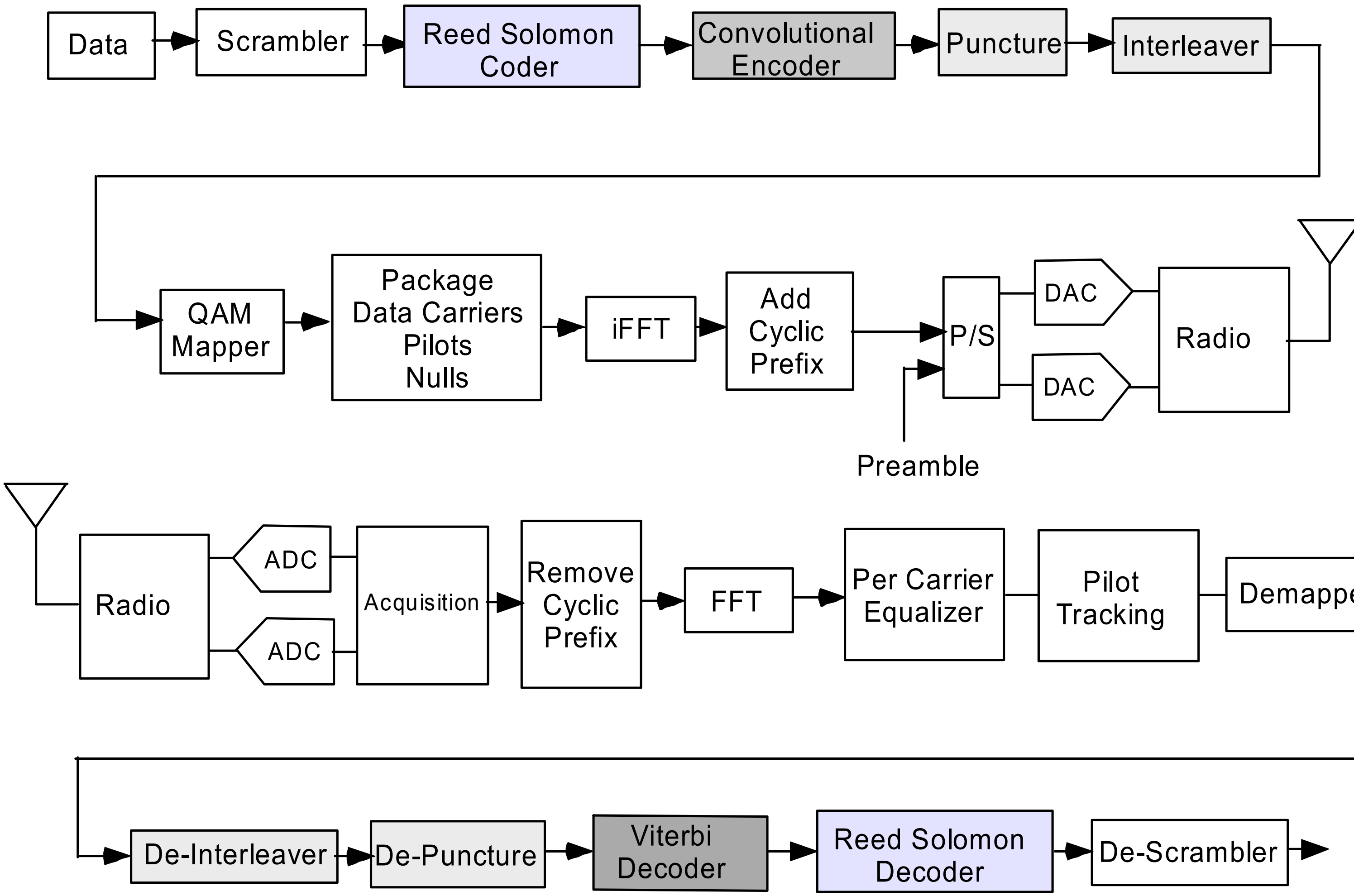



Downlink (DL)
BS
SS
SS
SS
Uplink (UL)
BS
SS
SS
SS

SS Time Synchronization

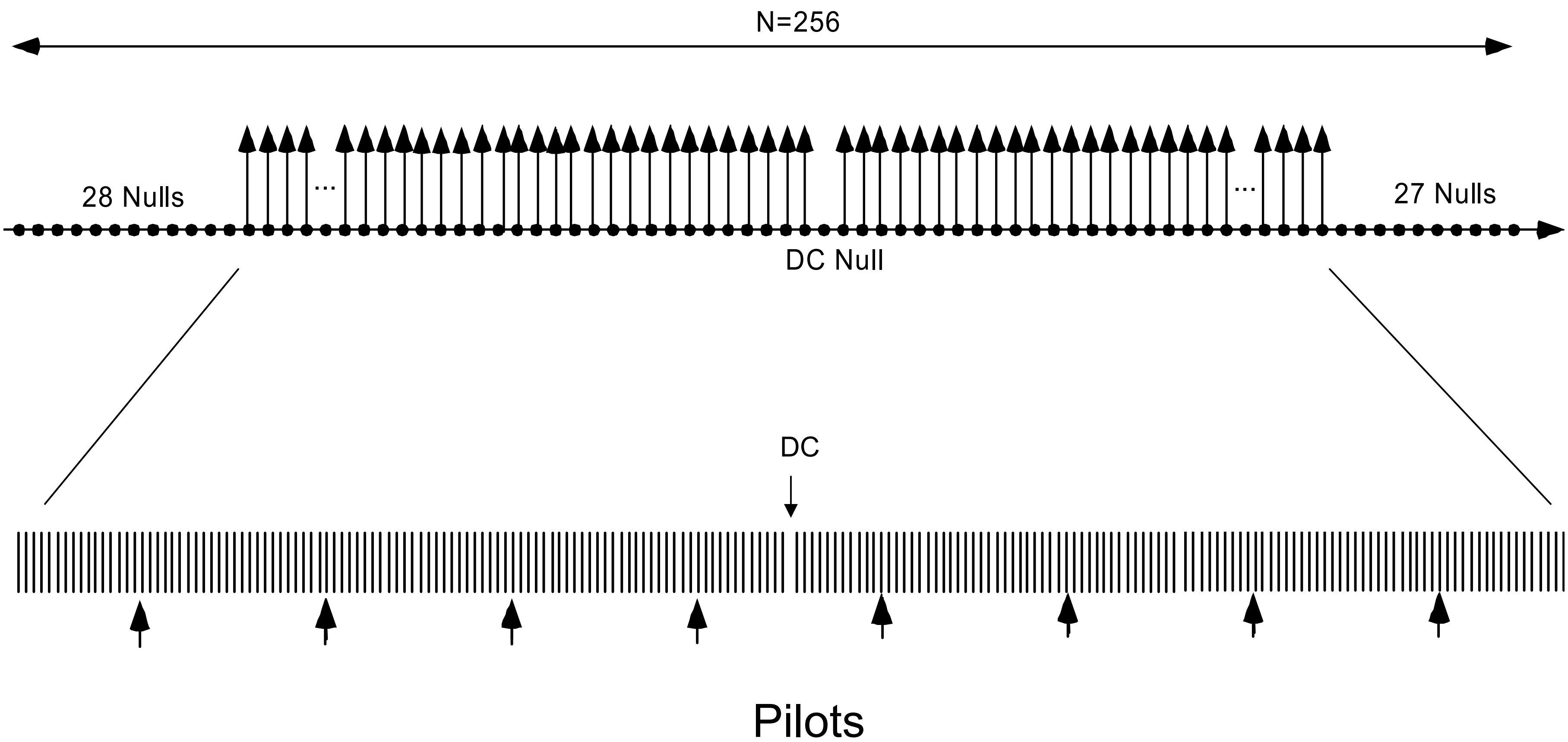
All SSs shall acquire and adjust their timing such that all uplink OFDM symbols arrive time coincident at the Base-Station to a accuracy of +/. 50% of the minimum guard-interval or better.

Concatenated FEC Reed-Solomon Outer Code
Convolutional Inner Code



Simplified Block Diagram for SS

OFDM Carrier Description



16a OFDM

Table 116ae—OFDM symbol parameters

Parameter	Value
N_{FFT}	256
N_{used}	200
$F_s/\ BW$	licensed channel bandwidths which are multiples of 1.75 MHz and license-exempt: 8/7 any other bandwidth: 7/6
$(T_g/\ T_b)$	1/4, 1/8, 1/16, 1/32
Number of lower frequency guard carriers	28
Number of higher frequency guard carriers	27
Frequency offset indices of guard carriers	–128,–127...,–101 +101,+102,...,127
Frequency offset indices of BasicFixedLocationPilots	–84,–60,–36,–12,12,36,60,84
Subchannel number: Allocated frequency offset indices of carriers	1:{–88,...,–76},{–50,...,–39},{1,...,13},{64,...,75} 2:{–63,…,–51},{–25,...–14},{26,...,38},{89,...,100} 3:{–100,…,–89},{–38,...,–26},{14,...,25},{51,...,63} 4:{–75,…,–64},{–13,...,–1},{39,...,50},{76,...,88}

Concatenated Reed-Solomon/ Convolutional Code (RS-CC)

The Reed-Solomon encoding shall be derived from a systematic RS ($N = 255,\ K = 239,\ T = 8$) code using GF($2^8$).

where:

N is the number of overall bytes after encoding

K is the number of data bytes before encoding

T is the number of data bytes which can be corrected.

The following polynomials are used for the systematic code:

Code Generator Polynomial: $g(x) = (x+\lambda^0)(x+\lambda^1)(x+\lambda^2)..(x+\lambda^{2T-1}),\ \lambda = 02_{HEX}$

Field Generator Polynomial: $p(x) = x^8 + x^4 + x^3 + x^2 + 1$

2T=16=255-239 T=8 correct 8 bytes (random or burst)

RS are linear block codes (subset of BCH)

Shortened RS Codes

- Conceptually making a number of data symbols zero at the encoder, not transmitting them and then re-inserting them at the decoder.

- Example The (255,239) can be shortened to (200, 184). The encoder takes a block of 184 data bytes, and conceptually adds 55 zero bytes, creates a (255,239) code word and transmits only the 184 data and 16 parity bytes.

- Equivalent to reducing both dimensions of the Generator Matrix by the same amount.

16a OFDM Convolutional Encoder

$G_1 = 171_{OCT}$ FOR X

$G_2 = 133_{OCT}$ FOR Y

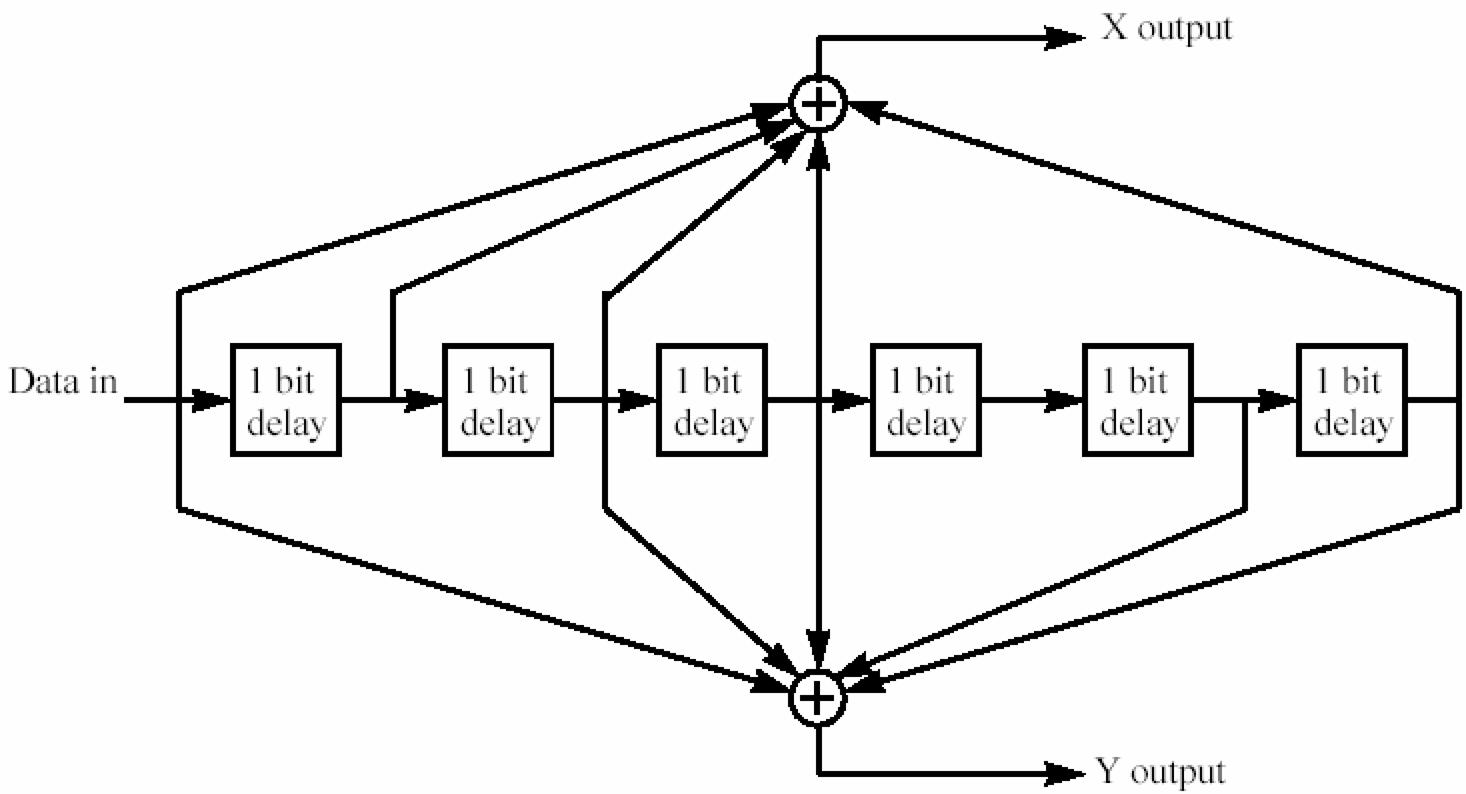


Figure 128ae—Convolutional encoder of rate 1/2

Puncturing

Table 116af—The inner convolutional code with puncturing configuration

	Code rates			
Rate	1/2	2/3	3/4	5/6
d_{free}	10	6	5	4
X	1	10	101	10101
Y	1	11	110	11010
XY	X_1Y_1	$X_1Y_1Y_2$	$X_1Y_1Y_2X_3$	$X_1Y_1Y_2X_3Y_4X_5$

5 input

6 Transmitted.

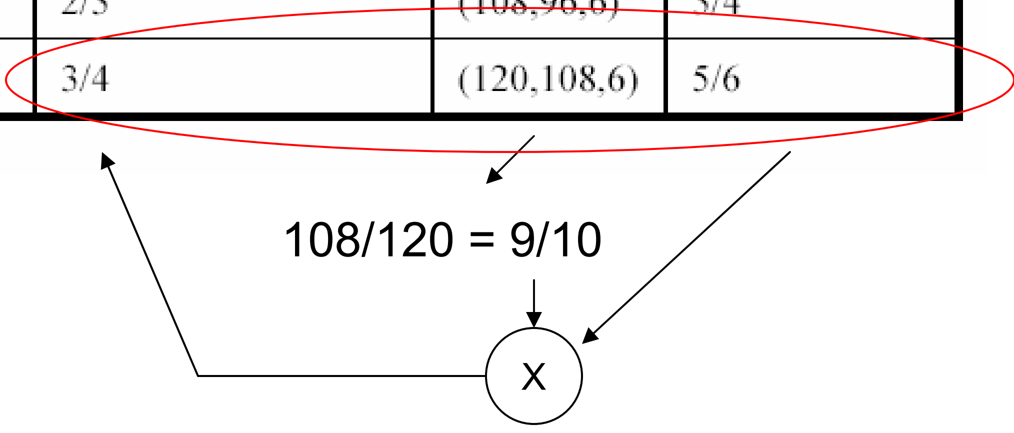
Rate=5/6

In the table, "1" means a transmitted bit and "0" denotes a removed bit.

16a OFDM

Table 116ag—Mandatory channel coding per modulation

Modulation	Uncoded block size (bytes)	Coded block size (bytes)	Overall coding rate	RS code	CC code rate
QPSK	24	48	1/2	(32,24,4)	2/3
QPSK	36	48	3/4	(40,36,2)	5/6
16-QAM	48	96	1/2	(64,48,8)	2/3
16-QAM	72	96	3/4	(80,72,4)	5/6
64-QAM	96	144	2/3	(108,96,6)	3/4
64-QAM	108	144	3/4	(120,108,6)	5/6



Constellations

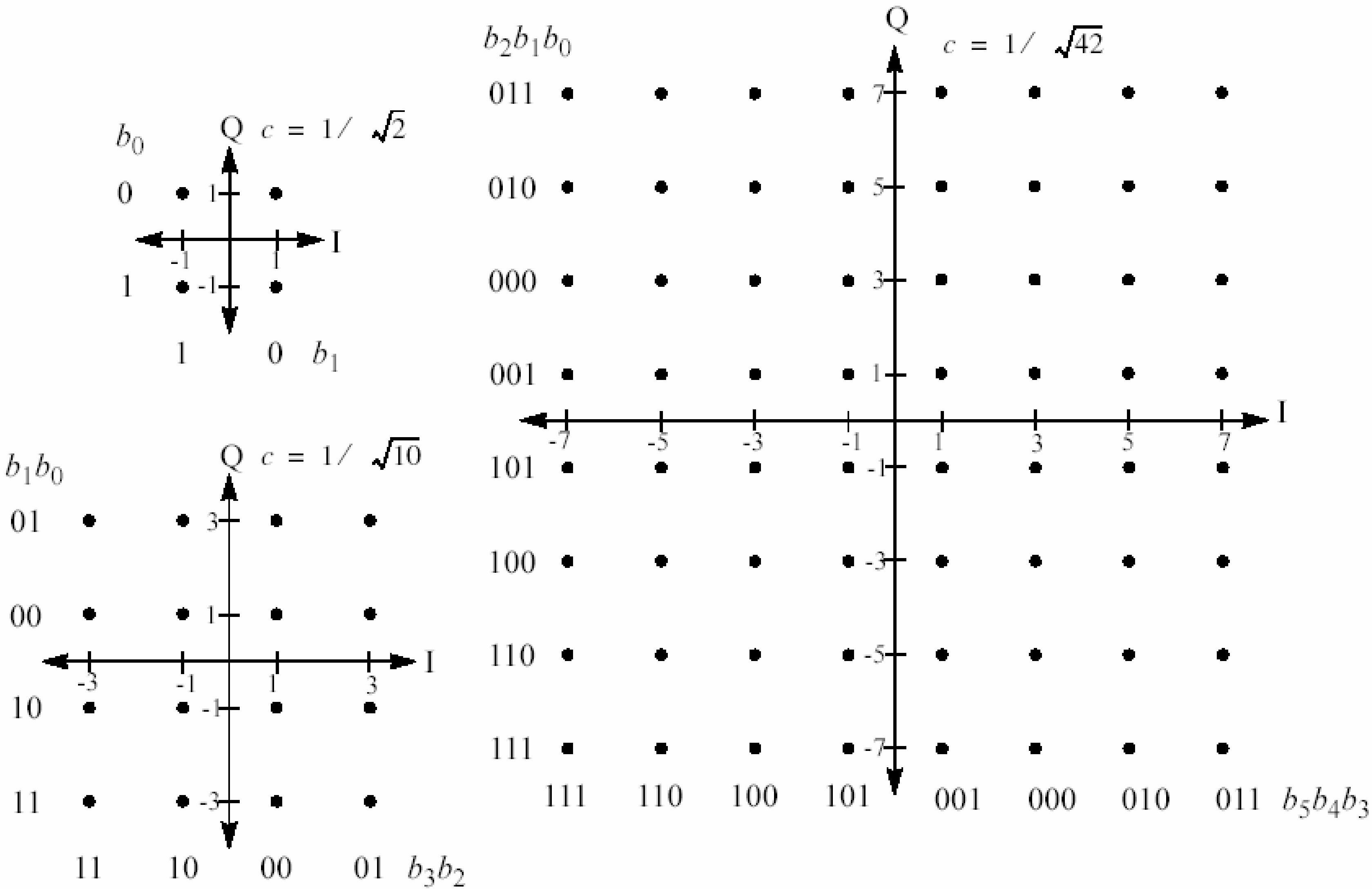


Figure 128ai—QPSK, 16-QAM and 64-QAM constellations

Rate ID's

Table 116ao—OFDM Rate ID encodings

Rate_ID	Modulation RS-CC rate
0	QPSK 1/2
1	QPSK 3/4
2	16-QAM 1/2
3	16-QAM 3/4
4	64-QAM 2/3
5	64-QAM 3/4
6–15	Reserved

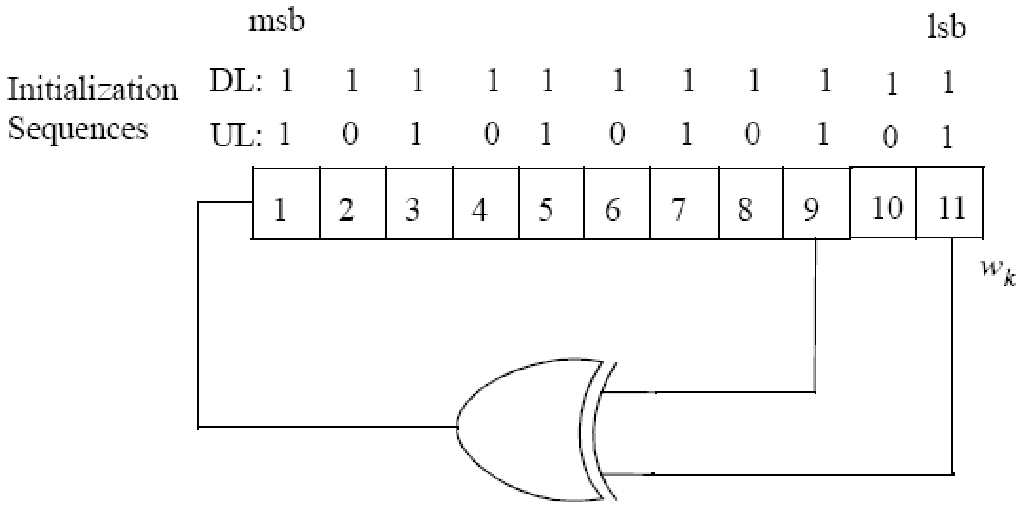
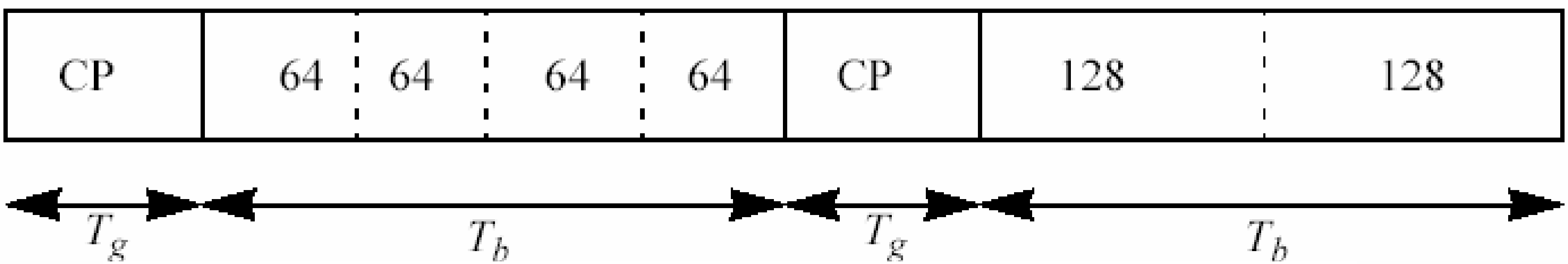


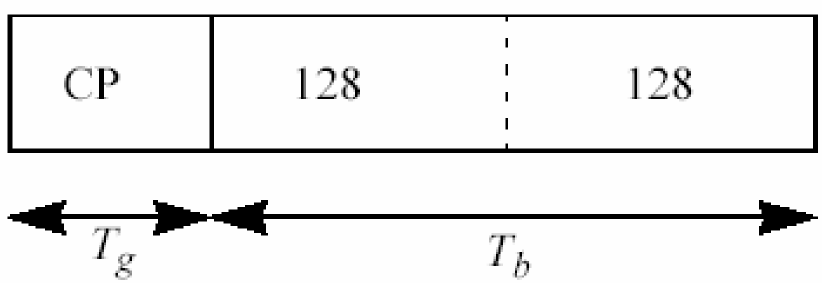
Figure 128aj—PRBS for pilot modulation

$$X^{11} + X^{9} + 1$$

OFDM DL Preamble



OFDM UL Preamble



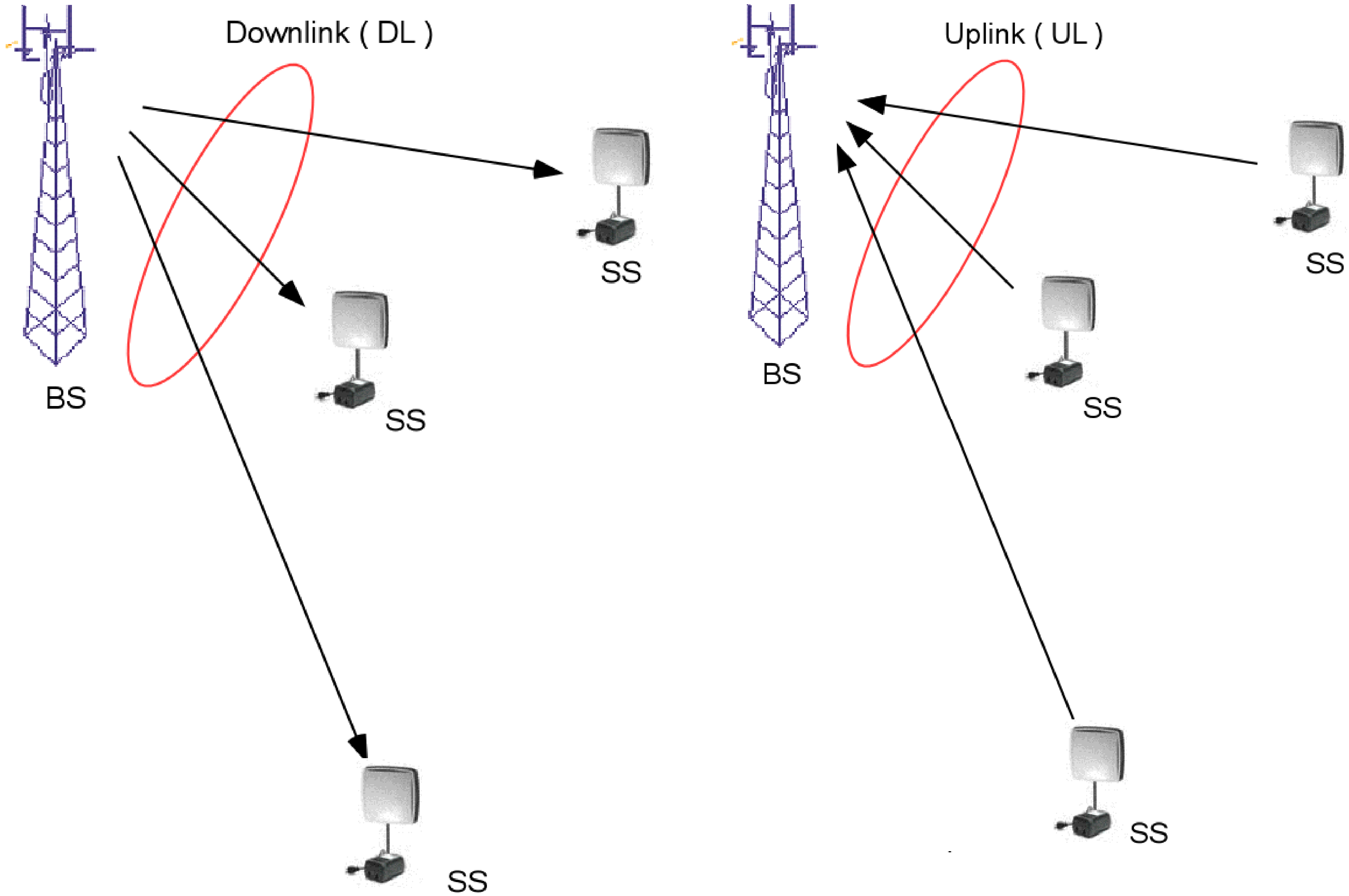
The frequency domain sequence for the 4 times 64 sequence is defined by:

S(-100:100) = {+1+j , 0 , 0 , 0 , +1+j , 0 , 0 , 0 , +1+j , 0 , 0 , 0 , +1-j , 0 , 0 , 0 , -1+j , 0 , 0 , 0 , +1+j , 0 , 0 , 0 ,
+1+j , 0 , 0 , 0 , +1+j , 0 , 0 , 0 , +1-j , 0 , 0 , 0 , -1+j , 0 , 0 , 0 , +1+j , 0 , 0 , 0 , +1+j , 0 , 0 , 0 ,
+1+j , 0 , 0 , 0 , +1-j , 0 , 0 , 0 , -1+j , 0 , 0 , 0 , +1-j , 0 , 0 , 0 , +1-j , 0 , 0 , 0 , +1-j , 0 , 0 , 0 ,
-1-j , 0 , 0 , 0 , +1+j , 0 , 0 , 0 , -1+j , 0 , 0 , 0 , -1+j , 0 , 0 , 0 , -1+j , 0 , 0 , 0 , +1+j , 0 , 0 , 0 ,
-1-j , 0 , 0 , 0 , 0 , 0 , 0 , 0 , -1-j , 0 , 0 , 0 , +1-j , 0 , 0 , 0 , +1+j , 0 , 0 , 0 , -1-j , 0 , 0 , 0 , -1+j ,
0 , 0 , 0 , +1-j , 0 , 0 , 0 , +1+j , 0 , 0 , 0 , -1+j , 0 , 0 , 0 , +1-j , 0 , 0 , 0 , -1-j , 0 , 0 , 0 , +1+j ,
0 , 0 , 0 , -1+j , 0 , 0 , 0 , -1-j , 0 , 0 , 0 , +1+j , 0 , 0 , 0 , +1-j , 0 , 0 , 0 , -1-j , 0 , 0 , 0 , +1-j ,
0 , 0 , 0 , +1+j , 0 , 0 , 0 , -1-j , 0 , 0 , 0 , -1+j , 0 , 0 , 0 , -1+j , 0 , 0 , 0 , -1-j , 0 , 0 , 0 , +1-j ,
0 , 0 , 0 , -1+j , 0 , 0 , 0 , +1+j}*sqrt(2)*sqrt(2)

The frequency domain sequence for the 2 times 128 sequence is defined by:

$P_1(-100:100)$ = sqrt(2)*sqrt(2)*{		
1, 0, -1, 0, -1, 0, -1, 0, 1, 0, 1, 0,	[-100:-89]	
1, 0, 1, 0, -1, 0, 1, 0, -1, 0, -1, 0, -1,	[-88:-76]	
0, 1, 0,-1, 0, 1, 0, 1, 0, 1, 0, 1,	[-75:-64]	
0,-1, 0, 1, 0, 1, 0, 1, 0, -1, 0, 1, 0,	[-63:-51	
-1, 0, 1, 0, 1, 0, -1, 0, -1, 0, 1, 0,	[-50:-39]	
-1, 0, 1, 0, -1, 0, 1, 0, 1, 0, -1, 0, 1,	[-38:-26]	
0, 1, 0, -1, 0, -1, 0, -1, 0, 1, 0, -1,	[-25:-14]	
0, -1, 0, -1, 0, -1, 0, -1, 0, 1, 0, 1, 0,	[-13:-1]	
0,	[0]	DC
0, 1, 0, -1, 0, -1, 0, 1, 0, -1, 0, 1, 0,	[1:13]	
1, 0, 1, 0, 1, 0, -1, 0, 1, 0, 1, 0,	[14:25]	
1, 0, 1, 0, -1, 0, 1, 0, -1, 0, -1, 0, -1,	[26:38]	
0, -1, 0, 1, 0, 1, 0, -1, 0, 1, 0, -1,	[39:50]	
0, -1, 0, -1, 0, -1, 0, -1, 0, -1, 0, -1, 0,	[51:63]	
-1, 0, 1, 0, 1, 0, 1, 0, -1, 0, -1, 0,	[64:75]	
-1, 0, 1, 0, 1, 0, -1, 0, -1, 0, -1, 0, 1,	[76:88]	
0, -1, 0, -1, 0, 1, 0, -1, 0, -1, 0, -1}	[89:100]	

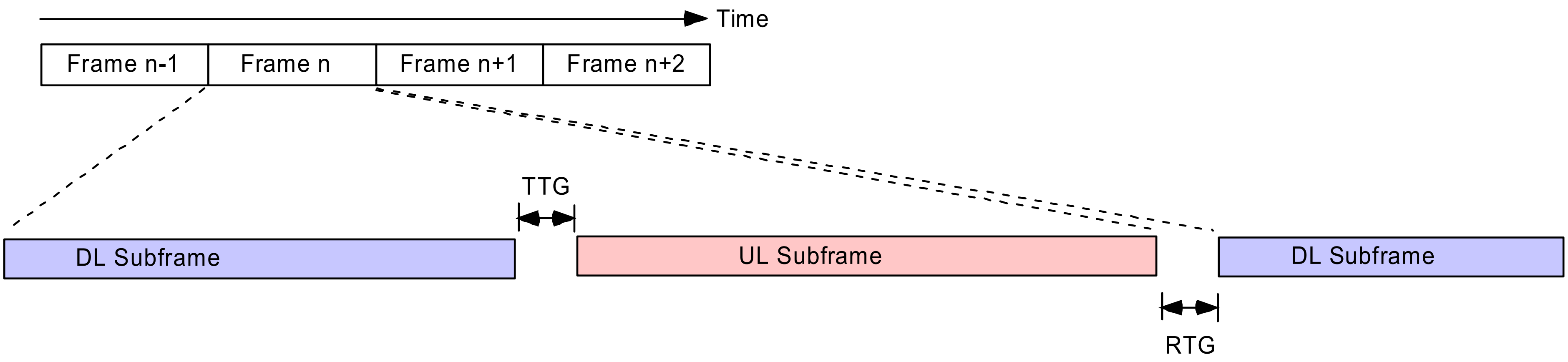
Time Division Duplex (TDD) Frame Structure


Downlink (DL)
BS
SS
SS
SS
Uplink (UL)
BS
SS
SS
SS

Frame

The OFDM PHY supports a frame-based transmission. A frame consists of a DL sub-frame and an UL sub- frame. A DL sub-frame consists of only one DL PHY PDU. A UL sub-frame consists of contention intervals scheduled for initial ranging and bandwidth request purposes and one or multiple UL PHY PDUs, each transmitted from a ***different*** SS.

TDD Frame



Min RTG and TTG: 5 μsec and must be multiple of PS

Physical Slot (OFDM OFDMA)

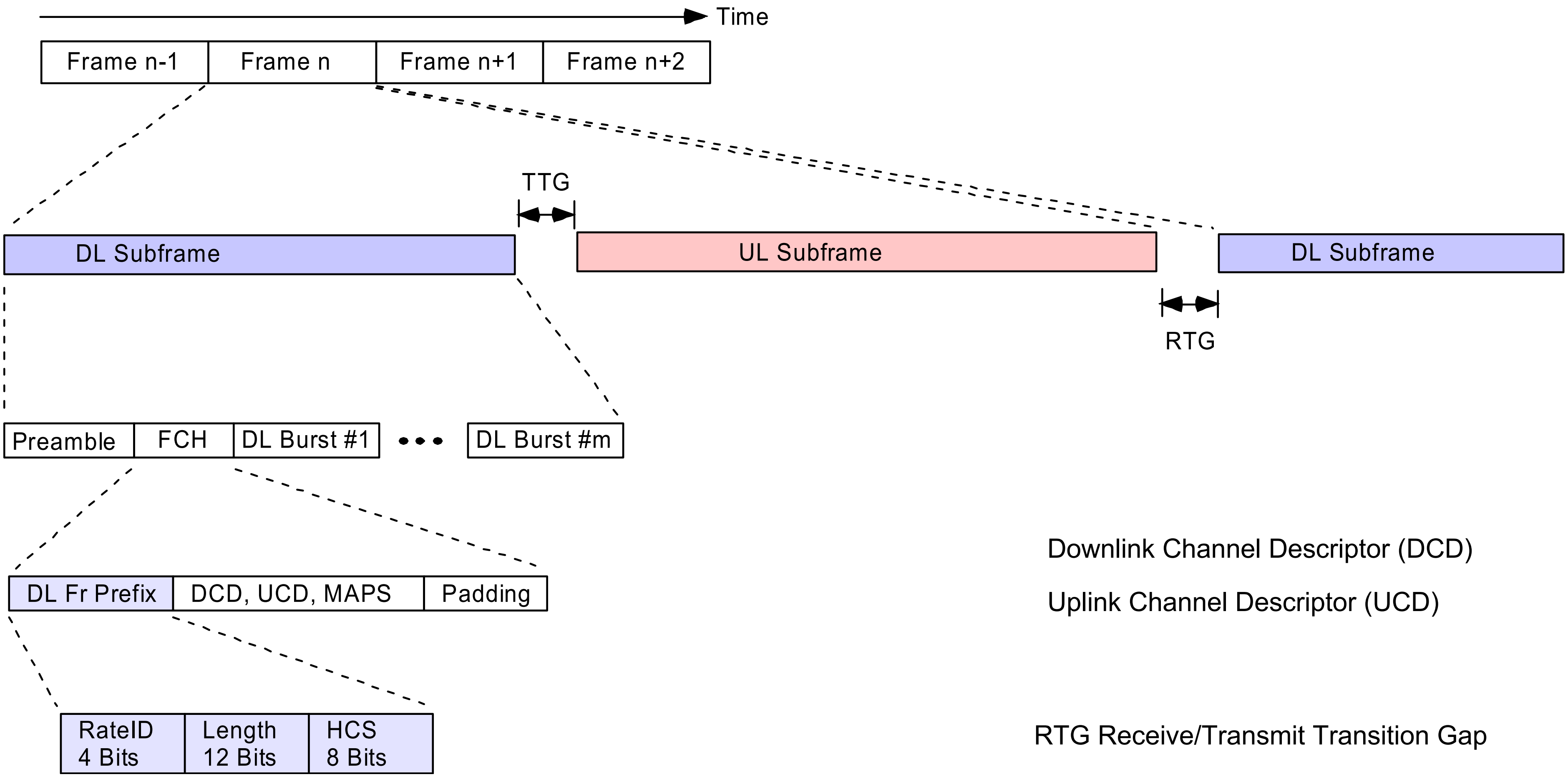
Physical Slot = 4 Sample Time

Sample Time = $1/f_s$

RTG Receive/Transmit Transition Gap

TTG Transmit/Receive Transition Gap

FCH Frame Control Header



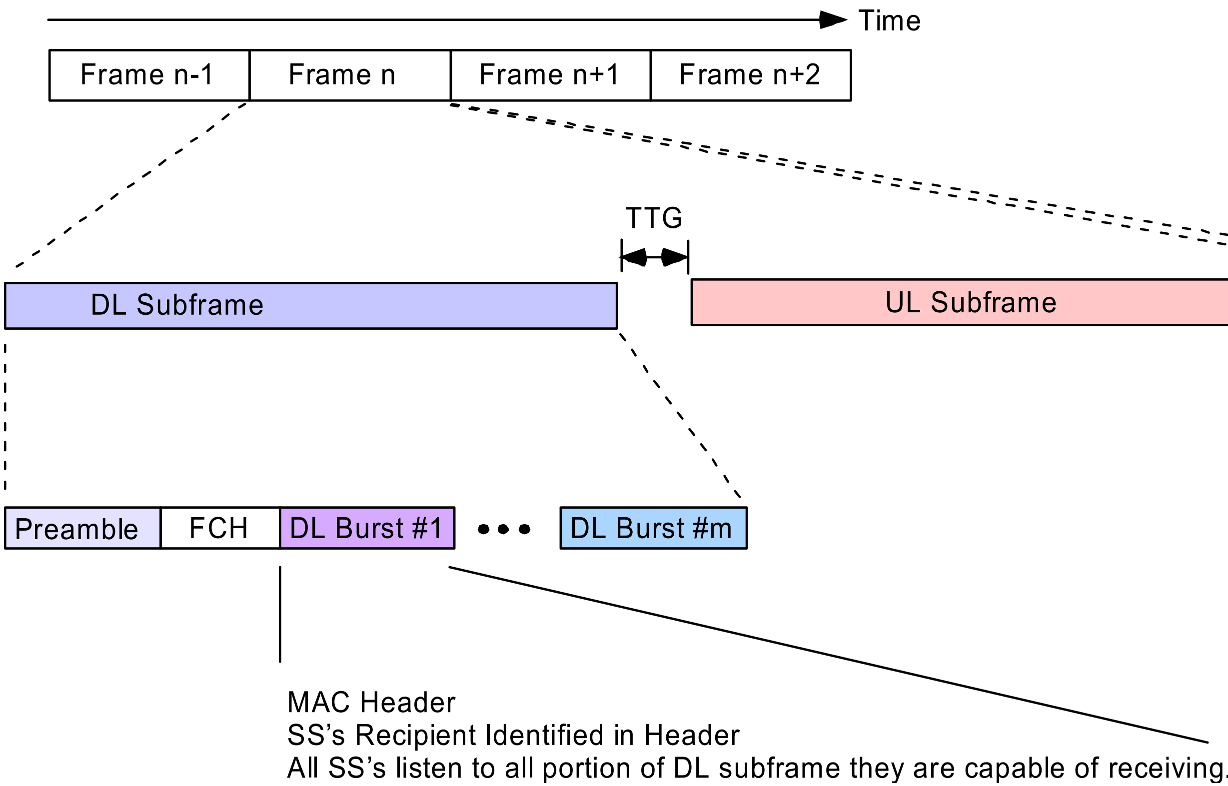
Downlink Channel Descriptor (DCD)

Uplink Channel Descriptor (UCD)

RTG Receive/Transmit Transition Gap

TTG Transmit/Receive Transition Gap

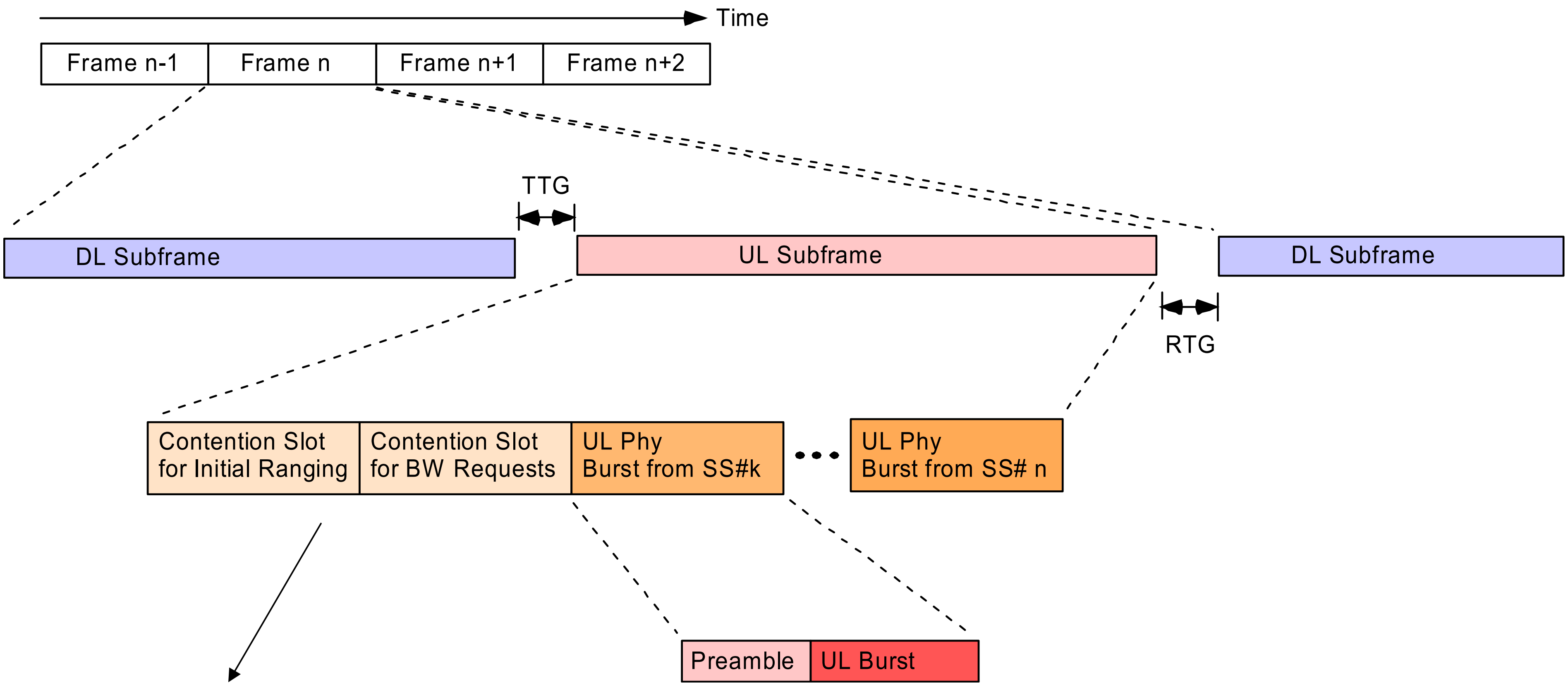
FCH Frame Control Header



RTG Receive/Transmit Transition Gap

TTG Transmit/Receive Transition Gap

FCH Frame Control Header



"Initial ranging transmissions shall consist of a long preamble and one OFDM symbol using the most robust mandatory burst profile."

RTG Receive/Transmit Transition Gap

TTG Transmit/Receive Transition Gap

FCH Frame Control Header

Uplink Burst Transmissions from Subscriber Stations

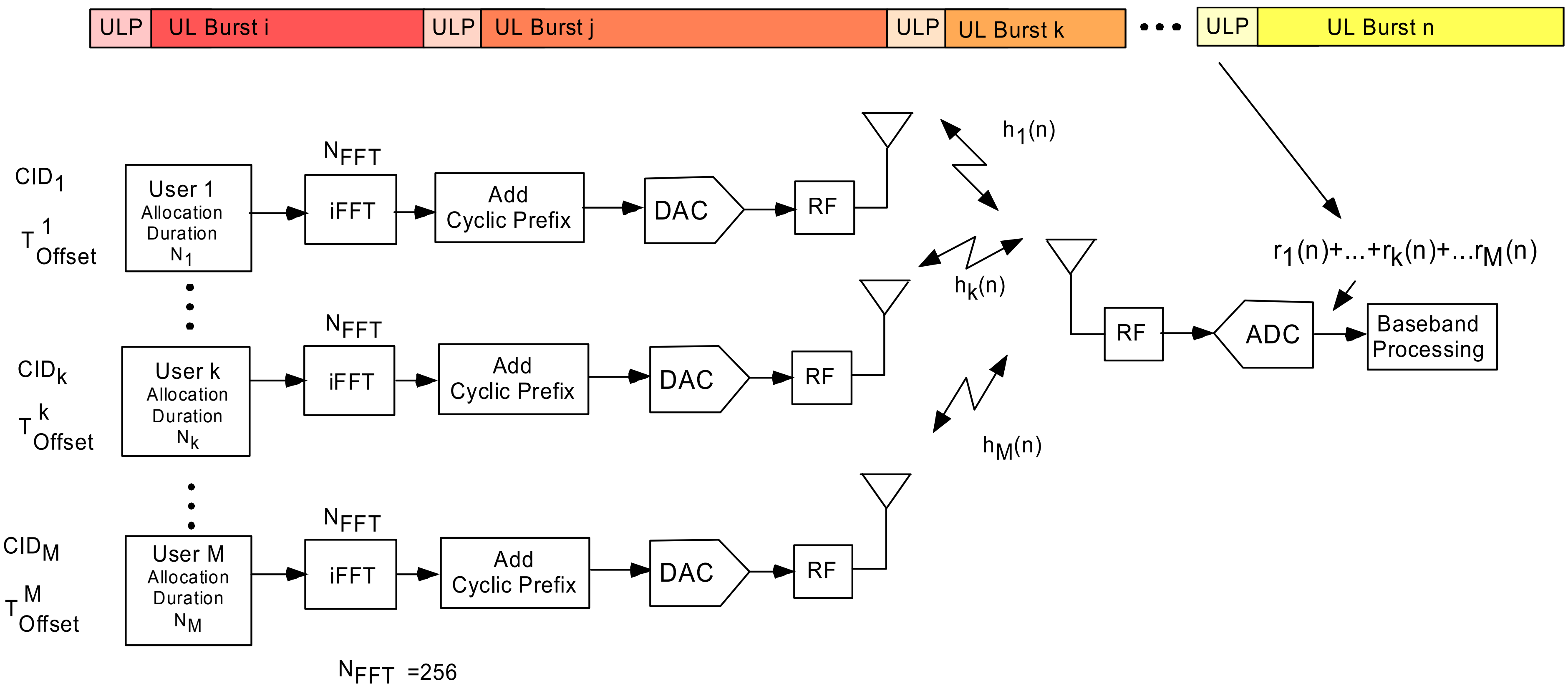


Table 116az—OFDM UL-MAP Information Element format

Syntax	Size	Notes
UL-MAP_Information_Element() {		
CID	16 bits	
UIUC	4 bits	
if (UIUC == 4)		
Focused_contention_IE()	28 bits	
else if (UIUC == 15)		
Extended UIUC dependent IE	variable	Power_Control_IE() or AAS_UL_IE() subchannelization_IE()
else {		
if (subchannelization[a]) {		
Subchannel Index	3 bits	0x1 = subchannel 1 0x5 = subchannel 1 and 2 0x2 = subchannel 2 0x6 = subchannel 3 and 4 0x3 = subchannel 3 0x0 = reserved 0x4 = subchannel 4 0x7 = reserved
Duration	5 bits	in OFDM symbols
Reserved	4 bits	Reserved
} else		
Duration	12 bits	
}		
}		

[a]When subchannelization is active (see 8.4.5.3.5), only UIUCs 5 through 13 shall be used.

DL Frame Prefix Format

Table 116ap—OFDM DL frame prefix format

Syntax	Size	Notes
DL_Frame_Prefix_Format() {		
Rate_ID	4 bits	
Length	12 bits	
HCS	8 bits	
}		

Rate_ID

Field that defines the burst profile of the following burst. Encoding is specified in Table 116ao.

Length

Number of OFDM symbols (PHY payload) in the burst immediately following the FCH burst. The minimum value shall be 6.

HCS

An 8-bit Header Check Sequence used to detect errors in the DL Frame Prefix. The generator polynomial is $g(D)= D^8 + D^2 + D + 1$.

Rate ID's

Table 116ao—OFDM Rate ID encodings

Rate_ID	Modulation RS-CC rate
0	QPSK 1/2
1	QPSK 3/4
2	16-QAM 1/2
3	16-QAM 3/4
4	64-QAM 2/3
5	64-QAM 3/4
6–15	Reserved

Sensitivity

Table 116bj—Receiver minimum input level sensitivity (dBm)

Bandwidth (MHz)	QPSK		16-QAM		64-QAM	
	1/2	3/4	1/2	3/4	2/3	3/4
1.5	–91	–89	–84	–82	–78	–76
1.75	–90	–87	–83	–81	–77	–75
3	–88	–86	–81	–79	–75	–73
3.5	–87	–85	–80	–78	–74	–72
5	–86	–84	–79	–77	–72	–71
6	–85	–83	–78	–76	–72	–70
7	–84	–82	–77	–75	–71	–69
10	–83	–81	–76	–74	–69	–68
12	–82	–80	–75	–73	–69	–67
14	–81	–79	–74	–72	–68	–66
20	–80	–78	–73	–71	–66	–65

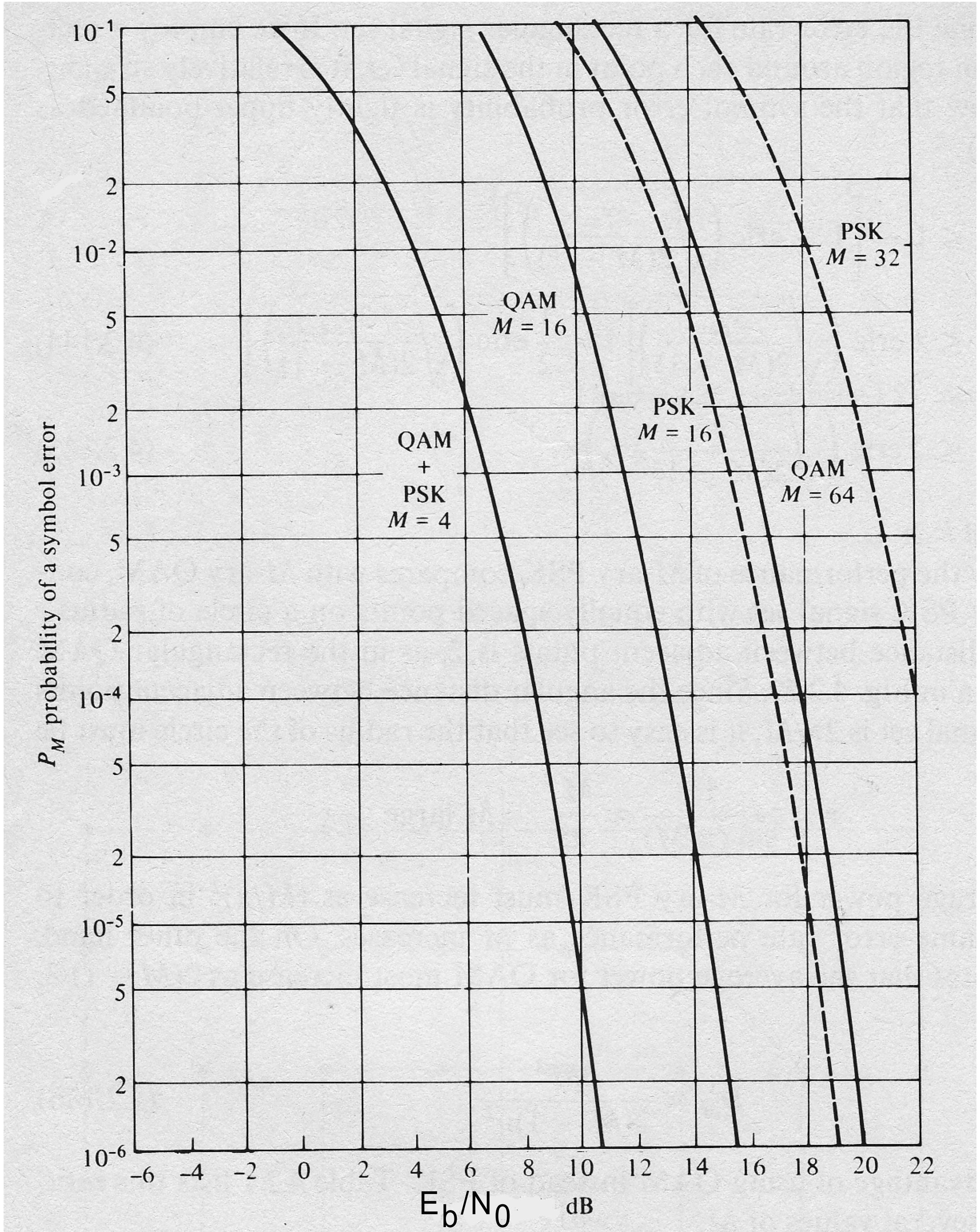
The bit error rate (BER) shall be less than 10^{-6} at the power levels shown in the Table

Assumptions

Table 116bk—Receiver SNR and E_b/N_0 assumptions

Modulation	E_b/N_0 (dB)	Coding rate	Receiver SNR (dB)
QPSK	10.5	1/2	9.4
		3/4	11.2
16-QAM	14.5	1/2	16.4
		3/4	18.2
64-QAM	19.0	2/3	22.7
		3/4	24.4

Table 116bj (as well as Table 116bi) are derived assuming 5 dB implementation loss, a Noise Figure of 7 dB and receiver SNR and *Eb*/*N0* values as listed in Table 116bk.



Poakis, “Digital Communications,” McGraw-Hill, 1983

Adjacent and Non-adjacent Channel Rejection

Table 116bl—Adjacent and non-adjacent channel rejection

Modulation/coding	Adjacent channel rejection dB)	Non-adjacent channel rejection (dB)
16-QAM-3/4	11	30
64-QAM-2/3	4	23