Signal Constellations and Mappings used in IEEE Wireless Standards

EE 161: Digital Communication Systems
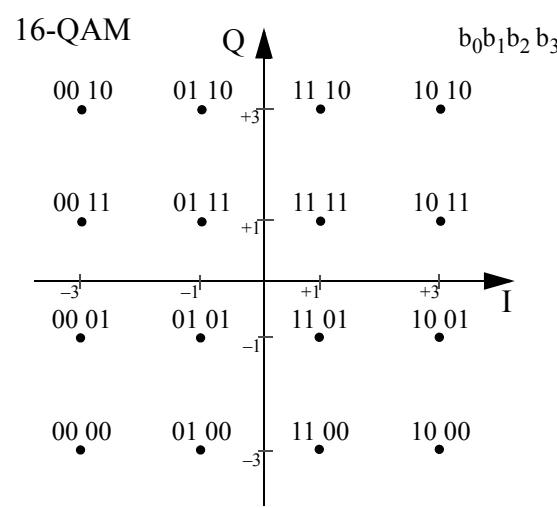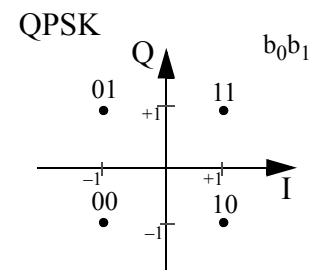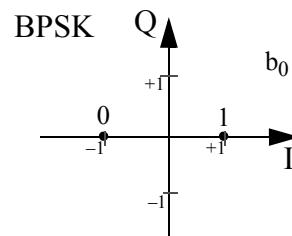
Robert Morelos-Zaragoza

San José State University
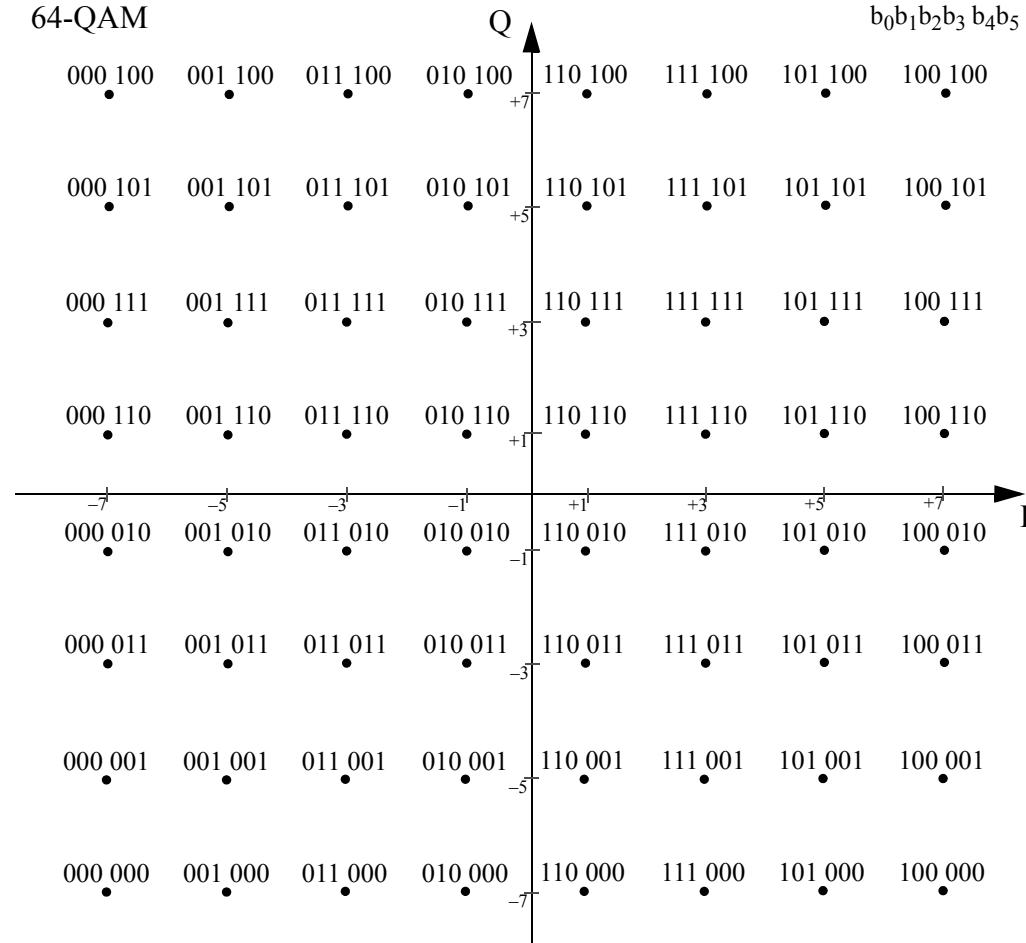
IEEE 802.3-2008: Polar Manchester

ONE BIT PERIOD

ENCODED WAVEFORM — CONSTANT "CD0"

ENCODED WAVEFORM — CONSTANT "CD1"

ENCODED WAVEFORM — ALTERNATING "CD0", "CD1"

ENCODED WAVEFORM — RANDOM DATA

Figure 7–10—Examples of Manchester waveforms

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IEEE 802.11-2007: Constellations (1)

BPSK

QPSK

16-QAM

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U N I V E R S I T Y

IEEE 802.11-2007: Constellations (2)

64-QAM

$b_0b_1b_2b_3\ b_4b_5$

Q

| 000 100 | 001 100 | 011 100 | 010 100 | 110 100 | 111 100 | 101 100 | 100 100 |

+7

| 000 101 | 001 101 | 011 101 | 010 101 | 110 101 | 111 101 | 101 101 | 100 101 |

+5

| 000 111 | 001 111 | 011 111 | 010 111 | 110 111 | 111 111 | 101 111 | 100 111 |

+3

| 000 110 | 001 110 | 011 110 | 010 110 | 110 110 | 111 110 | 101 110 | 100 110 |

+1

−7 −5 −3 −1   +1 +3 +5 +7   I

| 000 010 | 001 010 | 011 010 | 010 010 | 110 010 | 111 010 | 101 010 | 100 010 |

−1

| 000 011 | 001 011 | 011 011 | 010 011 | 110 011 | 111 011 | 101 011 | 100 011 |

−3

| 000 001 | 001 001 | 011 001 | 010 001 | 110 001 | 111 001 | 101 001 | 100 001 |

−5

| 000 000 | 001 000 | 011 000 | 010 000 | 110 000 | 111 000 | 101 000 | 100 000 |

−7

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IEEE 802.11-2007: Bit mappings

Table 17-7—BPSK encoding table

Input bit (b_0)	I-out	Q-out
0	−1	0
1	1	0

Table 17-8—QPSK encoding table

Input bit (b_0)	I-out	Input bit (b_1)	Q-out
0	−1	0	−1
1	1	1	1

Table 17-9—16-QAM encoding table

Input bits ($b_0 b_1$)	I-out	Input bits ($b_2 b_3$)	Q-out
00	−3	00	−3
01	−1	01	−1
11	1	11	1
10	3	10	3

Table 17-10—64-QAM encoding table

Input bits ($b_0 b_1 b_2$)	I-out	Input bits ($b_3 b_4 b_5$)	Q-out
000	−7	000	−7
001	−5	001	−5
011	−3	011	−3
010	−1	010	−1
110	1	110	1
111	3	111	3
101	5	101	5
100	7	100	7

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IEEE 802.11-2007: OFDM and Rates

Table 17-3—Modulation-dependent parameters

Modulation	Coding rate (R)	Coded bits per subcarrier (N_{BPSC})	Coded bits per OFDM symbol (N_{CBPS})	Data bits per OFDM symbol (N_{DBPS})	Data rate (Mb/s) (20 MHz channel spacing)	Data rate (Mb/s) (10 MHz channel spacing)	Data rate (Mb/s) (5 MHz channel spacing)
BPSK	1/2	1	48	24	6	3	1.5
BPSK	3/4	1	48	36	9	4.5	2.25
QPSK	1/2	2	96	48	12	6	3
QPSK	3/4	2	96	72	18	9	4.5
16-QAM	1/2	4	192	96	24	12	6
16-QAM	3/4	4	192	144	36	18	9
64-QAM	2/3	6	288	192	48	24	12
64-QAM	3/4	6	288	216	54	27	13.5

IEEE 802.11n-2009: Constellations

Table 20-21—Allowed relative constellation error versus constellation size and coding rate

Modulation	Coding rate	Relative constellation error (dB)
BPSK	1/2	−5
QPSK	1/2	−10
QPSK	3/4	−13
16-QAM	1/2	−16
16-QAM	3/4	−19
64-QAM	2/3	−22
64-QAM	3/4	−25
64-QAM	5/6	−28

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IEEE 802.11n: Space-Time Block Coding

Table 20-17—Constellation mapper output to spatial mapper input for STBC

N_{STS}	HT-SIG MCS field (bits 0–6 in HT-SIG$_1$)	N_{SS}	HT-SIG STBC field (bits 4–5 in HT-SIG$_2$)	i_{STS}	$\tilde{d}_{k, i, 2m}$	$\tilde{d}_{k, i, 2m+1}$
2	0–7	1	1	1	$d_{k, 1, 2m}$	$d_{k, 1, 2m+1}$
				2	$-d^*_{k, 1, 2m+1}$	$d^*_{k, 1, 2m}$
3	8–15, 33–38	2	1	1	$d_{k, 1, 2m}$	$d_{k, 1, 2m+1}$
				2	$-d^*_{k, 1, 2m+1}$	$d^*_{k, 1, 2m}$
				3	$d_{k, 2, 2m}$	$d_{k, 2, 2m+1}$
4	8–15	2	2	1	$d_{k, 1, 2m}$	$d_{k, 1, 2m+1}$
				2	$-d^*_{k, 1, 2m+1}$	$d^*_{k, 1, 2m}$
				3	$d_{k, 2, 2m}$	$d_{k, 2, 2m+1}$
				4	$-d^*_{k, 2, 2m+1}$	$d^*_{k, 2, 2m}$
4	16–23, 39, 41, 43, 46, 48, 50	3	1	1	$d_{k, 1, 2m}$	$d_{k, 1, 2m+1}$
				2	$-d^*_{k, 1, 2m+1}$	$d^*_{k, 1, 2m}$
				3	$d_{k, 2, 2m}$	$d_{k, 2, 2m+1}$
				4	$d_{k, 3, 2m}$	$d_{k, 3, 2m+1}$

# IEEE 802.15.3c-2009: Constellations
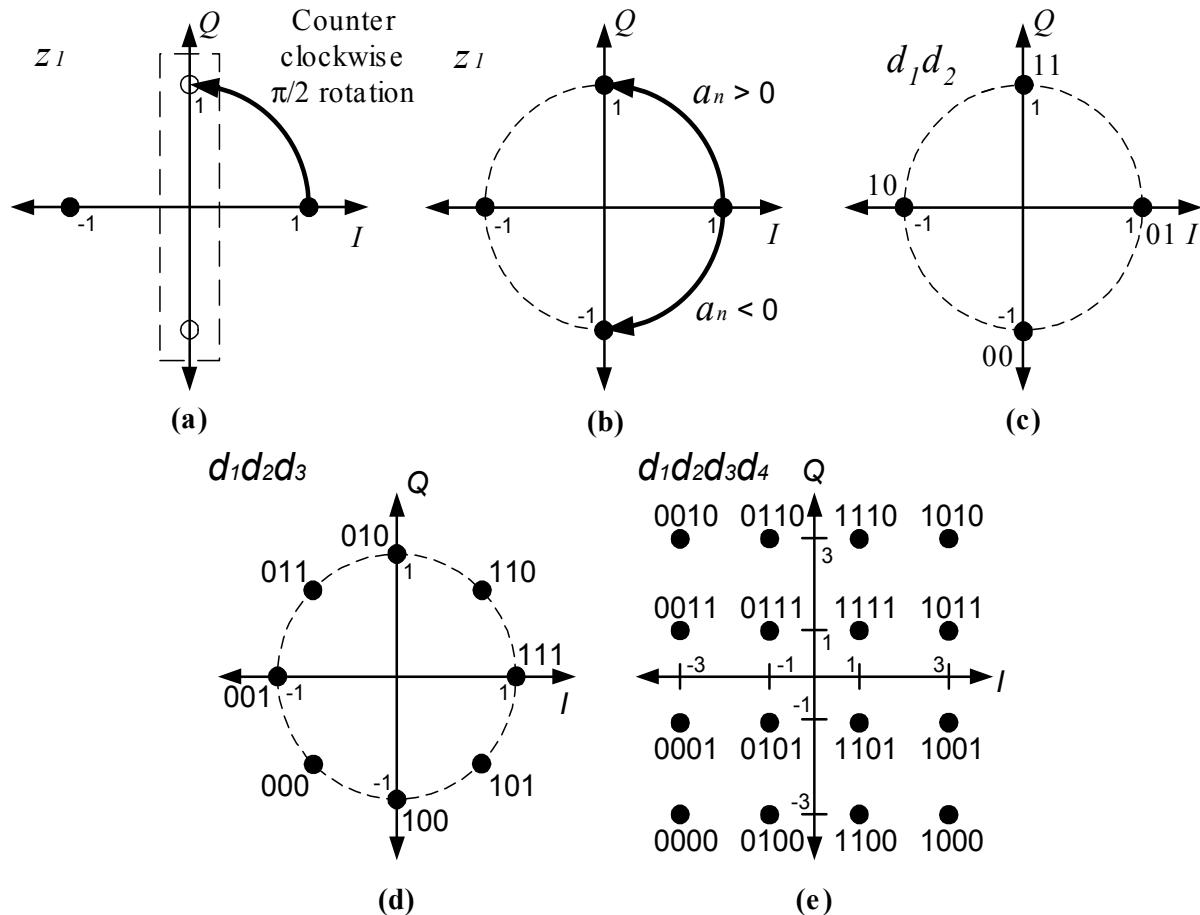
Figure 164—Constellation maps for modulations: (a) $\pi/2$ BPSK, (b) pre-coded (G)MSK, (c) $\pi/2$ QPSK, (d) $\pi/2$ 8-PSK, (e) $\pi/2$ 16-QAM

IEEE 802.15.3c-2009: Rates

Table 103—MCS dependent parameters

MCS class	MCS identifier	Data rate (Mb/s) with pilot word length = 0	Data rate (Mb/s) with pilot word length = 64	Modulation	Spreading factor, L_{SF}	FEC type
Class1	0	25.8 (CMS)	—	$\pi/2$ BPSK/(G)MSK[a]	64	RS(255,239)
	1	412	361		4	
	2	825	722		2	
	3	1650 (MPR)	1440		1	
	4	1320	1160	$\pi/2$ BPSK/(G)MSK	1	LDPC(672,504)
	5	440	385	$\pi/2$ BPSK/(G)MSK	2	LDPC(672,336)
	6	880	770		1	
Class2	7	1760	1540	$\pi/2$ QPSK	1	LDPC(672,336)
	8	2640	2310	$\pi/2$ QPSK	1	LDPC(672,504)
	9	3080	2700	$\pi/2$ QPSK	1	LDPC(672,588)
	10	3290	2870	$\pi/2$ QPSK	1	LDPC(1440,1344)
	11	3300	2890	$\pi/2$ QPSK	1	RS(255,239)
Class3	12	3960	3470	$\pi/2$ 8-PSK	1	LDPC(672,504)
	13	5280	4620	$\pi/2$ 16-QAM	1	LDPC(672,504)

IEEE 802.15.3c-2009: Unequal Error Protection

12.4 Audio/Visual mode of mmWave PHY

The Audio/Visual (AV) PHY is implemented with two PHY modes, the high-rate PHY (HRP) and low-rate PHY (LRP), both of which use orthogonal frequency domain multiplexing (OFDM). The data rates supported by the HRP are defined in Table 134.

Table 134—HRP data rates and coding

HRP mode index	Coding mode	Modulation	Inner code rate		Data rate (Gb/s)
			MSB	LSB	
			[7] [6] [5] [4]	[3] [2] [1] [0]	
0	EEP	QPSK	1/3		0.952
1	EEP	QPSK	2/3		1.904
2	EEP	16-QAM	2/3		3.807
3	UEP	QPSK	4/7	4/5	1.904
4	UEP	16-QAM	4/7	4/5	3.807
5	MSB-only retransmission	QPSK	1/3	N/A	0.952
6	MSB-only retransmission	QPSK	2/3	N/A	1.904

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IEEE 802.15.7-2011: OOK and PPM (1)

Table 73—PHY I operating modes

Modulation	RLL code	Optical clock rate	FEC		Data rate
			Outer code (RS)	Inner code (CC)	
OOK	Manchester	200 kHz	(15,7)	1/4	11.67 kb/s
			(15,11)	1/3	24.44 kb/s
			(15,11)	2/3	48.89 kb/s
			(15,11)	none	73.3 kb/s
			none	none	100 kb/s
VPPM	4B6B	400 kHz	(15,2)	none	35.56 kb/s
			(15,4)	none	71.11 kb/s
			(15,7)	none	124.4 kb/s
			none	none	266.6 kb/s

IEEE 802.15.7-2011: OOK and PPM (2)

Table 74—PHY II operating modes

Modulation	RLL code	Optical clock rate	FEC	Data rate
VPPM	4B6B	3.75 MHz	RS(64,32)	1.25 Mb/s
			RS(160,128)	2 Mb/s
		7.5 MHz	RS(64,32)	2.5 Mb/s
			RS(160,128)	4 Mb/s
			none	5 Mb/s
OOK	8B10B	15 MHz	RS(64,32)	6 Mb/s
			RS(160,128)	9.6 Mb/s
		30 MHz	RS(64,32)	12 Mb/s
			RS(160,128)	19.2 Mb/s
		60 MHz	RS(64,32)	24 Mb/s
			RS(160,128)	38.4 Mb/s
		120 MHz	RS(64,32)	48 Mb/s
			RS(160,128)	76.8 Mb/s
			none	96 Mb/s

IEEE 802.15.7-2011: Color-shift keying (CSK)

Table 106—*xy* color coordinates

Band (nm)	Code	Center (nm)	(*x, y*)
380–478	000	429	(0.169, 0.007)
478–540	001	509	(0.011, 0.733)
540–588	010	564	(0.402, 0.597)
588–633	011	611	(0.669, 0.331)
633–679	100	656	(0.729, 0.271)
679–726	101	703	(0.734, 0.265)
726–780	110	753	(0.734, 0.265)
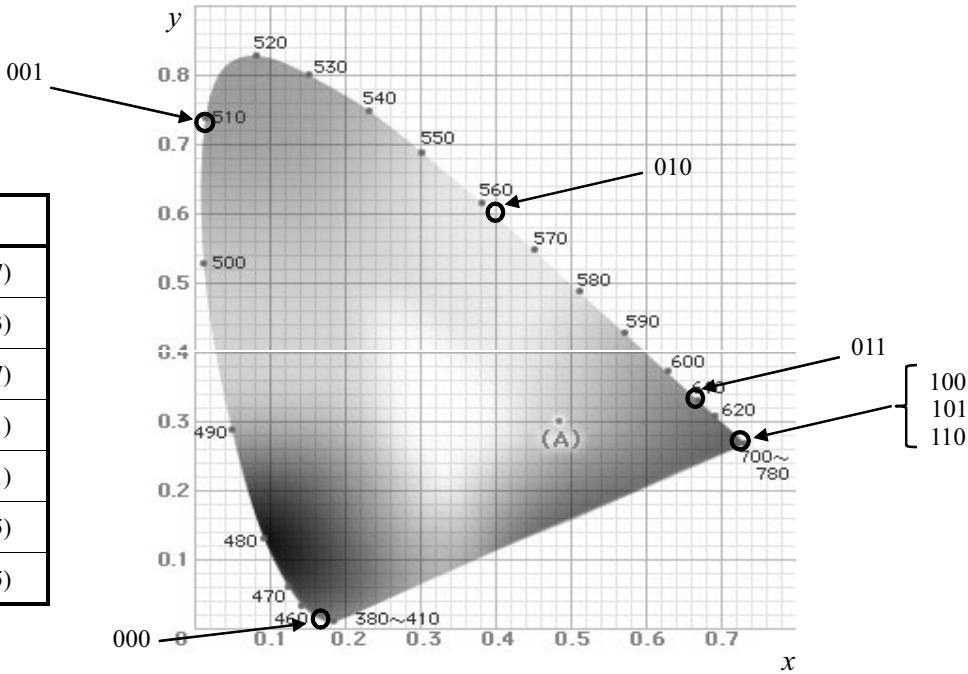
Figure 137—Center of color bands on *xy* color coordinates

IEEE 802.15.7-2011: CSK

Table 75—PHY III operating modes

Modulation	Optical clock rate	FEC	Data rate
4-CSK	12 MHz	RS(64,32)	12 Mb/s
8-CSK		RS(64,32)	18 Mb/s
4-CSK	24 MHz	RS(64,32)	24 Mb/s
8-CSK		RS(64,32)	36 Mb/s
16-CSK		RS(64,32)	48 Mb/s
8-CSK		none	72 Mb/s
16-CSK		none	96 Mb/s

IEEE 802.16-2009: QPSK
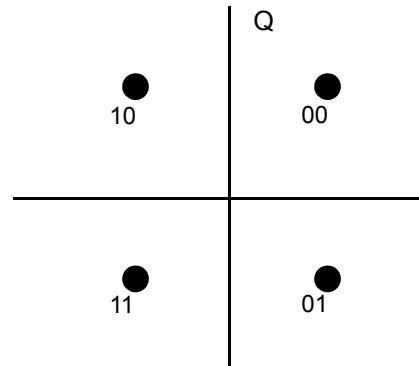
Figure 190—QPSK constellation

Table 228—QPSK bits to symbol mapping

B(1)	B(2)	I	Q
0	0	1	1
0	1	1	−1
1	0	−1	1
1	1	−1	−1

IEEE 802.16-2009: 16-QAM
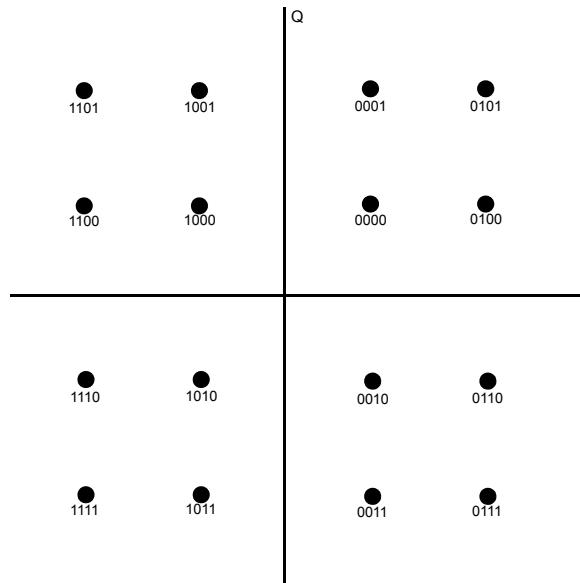
Figure 191—16-QAM constellation (gray-coded)

Table 229—16-QAM bits to symbol mapping

B(1)	B(2)	B(3)	B(4)	I	Q
0	1	0	1	3	3
0	1	0	0	3	1
0	1	1	0	3	−1
0	1	1	1	3	−3
0	0	0	1	1	3
0	0	0	0	1	1
0	0	1	0	1	−1
0	0	1	1	1	−3
1	0	0	1	−1	3
1	0	0	0	−1	1
1	0	1	0	−1	−1
1	0	1	1	−1	−3
1	1	0	1	−3	3
1	1	0	0	−3	1
1	1	1	0	−3	−1
1	1	1	1	−3	−3

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IEEE 802.16-2009: 64-QAM
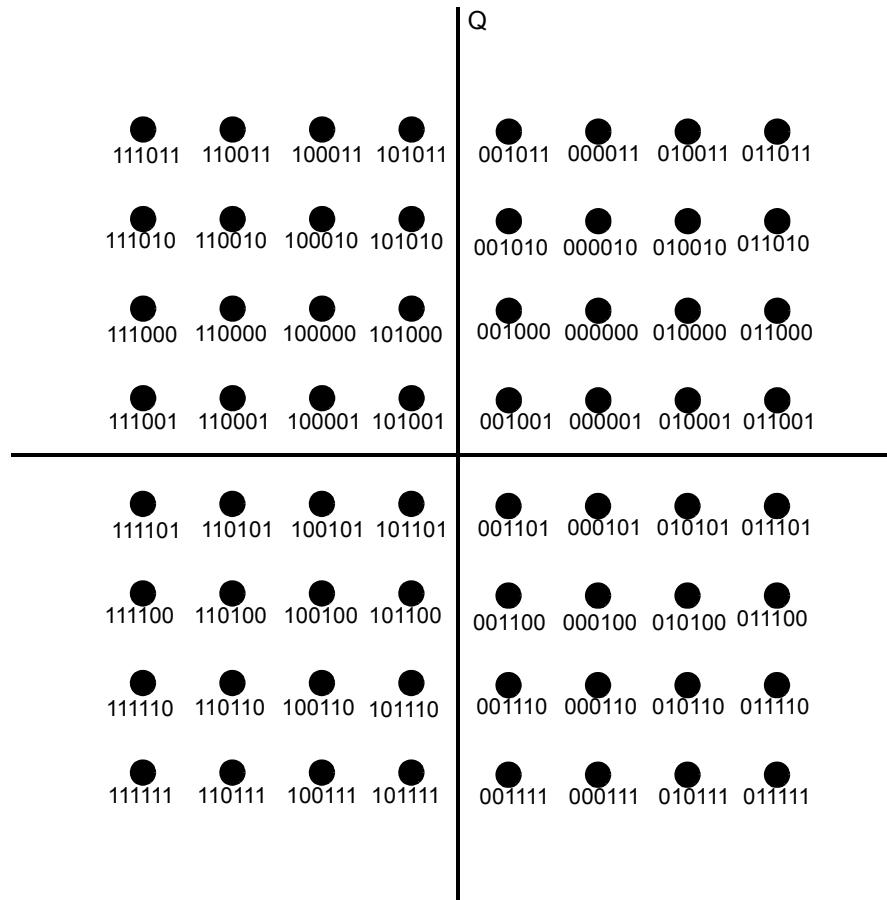
Figure 192—64-QAM constellation (gray-coded)

IEEE 802.16-2009: Alamouti (STBC)
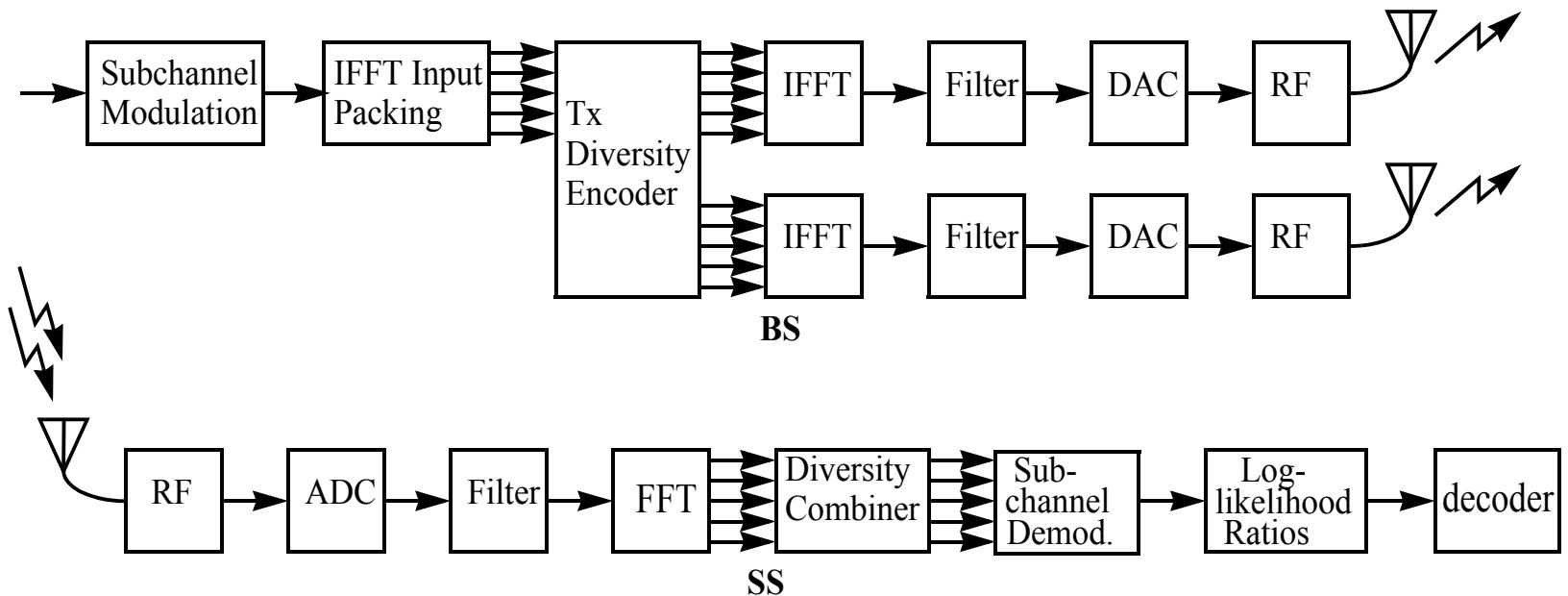
Figure 259—Illustration of STC

IEEE 802.20-2008: Modulations

Table 434—Modulation and coding rates

ModClass	Bits/Sym	Signal Set	Puncture	Shaper	Block Code
0	0.5	π/2 BPSK	Repeat	—	—
1	0.67	π/2 BPSK	1 of 4	—	—
2	1	QPSK	—	—	—
3	1.5	QPSK	2 of 6	—	—
4	2	8-PSK	—	—	(64,57)
5	2.5	8-PSK	—	—	(64,57)
6	3	12-QAM	2 of 6	3/4	(48,47)
7	3.5	16-QAM	2 of 6	4/4	(64,63)
8	4	24-QAM	2 of 6	5/4	(80,79)
9	4.5	32-QAM	2 of 6	5/5	(80,79)
10	5.5	64-QAM	2 of 5	6/6	(80,79)
11–15	RESERVED				

IEEE 802.22-2011: Modulations and rates

Table 198 — System parameters for WRAN

Parameters	Specification	Remark
Frequency range	54~862 MHz[a]	
Channel bandwidth	6, 7, or 8 MHz	According to regulatory domain (see Annex A).
Data rate	4.54 to 22.69 Mbit/s	See Table 202
Spectral Efficiency	0.76 to 3.78 bit/(s·Hz)	See Table 202
Payload modulation	QPSK, 16-QAM, 64-QAM	BPSK used for preambles, pilots and CDMA codes.
Transmit EIRP	4W maximum for CPEs. 4W maximum for BS's in the USA regulatory domain.	Maximum EIRP for BS's may vary in other regulatory domains.
Multiple Access	OFDMA	
FFT Size (N_{FFT})	2048	
Cyclic Prefix Modes	1/4, 1/8, 1/16, 1/32	
Duplex	TDD	

[a] Frequency range allocated to the Television Broadcasting Service in various parts of the world

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References

[1] IEEE 802 Part 3: Carrier sense multiple access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications, IEEE Computer Society, 2008.

[2] IEEE 802 Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, IEEE Computer Society, 2007.

[3] IEEE 802 Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications— Amendment 5: Enhancements for Higher Throughput, IEEE Computer Society, 2009.

[4] IEEE 802 Part 15.3: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for High Rate Wireless Personal Area Networks (WPANs) – Amendment 2: Millimeter-wave-based Alternative Physical Layer Extension, 2009

[5] IEEE 802 Part 15.7: Short-Range Wireless Optical Communication Using Visible Light, IEEE Computer Society, 2011.

[6] IEEE 802 Part 16: Air Interface for Broadband Wireless Access Systems, IEEE Computer Society, 2009.

[7] IEEE 802 Part 20: Air Interface for Mobile Broadband Wireless Access Systems Supporting Vehicular Mobility — Physical and Media Access Control Layer Specification, IEEE Computer Society, 2008.

[8] IEEE 802 Part 22: Cognitive Wireless RAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Policies and Procedures for Operation in the TV Bands, IEEE Computer Society, 2011.