

Wi-Fi Technology Fundamentals

Module-2 WLAN Physical Layer Session-2b Modulation and Coding/ MIMO Basics



FUNDAMENTALS COURSE

Last Session Recap.....





Module-2 WLAN Physical Layer Session-2a Frequency Allocation and Modulation Basics

✓ Frequency Spectrum
✓ Wi-Fi Frequencies
✓ Basics of Signals and Modulation
✓ Spread Spectrum Techniques

How to Stay Connected?



Access Course Webpage

Register to Get Updates



<u>Click here: Wi-Fi Technology Fundamentals</u> <u>Course (candelatech.com)</u>

 ✓ Access course notes, slides, video recordings



Click Here: Registration (zoho.in)

 ✓ Provide basic contact into to get calendar invites, reminders and updates about the material and sessions.

Join Whatsapp Group



Click here: WhatsApp Group Invite

 Provide basic contact into to get whatsapp messages about calendar invites, reminders and updates about the material and sessions.





Module-2 WLAN Physical Layer Session-2b Modulation and Coding/ MIMO Basics

Modulation

Modulation, is the process of varying one or properties of a periodic waveform called a carrier wave in order to carry information.

There are various forms of modulation, each designed to alter a particular characteristic of the carrier wave. The most commonly altered characteristics include amplitude, frequency, phase, pulse sequence, and pulse duration.

- FSK: Frequency of the carrier signal is varied to represent binary 1 and 0
- ASK: Amplitude of the carrier signal is varied to represent binary 1 and 0
- PSK: Phase of the carrier signal is varied to represent binary 1 and 0
- QAM: Amplitude and Phase of the carrier signal is varied to represent binary 1 and 0

Parameter	FSK	ASK	PSK	QAM
Bandwidth Needed	Higher	Low	Low	Lowest
Noise Immunity	Higher	Low	Higher	Lowest
Complexity	Low	Low	Higher	Highest
Data Rates	Low	Higher	Higher	Highest





Example : BPSK Modulation





Example : QPSK Modulation







Example: 16QAM Modulation





Amplitu	ude	Phase	_	FUND
Level	1	45deg		
Level	2	135deg	= 16 combin	ations
Level	3	225deg	(4bits)
Level	4	315deg		
0000		$\sqrt{}$		0001
0011				0010
0110				0111
0101		3 0.4		0100
1110				1111
1101				1100
1000				1001
1011				1010

The Throughput/Reliability Tradeoff









QPSK





8-PSK



Wi-Fi QAM Rates







1	0	24	4	C)A	\mathbb{N}	Λ															
		lacksquare		lacksquare	lacksquare	lacksquare	${}^{\bullet}$	lacksquare	lacksquare				${}^{\bullet}$			lacksquare						
		${}^{\bullet}$			${}^{\bullet}$	٠	۲	٠	${}^{\bullet}$				۲	۲		۲	۲	۲	۲	۲		
					${}^{\bullet}$			${}^{\bullet}$	${}^{\bullet}$				${}^{\bullet}$									
۲	۲	۲	۲	۲	${}^{\bullet}$	۲	۲	۲	۲			۲	۲	۲	۲	۲	۲	۲	۲	۲		
_		-	_																			
								~		• •	,										•	
•	•	•	•	•	•		1	0	b	its	/s'	yr	nl	ວດ	bl		•	•	•	•	⇒	
•	•	•	•	•	•		1	0	b	its	/s	yr	nl) (•	•	•	•	•	••••	
•	•	•	•	•	•		1	0	b	its	/s	yr	nl	ос •		•	•	•	•	•	••••	
•	•	•	•	•	•		1	0	b •	its	/s	yr	nl •			•	•	•	•	•	•••••	
•	•	•	•	•	•		1	0	b •	its •	/s	yr	nl			•	•	•	•	•	•	
•	•	•	•	•	•		1	0	b	its •	/S	yr	nl			••••	•	•	•	•	•••••	
•	•	•	•	•	•		1	0	b	its •	/s	yr	nl			••••	•	•	•	•	••••••	
•	•	• • • • • • •	• • • • • • •	•	•		1	0	b	its •	/s	yr	nl				• • • • • • • •	•	•	•	•	
							1	0	b	its •••	/S	yr	nl				•				• • • • • • • • •	
		• • • • • • • • •					1	0	b	its •••	/S	yr	nl				• • • • • • • • • •				• • • • • • • • • •	

-

	6	64 (QAI	M ∘♠					
	000 100	001 100	011 100	010 100 +7	110 100	111 100	101 100	100 100	
	000 101	001 101	011 101	010 101	110 101	111 101	101 101	100 101	
	000 111	001 111	011 111	010 111 • +3	110 111	111 111	101 111	100 111	
	000 110	001 110	011 110	010 110	110 110	111 110	101 110	100 110	
-	-7 000 010	-5 001 010	<u> 6 </u>	bits/	sym	bol	+5 11 010	+7 100 010	•
	000 011	001 011	011 011	010 011	110 011	111 011 •	101 011	100 011	
	000 001	001 001	011 001	010 001 • -5	110 001	111 001	101 001	100 001	
	000 000	001 000	011 000	010 000	110 000	111 000	101 000	100 000	



050	~													
256)	M		97 🌰	× •	■ 32	33	■ 35	▲ 34	• 38	■ 39	• 37	
0.000 0.000	-	#3 #53	-	in come			-		-		-	-	-	-
108 109	111	110	106	107 ●	105 🖷	104		• 41	4 3	• 42	4 6	47	• 45	•
124 125 C	127	126	122	123 🜒	121	120		• ⁵⁷	• ⁵⁹	● 58	• •2		6 1	•
116 0 117 0	119	118	114	115	113	112	•4	. 49	6 51	9 50	• 54	5 5	6 53	
84 🖷 85 🖷	87 •	86 •	82 e	83 •	81 •	80	● ¹⁶	• ¹⁷	● 19	• 18	• 22	• 23	• ²¹	•
82	95 •	94 ●	90 •	91 •	89 •	88 •	• 24	e 25	• 27	● 26	• ³⁰	• 31	• ²⁹	•
76 • 77 •	79 ●	78	74 ●	75	73	72 ●	•	<u> </u>	• ¹¹	• 10	• 14	• 15	• 13	•
68 ● 69 ●	71	70	' c	ο Γ	. :+	cla		n h			٠	• 7	<u>•</u> 3	•
63 ● 69 ● 196● 197 ● 196● 197 ●	71 • ••••••	70 •	Ę	3 k	oit	s/s	syr	nb	0	,	•134	• 135	•133	•
63 € 69 € 196€ 197 € 196€ 197 € 19820 1980	71 • ••••••••	70 • ••••••• 198 • 1 •••••••	- 	3 k 203 ●	Dit 201.	s/s ∞•	syr	nb •••	00	•13#	• 6 • 134 • 142	• 135	• 133 • 141	• • •
63 69 Baselin 69 1956 197 1966 197 1986 197 1986 197 1986 197 1986 205 1988 1988 204 205 1988 1988 2200 221 1988 1988	71 • •••••••••••••••••••••••••••••••••••	70 •	2020 2180 2180	3 k 203 € 180611 219 € 111111	201 • 201 • 217 •	S/S 200€ 200€ 2016€	•136 •152	nk 	• 139 • 155	•138 •138 •154	• 6 • 134 • 142 • 158	• 135 • 143 • 143	• 133 • 141 • 157	
63 69 69 69 69 69 69 69 69 69 69 69 69 69	71 • • • • • • • • • • • • • • • • • • •	70 0 198 1 198 206 2 198 206 2 198 19 198 198 19 198 19 198 19 198 198 19 198 19 198 19 198 19 198	2020 ,unine 2180 ,unine 2100 ,unine	3 k 203 • 1000011 219 • 211 • 1000011	201 • 217 • 209 •	S/S 200 ● 2016 ● 100 00 100 00 100 1	•136 •132 •14	137 •••••• •••••• ••••••• •••••••	• 139 • 139 • 155 • 155 • 157	•133 •133 •134 •154	134 134 142 2000 158 20150	• 135 • 135 • 143 • 143 • 143 • 159 • 151	• 133 • 141 • 141 • 157 • 149	
61 69 Bangan 69 15% 157 14800 105 14800 205 16800 10800 2010 221 16800 221 16800 10800 212 213 18800 213 18800 213 18800 213 18800 213 18800 213	71 • • • • • • • • • • • • • • • • • • •	70	2020 2130 2130 2100 21400 21400 21400 21400	203 • Lateria 219 • 1211 • 211 • 211 • 1000000	201 • 217 • 209 • 209 • 241 •	200 • 200 • 20	• 135 • 152 • 144 • 176	137 137 133 153 145 145 177	1139 1139 1155 1155 1147 1147 1179 1179 1179	•138 •138 •154 •146 •178	6 6 134 142 142 158 150 150 1122	• 7 • 135 • 143 • 143 • 143 • 159 • 59 • 50 • 51 • 151 • 151 • • 123 • • • • • • • • • • • • • • • • • • •	5 5 133 141 157 149 141	
61 69 Internet 1976 1964 197 Usernet 201 Usernet 201	71 memoria 1990	70		3 k 203 • 100 00111 211 • 101 1011 243 • 101 1011 243 • 101 1011 10111	201 • 217 • 217 • 209 • 241 • 241 • 249 •	200 • 	• 136 • 137 • 152 • 144 • 176 • 184	137 137 133 133 145 145 177 185	• 139 • 139 • 155 • 155 • 1147 • 1179 • 1179 • 1187	•1138 •1134 •1154 •1146 •1178 •1186	• 134 • 134 • 142 • 158 • 158 • 159 • 182 • 150 • 182	• 135 • 135 • 143 • 143 • 159 • 151 • 183 • 183 • 191	5 5 133 141 141 157 149 181 189	
61 69 Joseph 1976 1966 1976 Later 1000 2014 205 Later 1000 2014 2016 Later 1000 Later 213 Later 214 Later 213 Later 213 Later 213 Later Later Later 213 Later Later Later Later	71	70		203 • Landelia 219 • Taller 211 • Landelia 221 • Landelia 225 • Lindelia	201 • 201 • 217 • 209 • 241 • 244 • 249 • 213 • 213 •	200 •	• 136 • 152 • 152 • 144 • 176 • 184 • 168	1137 1137 1133 1143 1145 1147 1185 1185 1185 1185 1185	• 139 • 139 • 155 • 155 • 147 • 147 • 179 • 187 • 187 • 187 • 187 • 187	•133 •133 •134 •146 •178 •186 •170	• 134 • 142 • 158 • 150 • 150 • 152 • 150 • 152 • 150 • 150 • 152 • 150	• 7 • 135 • 143 • 143 • 143 • 143 • 143 • 159 • 159 • 151 • 155 •	133 133 141 157 149 149 181 189 118	

Error Vector Magnitude (EVM)

The error vector magnitude or EVM is a measure used to quantify the performance of a digital radio transmitter or receiver. A signal sent by an ideal transmitter or received by a receiver would have all constellation points precisely at the ideal locations, however various imperfections in the implementation (such as carrier leakage, low image rejection ratio, phase noise etc.) cause the actual constellation points to deviate from the ideal locations. Informally, EVM is a measure of how far the points are from the ideal locations.

Magnitude

Reference (ideal)

 $\phi = \text{phase error}$

Veasured vector Error

Modulation scheme	Code rate	EVM limit (802.11ac)	
BPSK	1/2	-5 dB	
QPSK	1/2	-10 dB	Q
QPSK	3/4	-13 dB	
16 QAM	1/2	-16 dB	L
16 QAM	3/4	-19 dB	
64 QAM	2/3	-22 dB	
64 QAM	3/4	-25 dB	
64 QAM	5/6	-27 dB	
256 QAM	3/4	-30 dB	
256 QAM	5/6	-32 dB	



RF Power and Units



The RF signal strength can be measured in Watts (W) using the amplitude or the signal waveform's top peak to the bottom peak height. Decibel (dB) conversion is used for exponential values.



Milliwatts and Decibels

Absolute Power	POWER CONVERSION FROM WATTS TO dBm					
	Power (W)	Power (dB)				
	100 W	+50 dBm				
	10 W	+40 dBm				
	1 W	+30 dBm				
	500 mW	+27 dBm				
	100 mW	+20 dBm				
	10 mW	+10 dBm				
	2 mW	+3 dBm				
	1 mW	0 dBm				
	0.5 mW	~3 dBm				
	0.1 mW	-10 dBm				
	0.01 mW	-20 dBm				



POWER CHANGE

Ξ

X 2

12

X 10

/ 10

Decibel (dB) Laws

dB VALUE

0 dB

+3 dB

-3 dB

+10 dB

There are three dB laws, which are based on dB changes of 0, 3, and 10: 1.Law of Zero – A value of 0 dB indicates that the absolute power values of the source P2 and the reference value P1 are the same

2.Law of 3s – A value of 3 dB indicates that the power value of P2 is twice P1 3.Law of 10s – A value of 10 dB indicates that the power value of P2 is 10 times that of P1



Source: https://study-ccnp.com/understanding-rf-power-db-conversion/

Received Signal Strength Indication (RSSI) is

a measurement of the power present in a received radio signal. It is also measured in dBm

			RSSI			Very Good
	-30 dBm	-60 dBm	-70 dBm	-80 dBm	-90 dBm	Good
WiFi						Weak
		Co	anaction Ha	alth		Poor
		Co	nnection Hea			No Connection

Signal to Noise Ratio (SNR)

Signal-to-noise ratio (SNR or S/N) is a measure used in science and engineering that compares the level of a desired signal to the level of background noise. SNR is defined as the ratio of signal power to noise power, often expressed in decibels. A ratio higher than 1:1 (greater than 0 dB) indicates more signal than noise.

Modulation	Code rate	$N_{\rm DBPS}$	Spectral efficiency (bps/Hz)	Required SNR (df
BPSK	1/2	26	0.5	-3.83
QPSK	1/2	52	1	0
QPSK	3/4	78	1.5	2.62
16-QAM	1/2	104	2	4.77
16-QAM	3/4	156	3	8.45
64-QAM	2/3	208	4	11.67
64-QAM	3/4	234	4.5	13.35
64-QAM	5/6	260	5	14.91
256-QAM	3/4	312	6	17.99



Coding Basics

Source Coding – uses compression techniques to reduce the size of the data transmitted.

Channel Coding – Adds redundancy to the transmitted data so as to recover the original data in case of bad channel conditions.

For example ³/₄ coding rate will mean, for every 3 bits of data , the transmitter will send a total of 4 bits by adding 25% information redundancy.

Received Data:





RF Performance Table (AP Datasheet)



ARUBA 570 SERIES WIRELESS ACCESS POINTS

RF PERFORMANCE TABLE

	Maximum transmit power (dBm) per transmit chain	Receiver sensitivity (dBm) per receive chain							
2.4GHz, 802.11b									
1 Mbps	22	-97							
11 Mbps	22	-89							
2.4GHz, 802.11g									
6 Mbps	22	-94							
54 Mbps	20	-76							
2.4GHz, 802.11n/ac HT20	2.4GHz, 802.11n/ac HT20								
MCS0	22	-93							
MCS8	19	-72							
2.4GHz, 802.11ax HE20									
MCS0	22	-93							
MCS11	17	-62							
5GHz, 802.11a									
6 Mbps	22	-95							
54 Mbps	20	-76							
5GHz, 802.11n/ac HT20/VHT2	20								
MCS0	22	-94							
MCS8	19	-72							

5GHz 802 11p/ac HT400/HT40		
5GH2, 602.111/ac H140/VH140		
MCS0	22	-92
MCS9	19	-68
5GHz, 802.11ac VHT80		
MCS0	22	-90
MCS9	19	-65
5GHz, 802.11ac VHT160		
MCS0	22	-84
MCS9	19	-59
5GHz, 802.11ax HE20		
MCS0	22	-94
MCS11	17	-62
5GHz, 802.11ax HE40		
MCS0	22	-91
MCS11	17	-60
5GHz, 802.11ax HE80		
MCS0	22	-87
MCS11	17	-57
5GHz, 802.11ax HE160		
MCS0	22	-85
MCS11	17	-53

Throughput/Range for various QAM Rates





- ch157-VHT-MCS:3-4NSS-80Mhz-SGI - ch157-VHT-MCS:2-4NSS-80Mhz-SGI - ch157-VHT-MCS:1-4NSS-80Mhz-SGI

ch157-VHT-MCS:0-4NSS-80Mhz-SGI

OFDM Example





802.11a OFDM PHY Parameters					
BW	20 MHZ				
OBW	16.6 MHZ				
Subcarrer Spacing	312.5 Khz (20MHz/64 Pt FFT)				
Information Rate	6/9/12/18/24/36/48/54 Mbits/s				
Modulation	BPSK, QPSK, 16QAM, 64QAM				
Coding Rate	1/2, 2/3, 3/4				
Total Subcarriers	52 (Freq Index -26 to +26)				
Data Subcarriers	48				
Pilot Subcarriers*	4 (-21, -7, +7, +21) *Always BPSK				
DC Subcarrier	Null (0 subcarrier)				



Multipath Basics

Multipath is created by the returned reflections of the original signal that are combined at the receiver. These reflections occur when the signal bounces from the various surfaces within the indoor environment.

Delay spread is generally defined as the difference between the time of arrival of the earliest component (e.g., the line-of-sight wave if there exists) and the time of arrival of the latest multipath component

Fading : In wireless communication, fading is a phenomenon in which the strength and quality of a radio signal fluctuate over time and distance. Fading is caused by a variety of factors, including multipath propagation, atmospheric conditions, and the movement of objects in the transmission path





MIMO Basics

A **radio chain** is defined as a single radio and all of its supporting architecture, including mixers, amplifiers, and analog/ digital converters.

A MIMO system consists of multiple radio chains, with each radio chain having its own antenna.

A MIMO system is characterized by the number of transmitters and receivers used by the multiple radio chains.

Spatial streaming(Nss) is a transmission technique used in MIMO wireless communication to transmit independent and separately coded data signals, from each of the multiple transmit antennas.



Basic Structure of a MIMO System





References



Basics of Modulation Techniques https://en.wikipedia.org/wiki/Modulation

Understanding Error Vector Magnitude <u>https://www.youtube.com/watch?v=rMVAQsUudSs</u>

OFDM Overview

https://rfmw.em.keysight.com/wireless/helpfiles/89600b/webhelp/subsystems/wlan-ofdm/content/ofdm_80211-overview.htm

Multipath Basics https://www.cisco.com/c/en/us/support/docs/wireless-mobility/wireless-lan-wlan/27147-multipath.html

MIMO Introduction https://www.youtube.com/watch?v=T7NyrG4_RSI











Number of participants - 193



Winner **Umeshraja N**



Score distribution - quiz 2a

Correct responses