Session 2B Notes

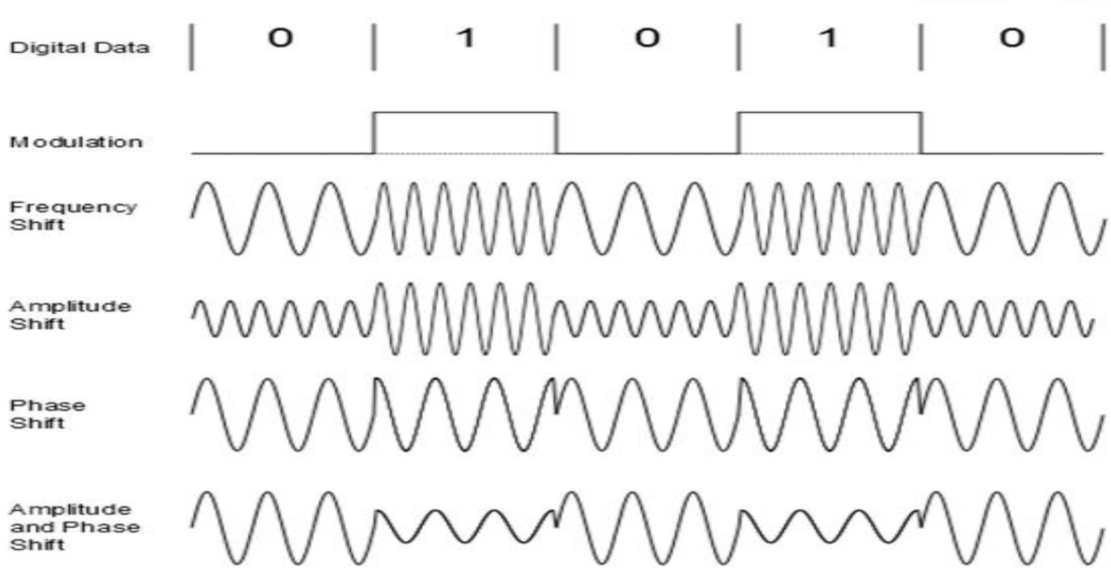
Modulation

Modulation is the process of varying one or more 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. Here Frequency alone of the carrier signal is being altered.
- **ASK:** Amplitude of the carrier signal is varied to represent binary 1 and 0. Here Amplitude alone of the carrier signal is being altered.
- **PSK:** Phase of the carrier signal is varied to represent binary 1 and 0. Here phase alone of the carrier signal is being altered.
- **QAM:** Amplitude and Phase of the carrier signal is varied to represent binary 1 and 0. Here two properties of the waveform are being altered.

Waveforms obtained as the result of different modulations performed on the same input data can be observed in the following diagram.

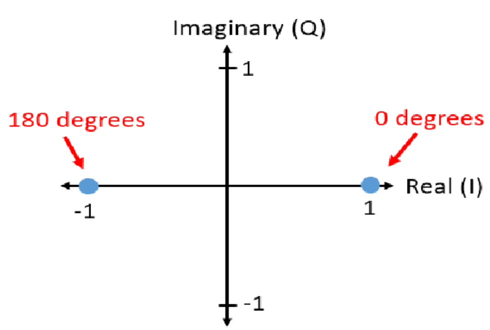


Below are the differences between FSK, ASK, PSK, QAM modulation based on the given parameters.

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 (Binary Phase-Shift Keying) Modulation

Binary Phase Shift Keying (BPSK) is a digital modulation scheme that uses two phases to represent binary information. Each symbol in the digital signal corresponds to a bit (either 0 or 1), and the modulation is achieved by manipulating the phase of the carrier wave.



- **Phase Representation:** One phase (e.g., 0 degrees, fig(a)) represents one bit (e.g., 0,fig(a)), and the opposite phase (e.g., 180 degrees, fig(b)) represents the other bit (e.g., 1,fig(b)).

- **Manipulation of Phase:** The phase of the carrier signal is shifted between these two values to encode the binary information. If the phase remains the same, it represents one bit, and if the phase is shifted, it represents the other bit (in fig(c) we can observe that the phase has been shifted from 0 to 180 degrees resulting in the transmission of the binary data “01”)

- **Simplicity:** BPSK is a straightforward and efficient modulation scheme, suitable for applications where simplicity and efficiency are crucial.

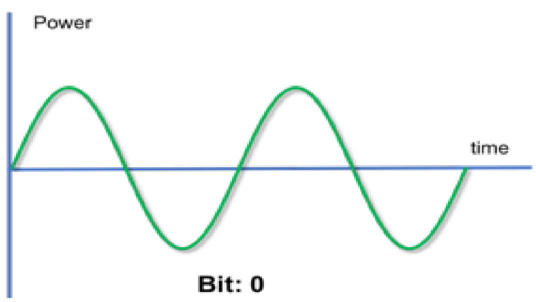


fig.(a)

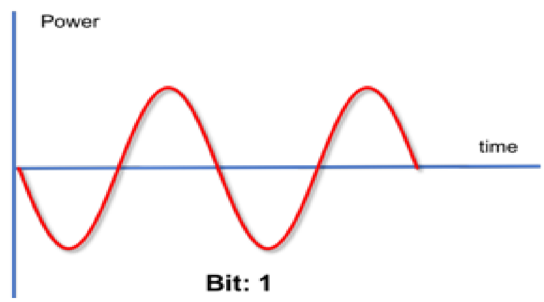


fig.(b)

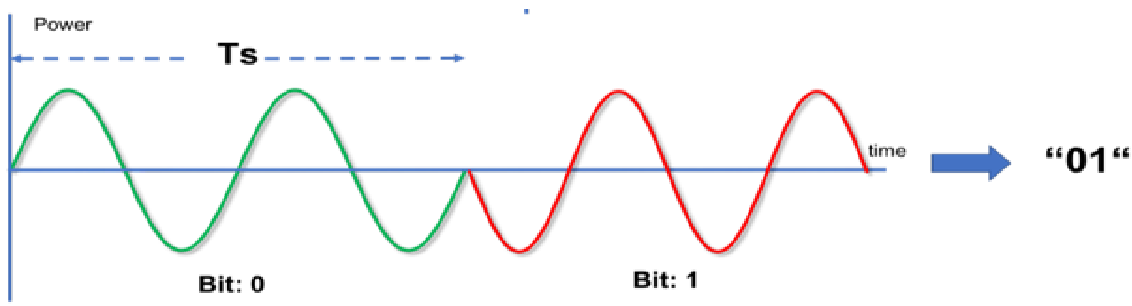


fig.(c)

Example: QPSK Modulation

Quadrature Phase Shift Keying (QPSK) transmits four symbols per packet, and it achieves this by using two bits to represent each symbol.

- **Representation of Symbols:** QPSK uses four different phase shifts to represent the four symbols. These phase shifts are typically 45, 135, 225 and 315 degrees, as shown in fig (a).

- **Bit-to-Symbol Mapping:** Each two-bit combination is mapped to one of the four possible phase shifts, determining which symbol is transmitted. The mapping might look like as shown in fig (a).
    - 00 - 225 degrees
    - 01 - 135 degrees
    - 10 - 315 degrees
    - 11 - 45 degrees

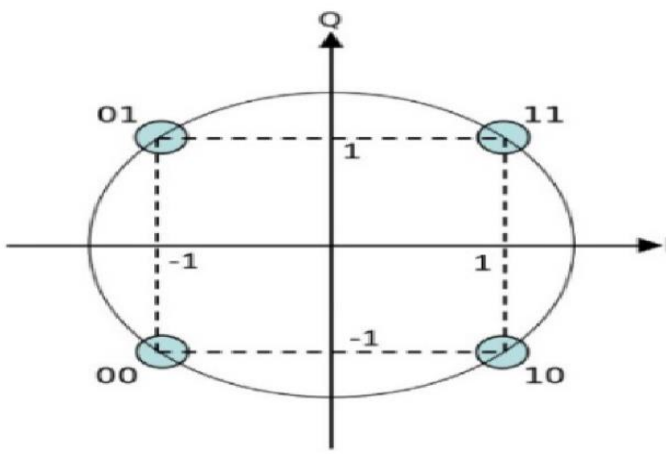


Figure (a)

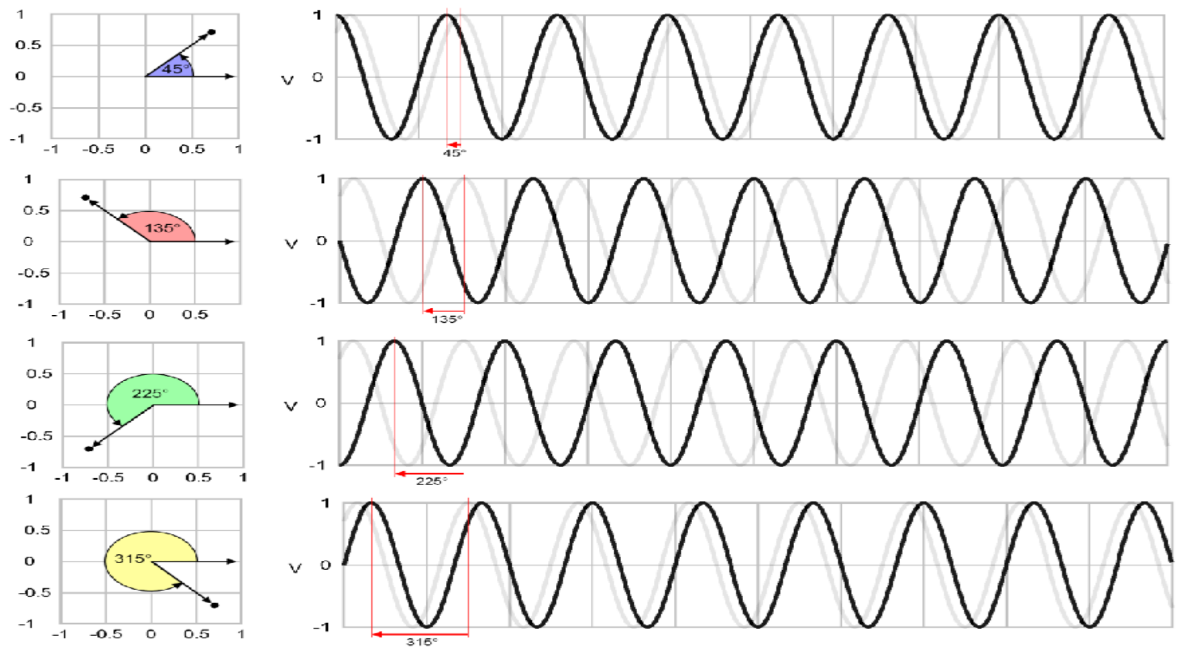


Figure (b)

In the above example of waveform(fig(b)), phases 45,135,225,315 degrees have been used to represent different information 00,01,10,11 respectively.

- **Throughput:** QPSK offers higher throughput compared to BPSK because it conveys two bits of information with each symbol, effectively doubling the data rate.

- **Efficiency:** While QPSK provides higher throughput, it also requires more sophisticated equipment to both modulate and demodulate the signals, as it involves more phase states than BPSK.

16QAM Modulation

Introduction to Modulation Rate:

- A slightly more complex modulation rate, known as 16-QAM (Quadrature Amplitude Modulation), involves 16 different combinations.
- 16-QAM is achieved by combining amplitude and phase modulation to transmit information.

Understanding 16-QAM:

- 16-QAM represents 16 combinations, which can transmit four bits of information. This results from 2 to the power of 4, giving 16 possibilities.
- In 16-QAM, there are four levels of amplitude (level one, level two, level three, level four) and four equally distributed phase shifts between 0 and 360 degrees.
- These 16 combinations are used to encode four bits of data, where each combination corresponds to a specific bit pattern.

Increased Throughput with 16-QAM:

- 16-QAM increases throughput significantly compared to BPSK (Binary Phase-Shift Keying).
- In BPSK, one symbol carries one bit, while 16-QAM allows each symbol to carry four bits.
- This four-fold increase in data transmission capability leads to a higher throughput when using 16-QAM.

Why Not Always Use 16-QAM:

- While 16-QAM offers superior throughput compared to BPSK, there are reasons for not always using it.
- The choice of modulation scheme depends on the specific communication needs and challenges.
- In scenarios with high noise or interference, simpler modulation schemes like BPSK may be more reliable.
- Factors such as channel conditions and noise levels influence the selection of modulation schemes.
- In adverse conditions, simpler modulations ensure more reliable data transmission.

Advantages of 16-QAM:

- 16-QAM offers increased throughput due to its ability to carry 4 bits per symbol.
- Higher order modulation schemes like 16-QAM enhance data transmission efficiency, especially in situations where bandwidth is limited.

Limitations and Considerations:

- Despite the advantages, 16-QAM requires a higher signal-to-noise ratio (SNR) for reliable communication.
- In noisy environments, simpler modulation schemes like BPSK might be preferred due to their robustness.

Conclusion:

- Choosing the right modulation scheme depends on the specific communication environment.
- While higher order modulations like 16-QAM offer increased data rates, practical considerations and channel characteristics dictate the choice of modulation in real-world applications.

The Throughput/Reliability Tradeoff

Introduction to the Trade-off:

Higher-order modulation rates offer better throughput but come at the cost of reliability due to the trade-off between throughput and reliability in modulation schemes.

BPSK Modulation Example:

In BPSK, a clear distinction between 0 and 180 degrees allows reliable reception in ideal conditions. In noisy channels, even a slight phase shift can create confusion, but the large gap between 0 and 180 degrees aids in correct estimation.

QPSK Modulation Example:

QPSK uses four phases (0, 90, 180, 270 degrees), reducing the gap between points and making correct estimation harder. Equidistant points at 45 degrees create ambiguity, resulting in a 50% probability of accurate reception.

Summary of the Trade-off:

- The fundamental idea is the throughput-reliability trade-off when selecting a modulation rate.
- Higher-order modulation increases throughput but decreases reliability in noisy channels.
- The choice of modulation rate should be based on the specific conditions and requirements of the communication channel.

Wi-Fi QAM Rates

Higher Order Modulation Rates:

- Increasing modulation complexity with schemes like 64-QAM brings more combinations but decreases the margin for error.
- 256-QAM offers 8 bits per symbol but requires very low noise and close proximity for reliable communication.
- As you move to higher-order modulation schemes (e.g., 16-QAM), the points in the constellation diagram get even closer.

- Closer constellation points result in higher error probability when noise is present in the channel.

Evolution of Modulation Schemes:

- With 1024-QAM and 4096-QAM, the granularity of combinations increases, demanding pristine RF channels for successful transmission.
- Higher-order modulation rates necessitate an extremely clean channel and close proximity between transmitter and receiver for effective communication.

Importance of Channel Quality:

- In summary, higher modulation rates allow more data transmission per symbol but demand superior channel conditions to overcome increased error probability.
- In real-world applications, the choice of modulation rate depends on balancing throughput needs with the reliability of the communication channel.

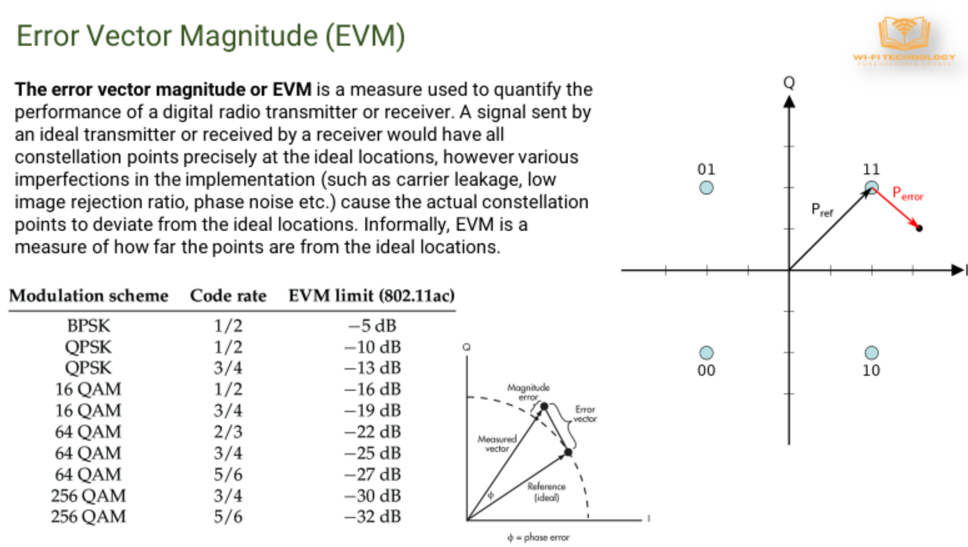
Noisy Channel Scenario:

- In a noisy channel, the transmitted signal can be distorted, leading to issues with reliability.
- Signal transmission may encounter obstacles, long distances, or interference from other devices, causing signal distortion.

Real-World Considerations:

- The choice of modulation rate depends on the level of noise in the channel.
- In a clean channel, you can use higher-order modulation for increased throughput.
- However, in a noisy environment,We may need to sacrifice throughput for reliability.

Error Vector Magnitude (EVM)



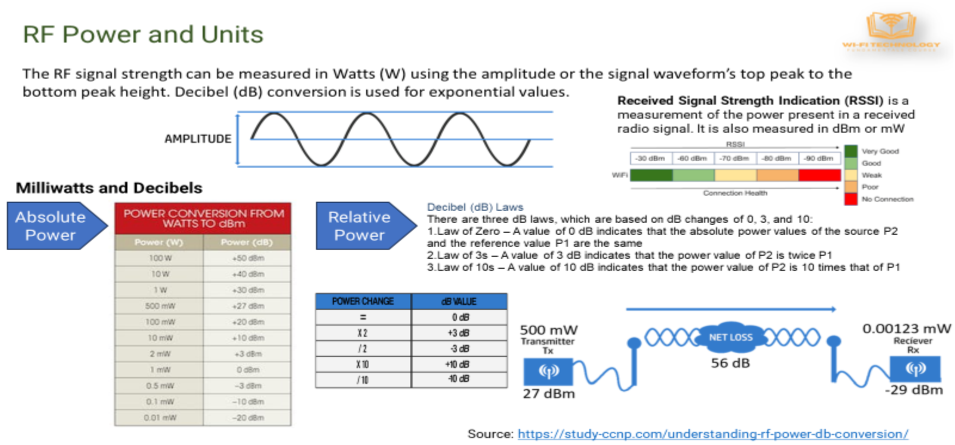
Error Vector Magnitude (EVM)

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.

Modulation scheme	Code rate	EVM limit (802.11ac)
BPSK	1/2	−5 dB
QPSK	1/2	−10 dB
QPSK	3/4	−13 dB
16 QAM	1/2	−16 dB
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

- Description: EVM (Error Vector Magnitude) is a critical metric used to assess the quality of digital signals in communication systems. It quantifies the accuracy of the received signal when compared to the expected or ideal signal point. EVM accounts for both amplitude and phase distortions in the received signal.
- For instance, in EVM analysis, the expected signal point is compared to the actual received signal point on a two-dimensional IQ (In-phase and Quadrature) constellation diagram. The difference between these points is calculated as the EVM, usually expressed as a percentage or in dB (decibels).
- High-quality digital communication systems aim for low EVM values because this indicates that the received signals closely match the ideal signals, ensuring reliable data transmission.

RF Power and Units

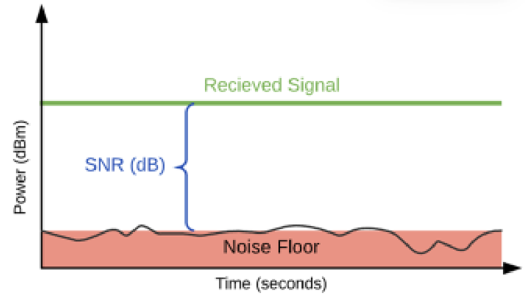


- Description: RF (Radio Frequency) power refers to the strength or power level of an RF signal. It's a fundamental parameter in wireless communication systems. RF power is measured in both absolute terms (Watts) and relative terms (dBm).
- In Watts, RF power is expressed in terms of absolute energy levels. For example, an RF transmitter might emit a signal with a power of 1 Watt.
- In dBm (decibel-milliwatts), RF power is measured relative to a reference of 1 milliwatt (0 dBm). This scale provides a more practical and convenient way to express power levels. For instance, 20 dBm corresponds to 100 milliwatts (mW), and 10 dBm corresponds to 10 mW.
- In the context of wireless communication systems, such as Wi-Fi, the transmit power of access points and the received power at client devices are critical factors in determining signal quality and coverage. Adjusting RF power levels is a strategy to optimize signal coverage and quality.

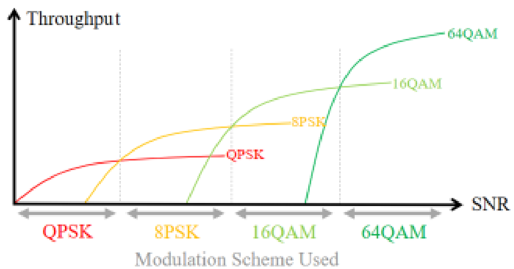
Signal to Noise Ratio (SNR):

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.

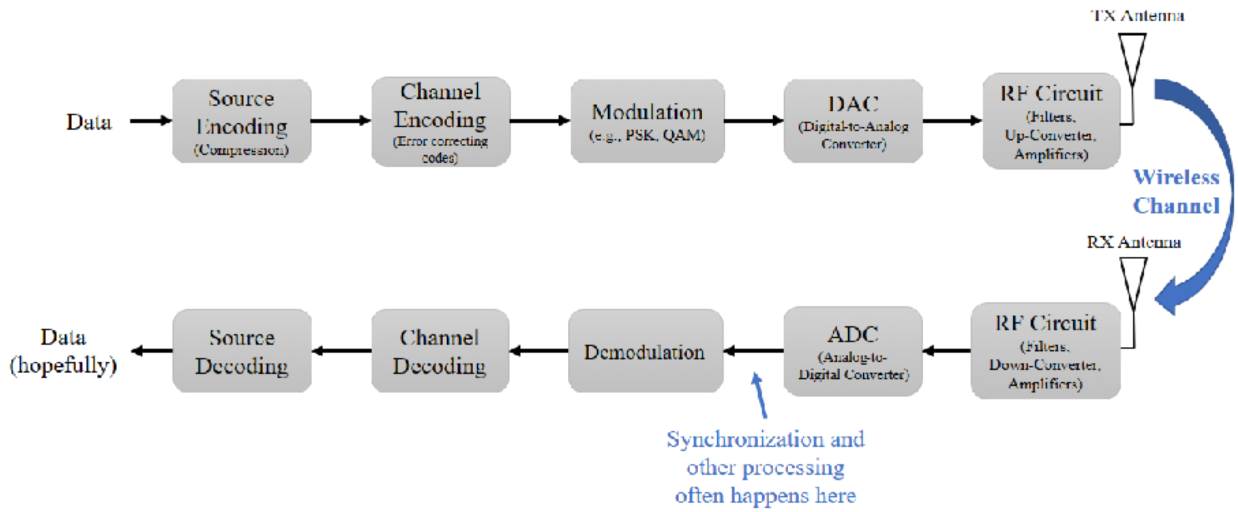


Modulation	Code rate	N_{DBPS}	Spectral efficiency (bps/Hz)	Required SNR (dB)
BPSK	1/2	26	0.5	−3.83
QPSK	1/2	52	1	0
QPSK	3/4	78	1.5	2.62
16-QAM	1/2	104	2	4.77
16-QAM	3/4	156	3	8.45
64-QAM	2/3	208	4	11.67
64-QAM	3/4	234	4.5	13.35
64-QAM	5/6	260	5	14.91
256-QAM	3/4	312	6	17.99



- Description: The Signal to Noise Ratio (SNR) is a measure of the quality of a communication signal, specifically, the ratio between the strength of the useful signal (the "signal") and the level of background interference or noise (the "noise"). SNR is essential in determining the reliability of communication links.
- A high SNR indicates a strong, clear signal with little interference relative to the signal level, resulting in excellent communication quality. A low SNR suggests that the noise level is relatively high compared to the signal, which can degrade communication quality and reliability.
- In Wi-Fi and other wireless technologies, SNR is a key factor in assessing network performance. A high SNR is desirable, as it indicates a robust and reliable connection. An SNR value is often expressed in decibels (dB) for practical measurement.
- Understanding SNR is crucial in network design and optimization, as it helps ensure that wireless devices can communicate effectively, even in the presence of environmental noise or interference. Maintaining a high SNR is a primary goal in ensuring reliable and high-quality wireless communication.

Coding Basics



Sender Process:

Source Coding

Source Coding is a process that optimizes the use of available bandwidth by employing compression techniques to minimize the number of bits required for data transmission. It achieves this by eliminating redundant bits, making the data more efficiently transmitted. In simpler terms, source coding reduces the data size for more effective and efficient communication over a given network or channel.

Channel Coding

Channel Coding is a process that introduces redundancy into the transmitted data to enable the recovery of the original information, especially in the presence of channel noise. The channel encoder adds error-correcting bits to the transmitted data to protect against alterations caused by noise during signal transmission. In essence, channel coding safeguards data integrity by including additional bits that can correct errors, ensuring the reliable retrieval of the original information, even under adverse channel conditions.

Modulation

Modulation is a process in which a carrier signal is used to encode information from a digital source, converting it into an analog signal. This analog signal is then suitable for transmission through a communication channel or medium. Modulation enables the combination of the information (digital data) with the carrier signal, allowing it to propagate effectively through the channel, and then be demodulated at the receiver to recover the original information. Additionally, prior to modulation, the digital signal is converted from its discrete, digital sequence to a continuous analog waveform to facilitate its journey through the communication medium.

Digital to Analog Converter

A Digital-to-Analog Converter (DAC) is an electronic device or circuit that takes a digital input, typically in the form of binary data or numbers, and converts it into a corresponding analog signal. The purpose of a DAC is to transform discrete digital values into a continuous voltage or current output that can be used in various applications, such as audio playback, communication systems, and control systems.In essence, a DAC takes a series of digital values, often represented in binary code, and translates them into an analog signal with varying voltage or current levels, creating a smooth, continuous waveform.

RF (Circuit)

In RF (Radio Frequency) circuits, various components are used to process and transmit radio frequency signals. These components include filters, up-converters, and amplifiers.
Filters are used to select or reject specific frequency components, ensuring that only the desired frequency band is passed through while attenuating unwanted frequencies.
Up-Converters(or mixers) shift the frequency of the input signal to a higher frequency range, which is often necessary for efficient signal transmission.
Amplifiers increase the power of the signal, making it stronger for transmission over long distances or through lossy mediums.

Receiver Process:

On the receiving end, RF circuitry receives the carrier signal, removes it, and performs analog to digital conversion.
Demodulation is performed, and then the process involves Channel decoding and Source decoding to retrieve the data.

Receiving the Carrier Signal

The process begins with the reception of the transmitted signal. This signal, often modulated onto a carrier signal, is received by the RF (Radio Frequency) circuitry of the receiver. This RF circuitry is designed to capture the incoming signal and prepare it for further processing.

Carrier Signal Removal

Once the RF circuitry has captured the signal, it must remove the carrier signal. This is necessary because the carrier signal was used for modulation during transmission but does not carry the original data itself. Removing the carrier signal leaves only the modulated data for further processing.

Analog to Digital Conversion (ADC)

The next step involves converting the analog signal into a digital one. This process is performed by an Analog-to-Digital Converter (ADC). The analog signal, which varies continuously, is sampled at discrete points in time, and each sample is quantized into a digital value. The result is a digital representation of the received signal.

Demodulation

Demodulation is the process of reversing the modulation that was applied during transmission. This step extracts the modulated data from the signal. The specific demodulation technique used depends on the modulation scheme employed during transmission (e.g., amplitude modulation, frequency modulation, phase modulation). By demodulating the signal, the receiver obtains the modulated data.

Channel Decoding

After demodulation, the receiver performs channel decoding. This is where error-correcting codes, added during the encoding process, are utilized. The channel decoder attempts to correct any errors that may have occurred during transmission, such as noise or interference. It uses the redundant information in the data to recover the original message as accurately as possible.

Source Decoding

The final step in the receiver process is source decoding. Here, the receiver interprets the corrected data and transforms it back into its original form. This process often involves removing any compression or encoding applied at the source before transmission. The result is the retrieval of the original digital data that was initially sent by the transmitter.

RF Performance Table (AP Datasheet)

DATA SHEET
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		
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/VHT20		
MCS0	22	-94
MCS8	19	-72

5GHz, 802.11n/ac HT40/VHT40		
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

The RF Performance Table within an Access Point (AP) Datasheet is a comprehensive document that provides detailed information about the radio frequency performance characteristics of a specific wireless access point device. This table is instrumental in helping network administrators, engineers, and users understand the capabilities and limitations of the access point, particularly in terms of transmitting and receiving wireless signals. It consists of the following concepts:

Modulation and Coding Schemes (MCS)

An RF Performance Table typically includes a range of MCS values. Each MCS value corresponds to a specific combination of modulation and coding schemes used for data transmission.

Receiver Sensitivity

For each MCS value, the table specifies the minimum received signal strength required for successful reception at that data rate. Receiver sensitivity is usually expressed in decibels (dBm) and gives an idea of how well the access point can receive signals at different signal strengths.

Data Rate (Mbps)

Corresponding to each MCS value, the table provides information on the maximum achievable data rate under ideal conditions, typically measured in megabits per second (Mbps).

Frequency Bands

If the access point supports multiple frequency bands, such as 2.4 GHz and 5 GHz, the table may separate the MCS values, receiver sensitivity, and data rates for each frequency band.

Channel Width

Some access points support different channel widths (e.g., 20 MHz, 40 MHz, 80 MHz). The table indicates which channel widths are supported and provides corresponding performance data.

Spatial Streams

The number of spatial streams for each MCS value is specified. Spatial streams affect data rate and overall performance by enabling multiple data streams to be transmitted or received simultaneously.

Transmit Power (dBm)

The table includes information about the maximum transmit power of the access point for each MCS value. Transmit power is vital for understanding the coverage and range of the access point.

Signal-to-Noise Ratio (SNR)

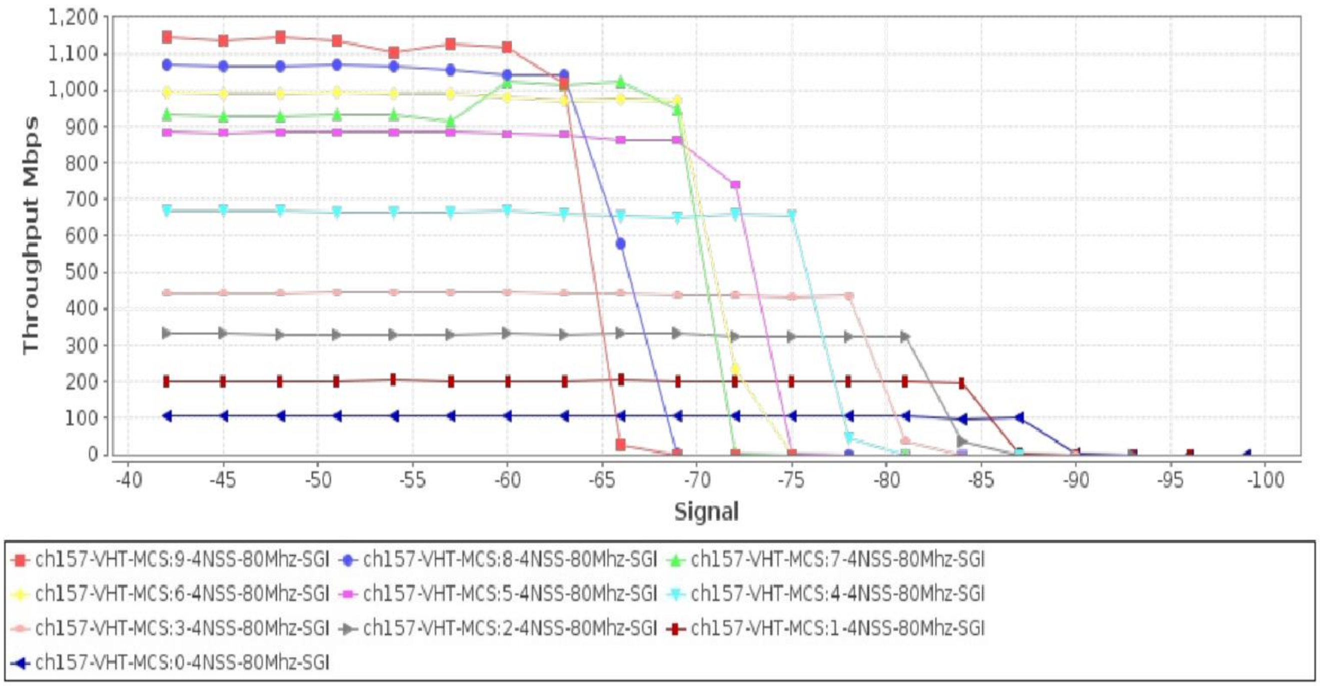
In some cases, the table may specify the SNR required for successful communication at each MCS value. A higher SNR generally results in better performance, especially in the presence of noise.

Comments or Notes

The RF Performance Table may include comments or notes offering additional context, guidelines, or best practices for interpreting the data. These notes often help users understand the significance of the provided information.

The RF Performance Table in an AP datasheet serves as a critical resource for network administrators and engineers. It allows them to assess the access point's capabilities, make informed decisions about its deployment, and understand its performance under varying signal conditions. This information is essential for optimizing wireless network setups and ensuring reliable connectivity.

Throughput/Range for various QAM Rates



This test evaluates the performance of a receiver in various signal conditions, focusing on how well it can receive data at different signal strengths.

Throughput Test with Different Modulation and Coding Schemes

The receiver sensitivity test involves conducting a throughput test with various modulation and coding schemes (MCS). MCS values represent different combinations of modulation and coding for data transmission.

High Modulation Rate (e.g., MCS9)

MCS9, characterized by 256-QAM modulation and 5x6 coding, is highlighted as an example of a high modulation rate. It allows for a very high data throughput, meaning more data is transmitted per unit of time. However, it has very little redundancy.

Impact of Signal Strength (RSSI)

The discussion notes that even though high modulation rates offer high throughput, they are sensitive to signal strength. If the receiver's Received Signal Strength Indicator (RSSI) falls below a certain threshold (e.g., -65 dBm), the throughput decreases significantly, leading to high bit error rates.

Trade-off Between Throughput and Reliability

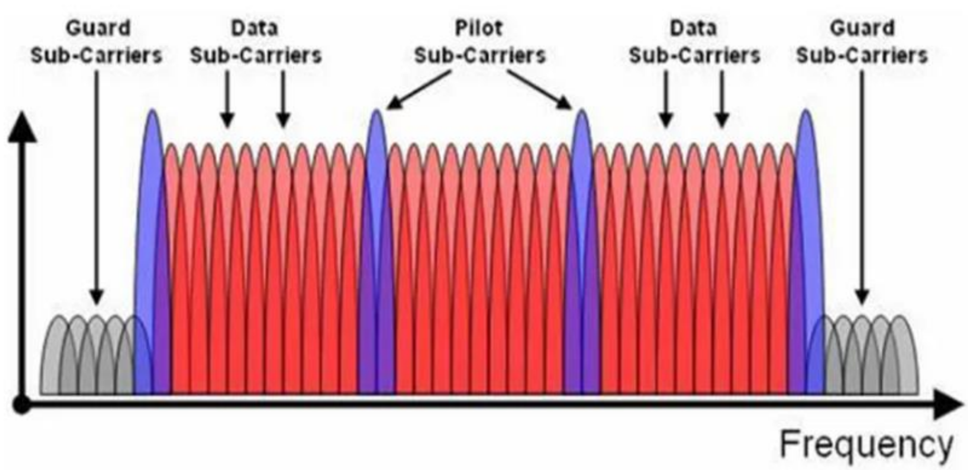
The main point emphasized in the transcript is the trade-off between throughput and reliability. Higher modulation rates provide higher throughput, but they are less reliable at lower signal strengths.

Conversely, lower modulation rates (e.g. MCS0 with BPSK and 1/2 coding) provide higher reliability but offer lower throughput.

This trade-off is crucial in making decisions about which modulation and coding schemes to use, depending on the specific requirements of the application, considering factors such as data rate needs, signal quality, and coverage area.

OFDM

OFDM (Orthogonal Frequency Division Multiplexing) serves as a crucial multiple access method in Wi-Fi, enabling efficient data transmission within the network. To understand its basic principles, consider the following breakdown:



Channel Band Utilization:

- In an OFDM system, the available channel bandwidth, for instance, a 20 MHz wide channel in the 5 GHz band, is broken down into smaller segments known as subcarriers.
- These subcarriers, typically 52 in number, each span approximately 300 to 312 kHz, effectively utilizing around 16.6 MHz of the total 20 MHz bandwidth.

Data and Pilot Subcarriers:

- Among these subcarriers, some are designated as pilot subcarriers, responsible for carrying essential metadata about the RF channel, contributing to improved communication reliability.

- The remaining subcarriers, marked as data subcarriers, carry the actual data. They can be modulated using various methods such as BPSK, QPSK, 16-QAM, or 64-QAM.

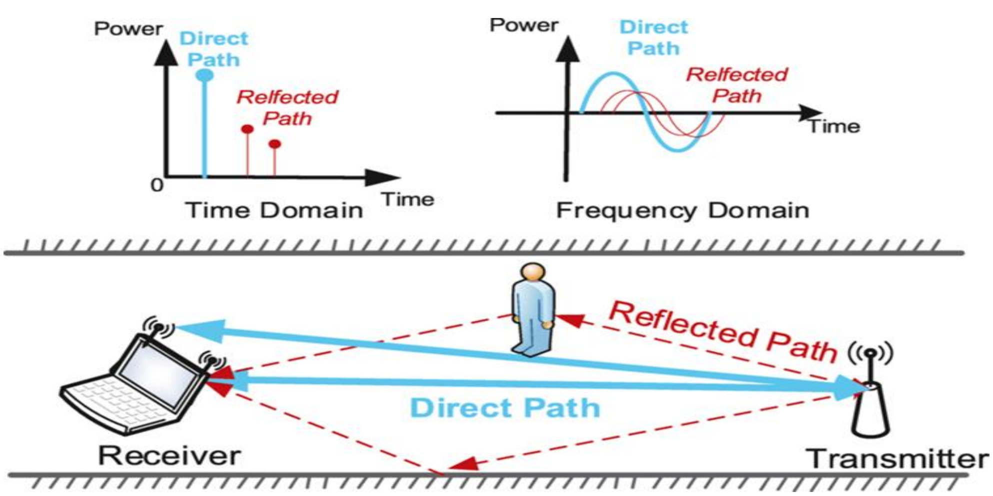
Signal Field and Modulation Rates:

- The OFDM burst comprises a signal field that conveys critical information to the receiver. This field includes details about the modulation rate used for data transmission in the following subcarriers.
- The modulation rate is carefully chosen, balancing throughput and reliability. Higher modulation rates lead to increased throughput but can compromise reliability, while lower rates enhance reliability at the cost of throughput.

The signal field is transmitted at a low modulation rate to ensure successful reception by the receiver. Once the receiver captures the signal field, it decodes the information, allowing it to prepare for the expected modulation rates in the subsequent data subcarriers.

This fundamental overview provides insights into how OFDM efficiently manages data transmission within Wi-Fi networks, promoting a better understanding of the mechanisms that drive wireless communication.

Multipath Basics



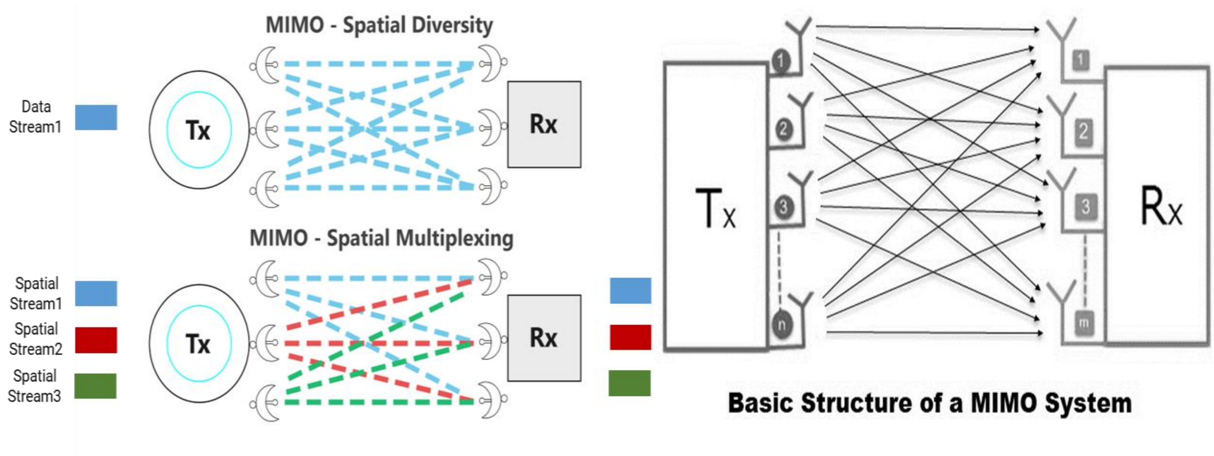
Multipath refers to the phenomenon where a receiver obtains information from a transmitter through multiple paths. In an indoor Wi-Fi environment, the transmitter sends signals that propagate in all directions, similar to ripples spreading in water. These signals can take various paths, including direct paths and paths that involve reflection from surfaces such as walls.

When signals bounce off surfaces, they may encounter absorption, leading to a loss of energy, or distortion, resulting in a phase shift. Consequently, the receiver picks up multiple copies of the transmitted signal, each with different characteristics, including variations in amplitude and phase.

The delay spread, which denotes the time difference between the first and last received copies of the signal, is a key factor in multipath communication. Moreover, the concept of fading is critical, representing the loss of signal energy during transmission. Various types of fading can occur, including flat fading, fading due to normal path loss, fading due to multipath, and fading caused by frequency variation leading to the Doppler effect.

Understanding these phenomena is crucial in comprehending the challenges and intricacies involved in indoor Wi-Fi communication, where the signal received by the receiver might be significantly different from the one transmitted by the sender.

MIMO Basics



MIMO, which stands for multiple-input multiple-output, refers to a technology that employs multiple radio chains for both transmitting and receiving data. In a single input single output (SISO) configuration, there's only one transmitter and one receiver. However, in MIMO setups, there are multiple transmitters and multiple receivers, enabling more robust and efficient communication. We'll delve deeper into MIMO technology in the next session.

Another important concept related to MIMO is spatial streams. Spatial streams pertain to the transmission of information across different paths. In spatial diversity, identical data is transmitted across all the transmitters and received by all the receivers, thereby enhancing reliability by minimizing the impact of multipath interference.

Conversely, in MIMO with spatial multiplexing, each radio chain simultaneously transmits multiple sets of information, significantly boosting the overall throughput. The employment of more antennas in this method can lead to a substantial increase in the overall data transmission rate.