Unit-4

RF Standards

This chapter covers the following topics

- IEEE 802.11 Standards—This section describes the standards that define the progressive generations of 802.11 wireless LANs.
- Wi-Fi Alliance—This section introduces the global industry association that promotes and certifies wireless LAN products to ensure interoperability.

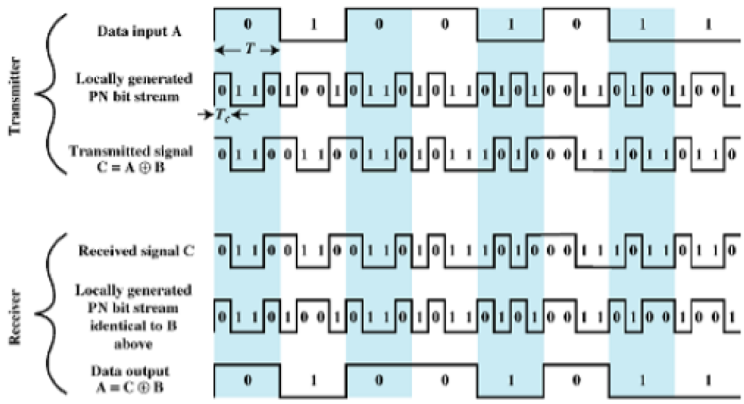
1. IEEE 802.11 Standards

1.1 The first IEEE standard 802.11-1997

1) The first IEEE standard 802.11 was released in 1997.
2) It defined wireless local area network (WLAN) technologies and protocols.
3) It operated in the 2.4 GHz frequency band and used direct-sequence spread spectrum (DSSS) technology.
4) It provided data transfer rates of up to 2 Mbps.
5) It used carrier sense multiple access with collision avoidance (CSMA/CA) as the media access control (MAC) protocol.
6) It allowed for ad-hoc and infrastructure network configurations.
7) It provided for encryption and authentication mechanisms.
8) It was widely adopted and became the basis for the development of subsequent IEEE 802.11 standards, including 802.11b, 802.11a, and 802.11g.

Band	Transmission Type	Modulation	Data Rate
2.4 GHz	FHSS	—	1, 2 Mbps
	DSSS	DBPSK	1 Mbps
		DQPSK	2 Mbps

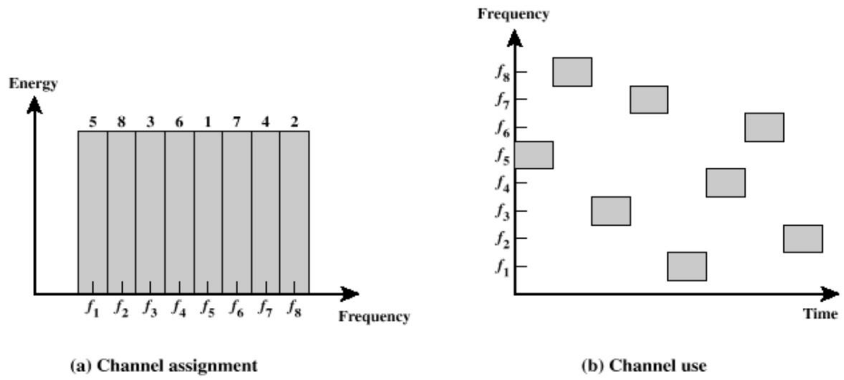
Direct-sequence spread spectrum (DSSS) is a method of transmitting data over a radio frequency that spreads the signal over a wider bandwidth than the original data signal. This is achieved by multiplying the data signal with a spreading code that is unique to the transmitter and receiver pair. The result is a wider, more complex signal that is harder to interfere with and more resistant to noise.



Example of DSSS

The basic idea behind CSMA/CA is that a device wanting to transmit data first listens to the channel to check if it is idle. If the channel is idle, the device begins to transmit its data. If the channel is already in use by another device, the device waits for a random amount of time before attempting to transmit again. This random backoff time helps to reduce the likelihood of multiple devices attempting to transmit at the same time.

Frequency-hopping spread spectrum (FHSS) is a method of transmitting data over a radio frequency by continuously switching between multiple frequencies within a certain bandwidth. The specific pattern of frequency switching is known to both the transmitter and the receiver, allowing them to stay synchronized and maintain a connection.



1.2 IEEE 802.11b Standard

To increase throughput over the original 802.11-1997 standard, 802.11b was introduced in 1999. It offered data rates of 5.5 and 11 Mbps through the use of Complementary Code

Keying (CCK). Because 802.11b was based on DSSS and was used in the 2.4-GHz band, it was **backward compatible** with the original standard IEEE802.11. Devices could select either 1, 2, 5.5, or 11 Mbps by simply changing the modulation and coding schemes

Band	Transmission Type	Modulation	Data Rate
2.4 GHz	DSSS	DQPSK with CCK	5.5 Mbps
			11 Mbps

In short, we can summarize the characteristics of the IEEE 802.11b as follows:

1) **Maximum data rate**: Up to 11 Mbps.
2) **Modulation schemes**: DQPSK, direct sequence spread spectrum (DSSS), complementary code keying (CCK), and Barker code.
3) Channel bandwidth: IEEE 802.11b uses a 22 MHz channel bandwidth.
4) Backward compatibility: Backward compatible with the original IEEE 802.11 standard, which operates at a lower data rate of 2 Mbps.
5) Range: The range of IEEE 802.11b varies depending on the environment and other factors, but it generally has a range of up to 100 meters indoors and up to 400 meters outdoors.
6) Security: The standard provides several security mechanisms, including Wired Equivalent Privacy (WEP) encryption and authentication using the Shared Key Authentication Protocol (SKAP).
7) Interference: Because it operates in the 2.4 GHz frequency band, IEEE 802.11b can experience interference from other devices that also use this frequency, such as cordless phones and microwave ovens.

It is worth noting that 802.11b is an older standard and has been largely replaced by newer standards such as 802.11g and 802.11n, which offer faster speeds and greater range.

1.3 IEEE 802.11g Standard

With 802.11b, the DSSS maximum data rate was limited to 11 Mbps. To increase data rates further, a different transmission type was needed. The 802.11g amendment was based on OFDM and was introduced in 2003. It is commonly called Extended Rate PHY

(ERP) or ERP-OFDM. Whenever you see ERP, think of 802.11g in the 2.4-GHz band.

Band	Transmission Type	Modulation	Data Rate
2.4 GHz	ERP-OFDM	BPSK 1/2	6 Mbps
		BPSK 3/4	9 Mbps
		QPSK 1/2	12 Mbps
		QPSK 3/4	18 Mbps
		16-QAM 1/2	24 Mbps
		16-QAM 3/4	36 Mbps
		64-QAM 2/3	48 Mbps
		64-QAM 3/4	54 Mbps

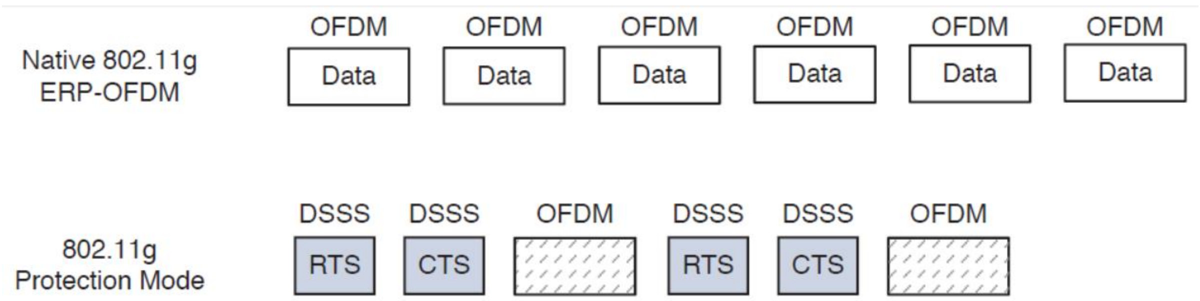
1) The IEEE 802.11g standard is a wireless networking protocol that operates in the 2.4 GHz frequency band.
2) It is an extension of the IEEE 802.11b standard and provides backward compatibility with **802.11b** devices.
3) The maximum data transfer rate supported by IEEE 802.11g is **54 Mbps**.
4) The standard uses orthogonal frequency-division multiplexing (**OFDM**) modulation, which allows for better performance and higher data transfer rates than the direct-sequence spread spectrum (DSSS) modulation used by IEEE 802.11b.
5) It supports both infrastructure mode and ad hoc mode of operation, allowing devices to connect to a wireless network either through a central access point or directly to other devices in peer-to-peer mode.
6) The standard includes built-in security features such as Wired Equivalent Privacy (WEP), Wi-Fi Protected Access (WPA), and WPA2 to ensure the confidentiality and integrity of wireless data transmissions.
7) IEEE 802.11g supports multiple-input and multiple-output (MIMO) technology, which uses multiple antennas to improve performance and reduce signal interference.
8) The standard has a range of up to 100 meters indoors and 300 meters outdoors, depending on the quality of the wireless signal and the presence of obstacles such

as walls and buildings.

Notices

- 802.11g and 802.11b use completely different transmission types—OFDM versus DSSS. This means that 802.11g and 802.11b devices cannot communicate directly because they cannot understand each other's RF signals.
- Devices using 802.11g and OFDM are able to downgrade and understand 802.11b DSSS messages. The reverse is not true.
- When two 802.11g devices are communicating with OFDM, 802.11b devices cannot understand any of the transmissions.

Solution: To allow both OFDM and DSSS devices to coexist on a wireless LAN, 802.11g offers a protection mechanism. The idea is to precede each 802.11g OFDM transmission with DSSS flags that 802.11b devices can understand.



Be aware that 802.11g has the following limitations:

- It is used in the 2.4-GHz band, which offers only three non-overlapping channels.
- OFDM devices are limited to a maximum transmit power of 15 dBm, rather than the 20 dBm limit for DSSS.

1.4 IEEE 802.11a Standard

1) **Frequency band**: It operates in the 5 GHz frequency band.
2) **Channel bandwidth**: It uses 20 MHz channel bandwidth.

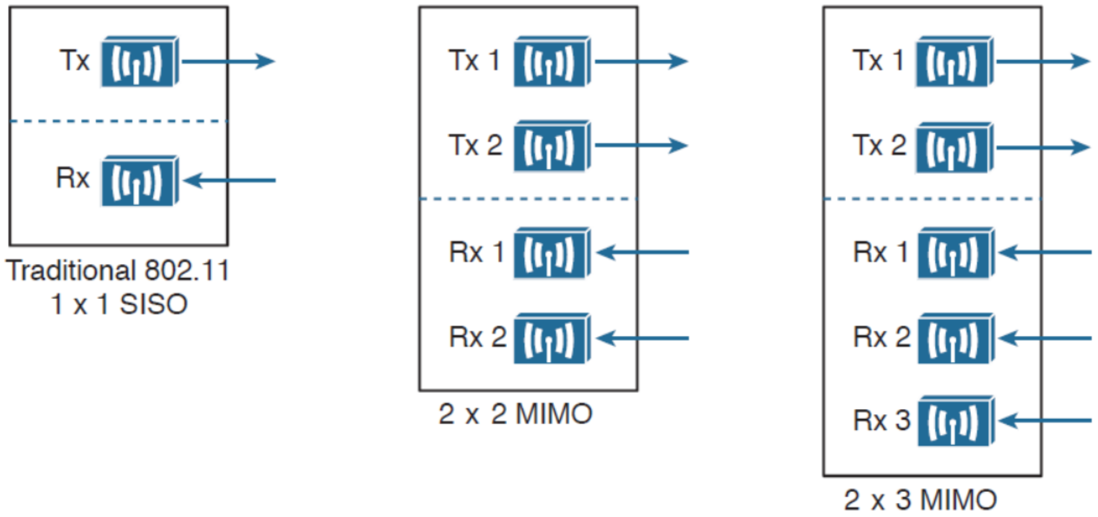
3) **Modulation**: It uses OFDM (Orthogonal Frequency Division Multiplexing) modulation.
4) **Data rate**: It supports data rates up to 54 Mbps.
5) **Multiple input multiple output (MIMO) technology**: It supports up to 8 spatial streams.
6) **Maximum range**: It has a maximum range of approximately 120 feet indoors and 390 feet outdoors.
7) **Security**: It uses the WEP (Wired Equivalent Privacy) security protocol, which is now considered insecure. However, it can be used with other more secure protocols such as WPA and WPA2.
8) **Compatibility**: It is not backward compatible with the earlier 802.11b and 802.11g standards which operate in the 2.4 GHz frequency band. However, it is compatible with the 802.11n and 802.11ac standards that operate in the 5 GHz frequency band.

Band	Transmission Type	Modulation	Data Rate
5 GHz	OFDM	BPSK 1/2	6 Mbps
		BPSK 3/4	9 Mbps
		QPSK 1/2	12 Mbps
		QPSK 3/4	18 Mbps
		16-QAM 1/2	24 Mbps
		16-QAM 3/4	36 Mbps
		64-QAM 2/3	48 Mbps
		64-QAM 3/4	54 Mbps

1.5 IEEE 802.11n Standard

- The IEEE 802.11g and 802.11a are capable of offering a 54-Mbps.
- The 802.11n amendment was published in 2009 in an effort to scale wireless LAN performance to a theoretical maximum of **600 Mbps**.
- IEEE 802.11n defines high throughput (HT) techniques applied to the 2.4- or 5-GHz band.

- IEEE 802.11n is backward compatible with OFDM used in 802.11g and 802.11a.
- IEEE 802.11n uses multiple radio components. This is known as a multiple-input, multiple-output (MIMO) system.



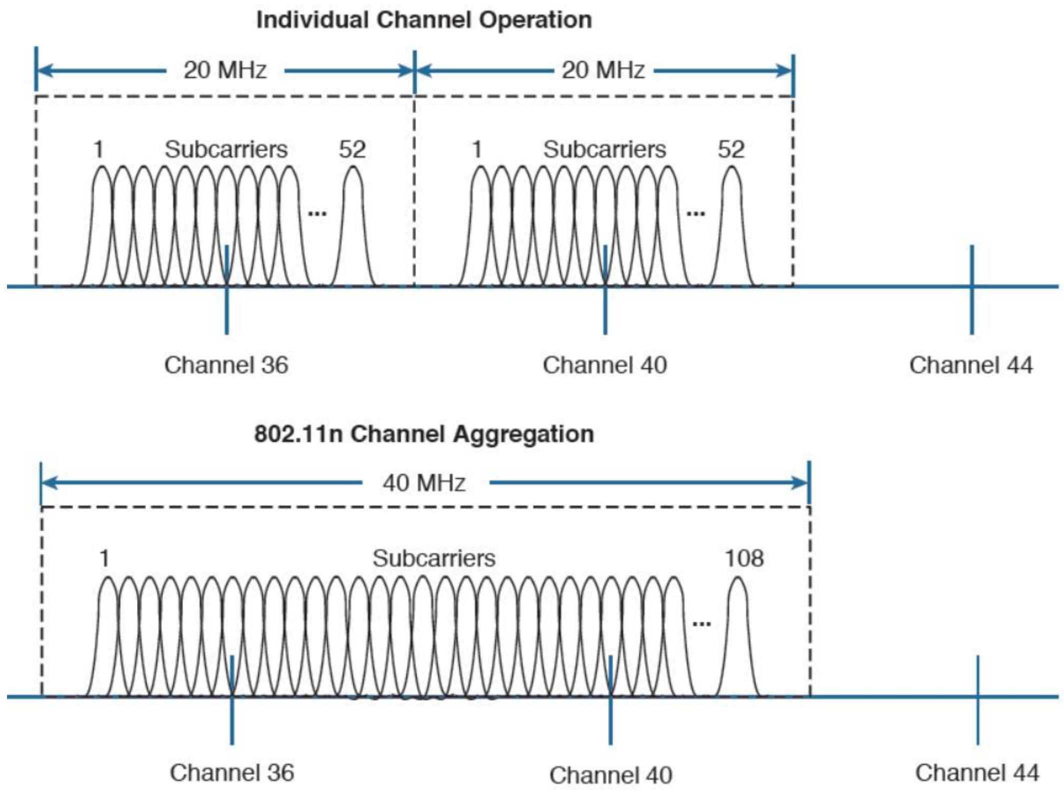
Example SISO and MIMO Devices

- IEEE 802.11n improves **throughput** using the following features
    - Channel aggregation
    - Spatial multiplexing (SM)
    - MAC layer efficiency
- IEEE 802.11n improves improve the **reliability** of the 802.11n RF signals using
    - Transmit beamforming (T×BF)
    - Maximal-ratio combining (MRC)

1.5.1 Channel Aggregation

- Channel aggregation can double the throughput by doubling the channel width.
- IEEE 802.11a or 802.11g wireless LAN device operates on one 20-MHz channel only (one channel at a time).
- Each 20-MHz OFDM channel has 48 subcarriers to carry data in parallel.
- The 802.11n amendment increased the 20-MHz channel throughput by increasing the number of data subcarriers to 52.
- The 802.11n operates on either a single 20-MHz channel or a single 40-MHz channel.

- By doubling the channel width to 40MHz, the throughput is also doubled.
- Aggregated channels must always bond two adjacent 20-MHz channels.



- Notice that the 20-MHz channels have a quiet space below and above, providing some separation between channels.
- When two 20-MHz channels are aggregated or bonded, the quiet space below and above remain, separating 40-MHz channels from each other.
- However, the quiet space that used to sit between the two 20-MHz channels can be used for additional subcarriers in the 40-MHz channel.
- The **trade-off** of using channel bonding is that **fewer channels remain** for other devices.
- When channels are aggregated, the total number of available channels in a band decrease.
- For example, the 5-GHz band is made up of 23 non-overlapping 20-MHz channels. If aggregated 40-MHz channels are used instead, only 11 non-overlapping channels would be possible.

4.5.2 Spatial Multiplexing

The basic concept of multiplexing: divide (multiplex) transmits a data stream several branches and transmit via several (independent) channels trough:

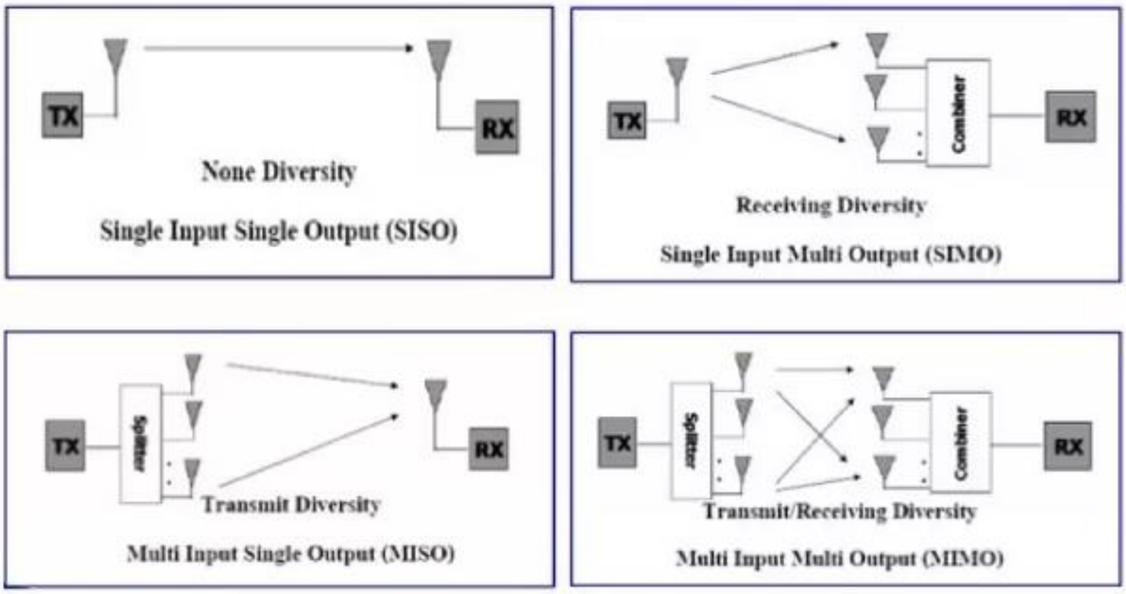
1) Time domain: time–division multiplexing (TDM)
2) Frequency domain: frequency–division multiplexing (FDM)
    - Orthogonal (OFDM)
    - Single carrier FDMA (SC-FDM).
3) Code domain: Code division multiplexing (CDMA)
4) Space domain: space–division multiplexing (SDM) or spatial multiplexing.

A diversity scheme is a method that is used to develop information from several signals transmitted over independent fading paths.

Spatial stream: each independent data stream is known as spatial stream. Each unique stream contains different data than other stream.

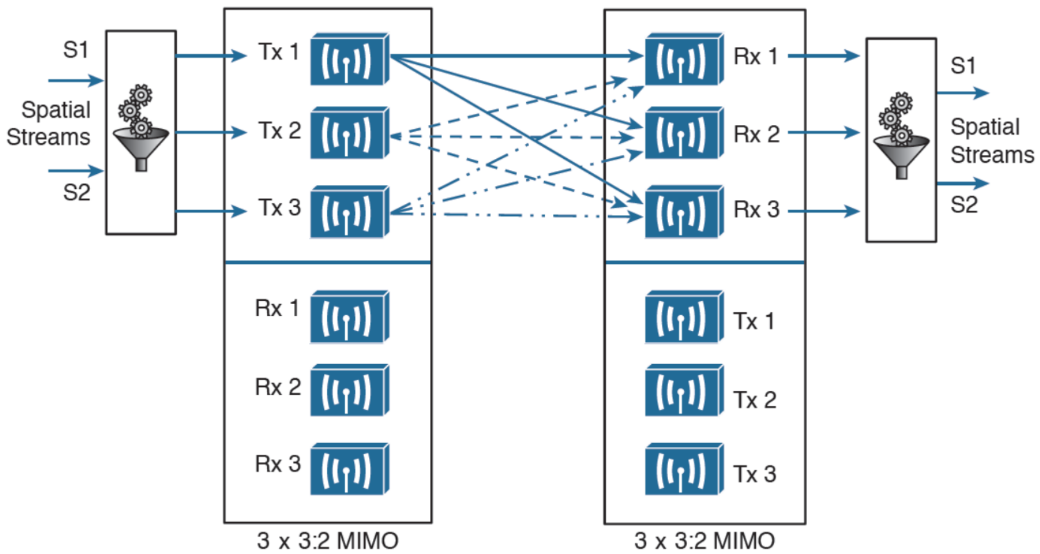
Spatial diversity:

- Spatial diversity in wireless communication refers to the use of multiple antennas to improve the quality and reliability of wireless communication.
- By deploying multiple antennas at either the transmitter, receiver or both ends, it is possible to exploit the spatial diversity of the wireless channel to achieve better performance.
- Multiple streams follow different path because of **space** difference between transmitting antennas.



Spatial multiplexing: Sending multiple independent streams of unique data using spatial diversity — all antennas operate on the same channel.

The number of spatial streams that a device can support is usually designated by adding a colon and a number to the MIMO radio specification. For example, a 3×3:2 MIMO device would have three transmitters, three receivers, and would support two unique spatial streams.



4.5.3 MAC Layer Efficiency

Even without multiple radio chains, 802.11n offers some important methods to make data communication more efficient. Two of the methods are as follows:

1) *Block acknowledgment*

With 802.11n, data frames can be transmitted in one burst. Only one acknowledgment is expected from the recipient after the burst is complete. In other words, 802.11n introduces Block ACK, which allows multiple frames to be acknowledged with a single acknowledgement message. This reduces the number of acknowledgements required and improves the efficiency of the network.

2) *Guard interval*

The 802.11 standard requires a guard interval (GI), a period of 800 nanoseconds, between each OFDM symbol that is transmitted to protect against ISI. As an option, you can configure 802.11n devices to use a much shorter 400-nanosecond guard interval. This allows OFDM symbols to be transmitted more often, increasing throughput by about 10 percent, at the expense of making data corruption more likely.

4.5.4 Beamforming

- Beamforming allows an access point to effectively concentrate its signal at the client's location. This results in a better signal, SNR and potentially a great throughput.
- The 802.11n standard defines a few methods of beamforming.

1) Implicit beamforming: In this method, the transmitter estimates the channel characteristics based on feedback from the receiver and adjusts the signal to improve the signal strength and reduce interference.

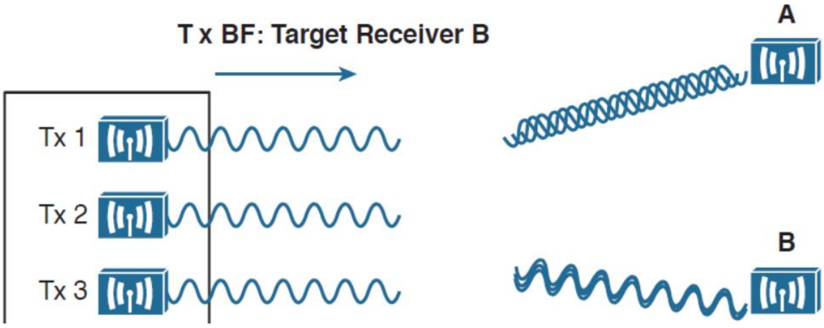
2) Explicit beamforming: This method requires the transmitter and receiver to exchange information about the channel characteristics, such as signal-to-noise ratio and channel quality, to optimize the signal. Explicit beamforming requires a special feedback mechanism and hardware support.

3) Transmit beamforming (TxBF): TxBF is a technique that uses multiple antennas to transmit a focused beam in a specific direction, which improves the signal strength and reduces interference. TxBF requires the transmitter to have

multiple antennas and a mechanism to select the best antenna to use for each transmission.

4) Receive beamforming (RxBF): RxBF is a technique that uses multiple antennas at the receiver to capture signals from different directions and combine them to improve the signal strength and reduce interference. RxBF requires the receiver to have multiple antennas and a mechanism to combine the signals received from each antenna.

- In the following Figure, an 802.11n device using transmit beamforming to target device B. The phase of each copy of the transmitted signal is adjusted so that all three signals arrive at device B more or less in phase with each other. The same three signal copies also arrive at device A, which is not targeted by T×BF. As a result, the signals arrive as is and are out of phase.



4.5.5 Maximal-Ratio Combining

1) An 802.11n device can use multiple antennas and radio chains to receive the multiple transmitted copies of the signal. One copy might be better than the others, or one copy might be better for a time, and then become worse than the others.
2) IEEE 802.11n offers maximal-ratio combining (MRC) algorithms.
3) MRC algorithms are used to combine multiple received signals by looking at each unique signal and optimally combining the signals in a method that is additive as opposed to destructive.
4) MIMO systems using MRC will effectively raise the SNR level of the received signal.

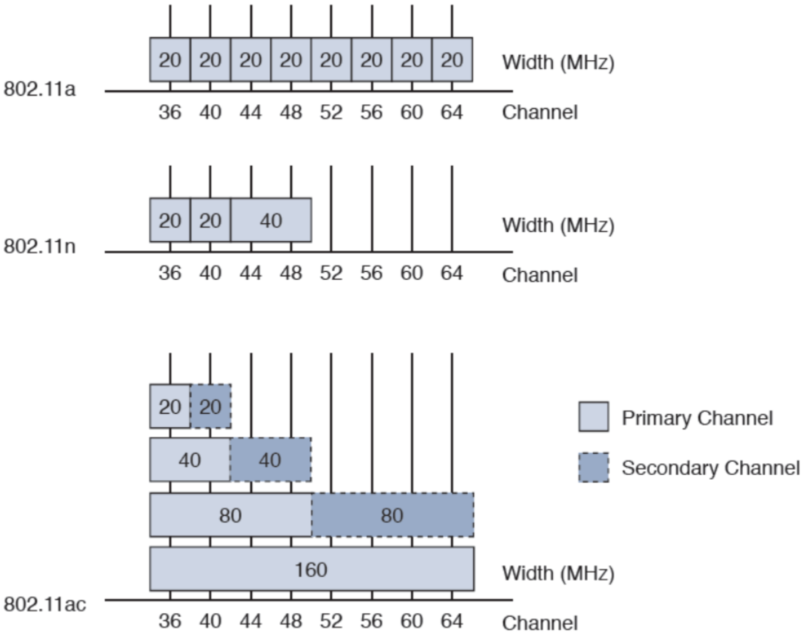
5) MRC is useful when a non-MIMO radio transmits to a MIMO receiver and multipath occurs.
6) The MRC algorithm focuses on the **signal with the highest SNR level**; however, it may still combine information from the noisier signals. The end result is that less data corruption occurs because a better estimate of the original data has been reconstructed.
7) MRC uses a receive-combining function that assesses the phase and SNR of each incoming signal. Each received signal is phase-shifted so that they can be combined. The amplitude of the incoming signals is also modified to focus on the signal with the best SNR.

1.6 IEEE 802.11ac Standard

The 802.11ac amendment, takes the best of 802.11n and offers a new generation that is much faster and more scalable.

4.6.1 Robust Channel Aggregation

- The channel width can be 20, 40, 80, or 160 MHz.
- With 23 available channels, the number of **non-overlapping aggregated channels decreases as the channel width increases**. For example, there are only eleven 40-MHz channels, five 80-MHz channels, and two 160-MHz channels available.
- The channel width can vary dynamically, on a frame-by-frame basis.



Channel Width Comparison Between 802.11a, 802.11n, and 802.11ac

4.6.2 Dense Modulation

Devices using 802.11ac can take advantage of 256-QAM modulation for higher data throughput. The difference between 256-QAM and 64-QAM (the best 802.11n offering) is about 25 percent higher data rates.

Table 2-11 IEEE 802.11ac Modulation and Coding Schemes

MCS Index	Modulation and Coding Scheme
0	BPSK 1/2
1	QPSK 1/2
2	QPSK 3/4
3	16-QAM 1/2
4	16-QAM 3/4
5	64-QAM 2/3
6	64-QAM 3/4
7	64-QAM 5/6
8	256-QAM 3/4
9	256-QAM 5/6

IEEE 802.11ac is a standard for wireless local area networks (WLANs) that was released in 2013. It operates in the 5 GHz frequency band, and some of its characteristics include:

1) **Maximum data rate**: The maximum data rate for IEEE 802.11ac is **6.93 Gbps**, which is significantly faster than the maximum data rate of IEEE 802.11n.
2) **Modulation schemes**: IEEE 802.11ac uses multi-user MIMO (MU-MIMO) technology, which allows for multiple streams of data to be transmitted simultaneously to multiple devices. It also uses OFDM modulation.

3) **Channel bandwidth**: IEEE 802.11ac can use up to an 160 MHz channel bandwidth, which allows for higher data rates.
4) **Backward compatibility**: IEEE 802.11ac is backward compatible with IEEE 802.11n and other previous standards, which allows devices using these older standards to connect to an IEEE 802.11ac network.
5) **Range**: IEEE 802.11ac has a similar range to IEEE 802.11n, with a range of up to 70 meters indoors and up to 250 meters outdoors.
6) **Security**: The standard provides several security mechanisms, including WEP, WPA, and WPA2 encryption, as well as authentication using EAP.
7) **Interference**: IEEE 802.11ac is less susceptible to interference from other devices than previous standards due to its use of MU-MIMO and beamforming technology.

2. Questions

7. Which of the following standards apply to wireless LAN operation in the 5-GHz band? (Choose all that apply.)

    a. IEEE 802.1
    b. IEEE 802.11g
    c. IEEE 802.11a
    d. IEEE 802.11n
    e. IEEE 802.11ac
    f. IEEE 802.11b
    g. IEEE 802.11-2012

8. Which of the following wireless LAN standards use OFDM for transmissions? (Choose all that apply.)

    a. 802.11-1997

b. 802.11b

c. 802.11g

d. 802.11a

9. Which one of the following correctly specifies the maximum theoretical data rate of the 802.11b, 802.11a, and 802.11n standards, respectively?

a. 11 Mbps, 54 Mbps, 600 Mbps

b. 54 Mbps, 54 Mbps, 150 Mbps

c. 1 Mbps, 11 Mbps, 54 Mbps

d. 11 Mbps, 20 Mbps, 40 Mbps

10. A 2×3 MIMO device correctly describes which one of the following?

a. A device with two radios and three antennas

b. A device with two transmitters and three receivers

c. A device with two bonded channels and three spatial streams

d. A device with two receivers and three transmitters

11. An 802.11n device can aggregate channels to which one of the following maximum widths?

a. 5 MHz

b. 20 MHz

c. 40 MHz

d. 80 MHz

12. Which one of the following standards can make use of multiple spatial streams on a transmitter and a receiver? (Choose all that apply.)

a. 802.11n

b. 802.11b

c. 802.11g

d. 802.11a

e. 802.11ac

f. All of these answers are correct.

13. Which one of the following is the highest or best modulation scheme that can be

used with 802.11ac devices?

a. QPSK 3/4

b. 256-QAM

c. 128-QAM

d. 64-QAM

e. 16-QAM

14. What is the maximum number of spatial streams supported by 802.11ac?

a. 1

b. 2

c. 4

d. 8

e. 16

15. Which one of the following organizations certifies 802.11 interoperability?

a. ITU-R

b. FCC

c. IEEE

d. Wi-Fi Alliance

e. Cisco