

Wi-Fi & Bluetooth

Wi-Fi Standards

Wi-Fi Standards

❖ Wi-Fi Standards

- Wi-Fi specifications are based on the IEEE 802.11 standards
- Specifies how Wi-Fi works and its requirements
 - Packet, MAC, channel, modulation, data rate, etc.
 - IEEE 802.11a can achieve up to 54 Mbps
 - IEEE 802.11b can achieve up to 11 Mbps
 - IEEE 802.11g can achieve up to 54 Mbps
 - IEEE 802.11n can achieve up to 150 Mbps
 - IEEE 802.11ad can achieve up to 7 Gbps

Wi-Fi Standards

❖ IEEE 802.11-1997

- Released in June 1997
- Original version of the IEEE 802.11 standards
- Supports 1 Mbps or 2 Mbps data rates
- Uses CSMA/CA in 2.4 GHz ISM band or Infrared
- PHY (Physical Layer) Modulation Schemes
 - FHSS (Frequency Hopping Spread Spectrum)
 - DSSS (Direct Sequence Spread Spectrum)
 - IR (Infrared)

Wi-Fi Standards

❖ IEEE 802.11a

- Released in Sep. 1999 as an amendment to the 802.11 original standards
- Supports error correction coding
- Defines requirements for OFDM comm.
 - OFDM: Orthogonal Frequency Division Multiplexing
- OFDM usage increased the data rate up to 54 Mbps
- Interoperable in the 5 GHz ISM band

Wi-Fi Standards

❖ IEEE 802.11b

- Released in Sep. 1999
- Direct extension of the original standard in the aspect of modulation technique
 - Uses HR-DSSS/High-DSSS & CCK modulation
 - HR-DSSS: High-Rate Direct Sequence Spread Spectrum
 - CCK: Complementary Code Keying
- Data rate increased to 11 Mbps
- Operates in the 2.4 GHz ISM band

Wi-Fi Standards

❖ IEEE 802.11e

- EDCA (Enhanced Distributed Channel Access)
 - Provides QoS (Quality of Service) support
 - DiffServ (Differentiated Services) Priority support
 - Voice > Video > Best Effort Data > Background Data
- IEEE 802.11e EDCA was incorporated into 802.11-2007 standard rollups, and was applied to later standards including IEEE 802.11n, 802.11p, 802.11ac, etc.

Wi-Fi Standards

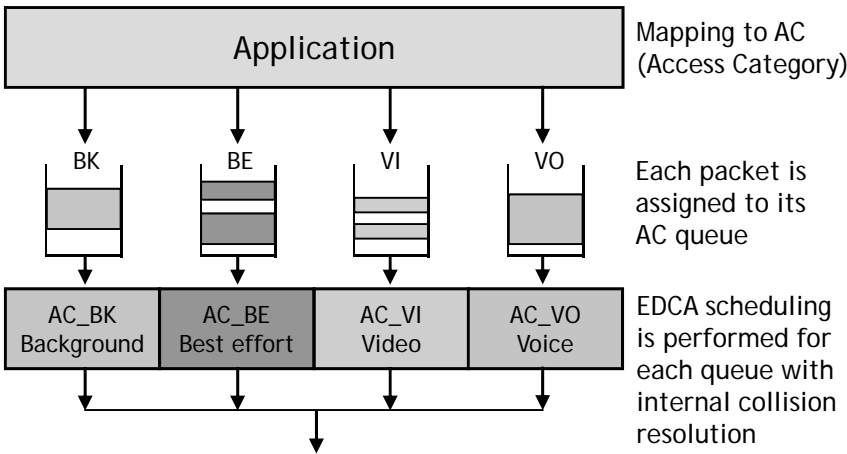
❖ IEEE 802.11e EDCA

- Important for delay-sensitive applications
 - Example: VoIP & Multimedia Streaming
- Defines 4 priority levels of application called ACs (Access Categories)

Priority (Low → High)	Access Category Index	AC	Description
0	1	AC_BK	Background
1	0	AC_BE	Best effort
2	2	AC_VI	Video
3	3	AC_VO	Voice

Wi-Fi Standards

❖ IEEE 802.11e EDCA



Wi-Fi Standards

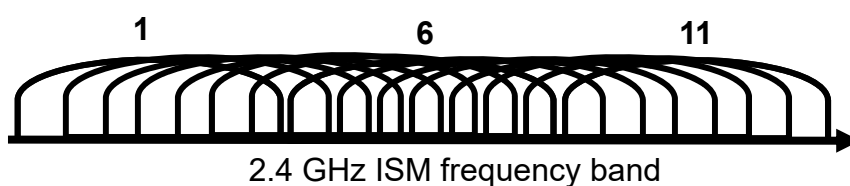
❖ IEEE 802.11g

- Released in Jun. 2003 as an amendment to IEEE 802.11b
 - Operates in the 2.4 GHz band like IEEE 802.11b
 - Hardware compatibility with 802.11b hardware
- Uses OFDM modulation
 - Based on the excellent performance experienced in using OFDM in IEEE 802.11a

Wi-Fi Standards

❖ IEEE 802.11g

- Interference prevention frequency channel selection
- Uses only the non-overlapping channels among the 14 channels
 - In the USA, channels 1, 6, 11 do not overlap



Wi-Fi Standards

❖ IEEE 802.11-2007

- First rollup standards released in Mar. 2007
- Merges 8 amendments (802.11a, b, d, g, h, i, j, e) with the original standard
 - 802.11d (2001): Country information added on a packet
 - 802.11h (2003): Provide DFS and TPC
 - DFS: Dynamic Frequency Selection
 - TPC: Transmit Power Control
 - 802.11i (2004): Security support by protected access
 - 802.11j (2004): Japanese frequency support (4.9 GHz)
 - 802.11e (2005): QoS (Quality of Service) support

Wi-Fi Standards

❖ IEEE 802.11n

- Released in Oct. 2009
- Improves network throughput using MIMO
 - MIMO: Multiple Input & Multiple Out
 - MIMO uses multiple antennas to transmit through overlapping frequency channels simultaneously
- Operates in both 2.4 GHz and 5 GHz
- Higher data rate up to 150 Mbps

Wi-Fi Standards

❖ IEEE 802.11p

- Released in Jul. 2010 to support WAVE
 - WAVE: Wireless Access in Vehicular Environment
- Operates in the 5.9 GHz channel
- Uses OFDM & EDCA (Enhanced Distributed Channel Access)
- Maximum data rate is 54 Mbps
- Supports V2X communication
 - V2V: Vehicle-to-Vehicle (OBU: On Board Unit)
 - V2I: Vehicle-to-Infrastructure (RSU: Road Side Unit)
 - V2P: Vehicle-to-Person (e.g., Smartphone, Smart Watch)

Wi-Fi Standards

❖ IEEE 802.11ac

- Released in Dec. 2013 as an amendment built upon 802.11n
- Focusing on higher throughput (data rate)
- New features
 - Support wider channel in the 5 GHz band
 - 80 or 160 MHz Bandwidth (40 MHz in IEEE 802.11n)
 - Extended MIMO to MU-MIMO (Multi-User MIMO)
 - High-density modulation
- Data rate up to 866.7 Mbps (at 160 MHz)

Wi-Fi Standards

❖ IEEE 802.11ad

- Released in Dec. 2012 (WiGig specs)
 - WiGig (Wireless Gigabit Alliance) was subsumed by the Wi-Fi Alliance in March 2013
- Uses the 60 GHz IMS band along with traditional Wi-Fi network to support data rates up to 7 Gbps
 - Ten times faster than IEEE 802.11n
- Supports wirelessly interconnected homes
 - Wireless TV Displays and Audio

Wi-Fi Standards

❖ IEEE 802.11ah

- Released in Dec. 2016 in order to support emerging IoT technology
- Operates in the 900 MHz band with a narrow bandwidth (1~16 MHz)
 - Alternative spectrum
 - Offloading traffic to under giga Hertz bands
- Low power consumption
 - Relay for service range extension
 - Wake/doze period protocol

Wi-Fi Standards

❖ IEEE 802.11ah

- Provides connectivity to thousands of IoT devices using 1 AP (Access Point)
 - Supports M2M & IoT market
 - Smart metering, smart home
- Data rate up to 347 Mbps
 - Sufficient for simultaneous support of multiple IoT applications of various types

Wi-Fi Standards

IEEE 802.11 Network PHY Standards (1/2)				
802.11 Protocol	Release Date	Frequency	Bandwidth	Stream Data Rate
802.11-1997	Jun. 1997	2.4 GHz	22 MHz	1, 2 Mbps
802.11a	Sep. 1999	5 GHz	20 MHz	6 ~ 54 Mbps
		3.7 GHz		
802.11b	Sep. 1999	2.4 GHz	22 MHz	1 ~ 11 Mbps
802.11g	Jun. 2003	2.4 GHz	20 MHz	6 ~ 54 Mbps
802.11-2007	Mar. 2007	2.4/5 GHz	22/20 MHz	1 ~ 54 Mbps
802.11n	Oct. 2009	2.4/5 GHz	20 MHz	7.2 ~ 72.2 Mbps
			40 MHz	15 ~ 150 Mbps

Wi-Fi Standards

IEEE 802.11 Network PHY Standards (2/2)				
802.11 Protocol	Release Date	Frequency	Bandwidth	Stream Data Rate
802.11p	Jul. 2010	5.9 GHz	5/10/20 MHz	1.5 Mbps ~ 54 Mbps
802.11ac	Dec. 2013	5 GHz	20 MHz	7.2 ~ 96.3 Mbps
			40 MHz	15 ~ 200 Mbps
			80 MHz	32.5 ~ 433.3 Mbps
			160 MHz	65 ~ 866.7 Mbps
802.11ad	Dec. 2012	60 GHz	2.16 GHz	Up to 7 Gbps
802.11ah	Dec. 2016	0.9 GHz	1 ~ 16 MHz	Up to 347 Mbps

Wi-Fi Standards

IEEE 802.11 Network PHY Standards (1/2)				
802.11 protocol	Frequency	Modulation	Approximate Range	
			Indoor (m)	Outdoor (m)
802.11-1997	2.4 GHz	DSSS, FHSS	20	100
802.11a	5 GHz	OFDM	35	120
	3.7 GHz		-	5000
802.11b	2.4 GHz	DSSS	35	140
802.11g	2.4 GHz	OFDM, DSSS	38	140

Wi-Fi Standards

IEEE 802.11 Network PHY Standards (2/2)				
802.11 protocol	Frequency	Modulation	Approximate Range	
			Indoor (m)	Outdoor (m)
802.11n	2.4/5 GHz	OFDM (MIMO-4)*	70	250
802.11p	5.9 GHz	OFDM	N/A	1,000 (1 km)
802.11ac	5 GHz	OFDM (MIMO-8)*	35	-
802.11ad	60 GHz	OFDM	10	10
802.11ah	0.9 GHz	MIMO-OFDM		

* MIMO-4 and MIMO-8 represent that the allowable MIMO streams are 4 and 8, respectively

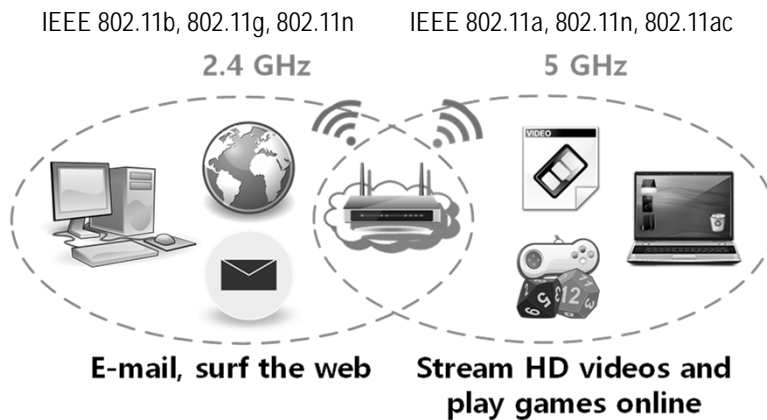
Wi-Fi Standards

❖ Dual Band

- Dual band is the capability to transmit on the 5 GHz band and also the 2.4 GHz band
 - Ordinary Wi-Fi equipment supports communication in only a signal band
- 2.4 GHz band
 - IEEE 802.11b, 802.11g, 802.11n
- 5 GHz band
 - IEEE 802.11a, 802.11n, 802.11ac

Wi-Fi Standards

❖ Example of Dual Band



Wi-Fi Standards

❖ Wi-Fi Direct

- Wi-Fi Direct devices can connect directly to one another without access to a traditional network
 - Extension to the Ad Hoc mode
- With optional services, users can send files, print documents, play media, and display screens between and among devices

Wi-Fi Standards

❖ Wi-Fi Direct

- Supported Connection Types
 - One-to-one device connection
 - Group of several devices can connect simultaneously

Wi-Fi Standards

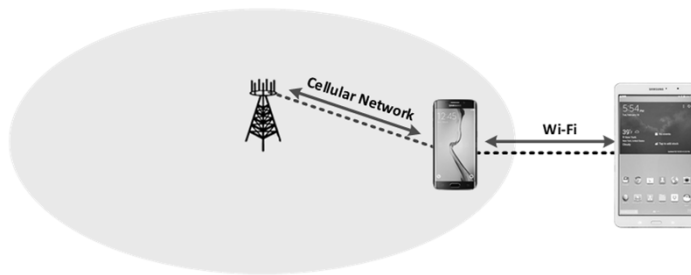
❖ Tethering (Hotspot)

- Tethering refers to connecting one device to another
- In the context of mobile phones or Internet tablets, tethering allows sharing the Internet connection of the phone or tablet with other devices (such as laptops)

Wi-Fi Standards

❖ Tethering (Hotspot)

- A Wi-Fi STA can make connection to the Internet by connecting to a tethering enabled smartphone using Wi-Fi



Wi-Fi & Bluetooth

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References

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