IEEE 802.11

EE586 – Wireless Networking: Architecture, Protocols, & Standards

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History & Background

- Legacy 802.11 standard was implemented in 1997 which specified two raw data 1Mbps and 2Mbps for transmission
- It provided CSMA/CA as a means for multiple access, avoiding collision. 802.11 devised to serve a confined area, usually several hundred meters in length
- Operates in the unlicensed ISM band. Uses low cost equipment for deployment.
- RF frequency spectrum use of IEEE 802.11 varies by country. In the US, 802.11 allocated free spectrum use as allowed by the FCC Rules & Regulations
- In 1999 the 802.11b was ratified, serving as an amendment to the legacy standard
- 802.11n was ratified in 2009 to serve as the latest current standard

Wi-Fi Alliance

- Trade group that owns the "Wi-Fi" trademark
- Runs certification testing on Wi-Fi products so as to ensure they are compliant
- Ensures equipment is interoperable once deployed to end-user
- Virtually all 802.11 equipment manufacturers are members

WLAN – Wi-Fi

- The growing demand for wireless data services gave rise to short-range wireless connectivity where multiple devices connect to a shared node called an Access Point (AP)
- Wireless local-area networks, WLANs, use the 802.11 protocol – often deployed in places like airports, hotels, coffee shops

Standards[4]

Standards Summary

IEEE 802.11 - The original 1 Mbit/s and 2 Mbit/s, 2.4 GHz RF and IR standard

IEEE 802.11a - 54 Mbit/s, 5 GHz standard (1999, shipping products in 2001)

IEEE 802.11b - Enhancements to 802.11 to support 5.5 and 11 Mbit/s (1999)

IEEE 802.11d - international (country-to-country) roaming extensionsNew countries

IEEE 802.11e - Enhancements: QoS, including packet bursting

IEEE 802.11F - Inter-Access Point Protocol (IAPP)

IEEE 802.11g - 54 Mbit/s, 2.4 GHz standard (backwards compatible with b) (2003)

IEEE 802.11h - 5 GHz spectrum, Dynamic Channel /Frequency Selection (DCS/DFS) and Transmit Power Control (TPC) for European compatibility

IEEE 802.11i (ratified 24 June 2004) - Enhanced security

IEEE 802.11j - Extensions for Japan

IEEE 802.11k - Radio resource measurements

IEEE 802.11n - Higher throughput improvements

IEEE 802.11p - WAVE - Wireless Access for the Vehicular Environment (such as ambulances and passenger cars)

IEEE 802.11r - Fast roaming

IEEE 802.11s - Wireless mesh networking

IEEE 802.11T - Wireless Performance Prediction (WPP) - test methods and metrics

IEEE 802.11u - Interworking with non-802 networks (e.g., cellular)

IEEE 802.11v - Wireless network management

Of these the most widely known standards are the network bearer: 802.11a, 802.11b, 802.11g, and 802.11n

4. IEEE, Wireless LAN 802.11 Wi-Fi

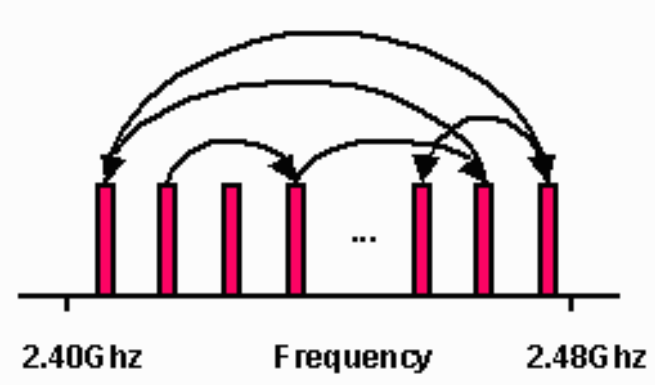
Physical Layer Specifications[5]

	802.11A	802.11B	802.11G	802.11N
Date of standard approval	July 1999	July 1999	June 2003	Oct 2009
Maximum data rate (Mbps)	54	11	54	~600
Modulation	OFDM	CCK or DSSS	CCK, DSSS, or OFDM	CCK, DSSS, or OFDM
RF Band (GHz)	5	2.4	2.4	2.4 or 5
Number of spatial streams	1	1	1	1, 2, 3, or 4
Channel width (MHz) nominal	20	20	20	20, or 40

- IEEE 802.11 provides a set of physical layer and MAC specifications for implementing WLAN i.e. modulation, multiple access method, as well as achievable data rates that each of the standard versions support.
- Digital Modulation used to support higher data rates and greater information capacity. Spread spectrum entails spreading the signal over a frequency bandwidth much greater than that of the signal bandwidth.

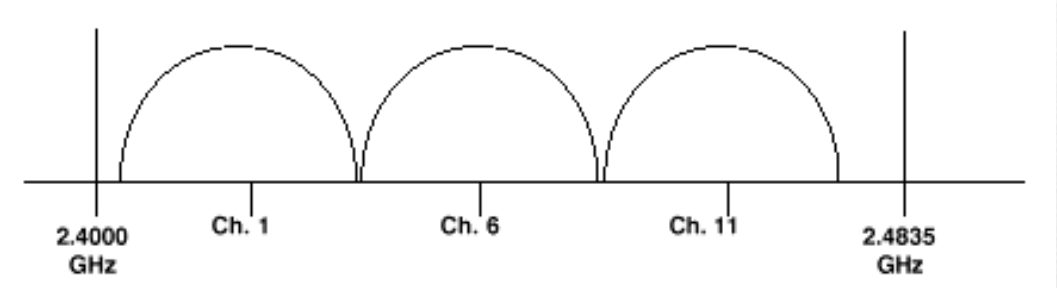
5. Radio Electronics, IEEE Standards Tutorial

Frequency Hopping Spread Spectrum, FHSS



- One of the variants of spread spectrum where carrier frequencies are continuously switched in sync with both transmitter and receiver
- Supports 79 channels
- Achieves low data rates 1-2 Mbps
- Uses GSFK modulation at Fclk=1Msymbol/sec
- Used in the original 802.11

Direct-Sequence Spread Spectrum, DSSS



- Signal is concatenated with a sequence and spread over a 20 MHz bandwidth
- In North America, only 3 non-overlapping channels are available in the 2 GHz band: Channels 1, 6, and 11
- Uses DBPSK and DQPSK digital modulation methods
- Achieves higher data rates 1, 2, 5.5, and 11 Mbps
- Used in 802.11b

Orthogonal Frequency Division Multiplexing, OFDM[8]

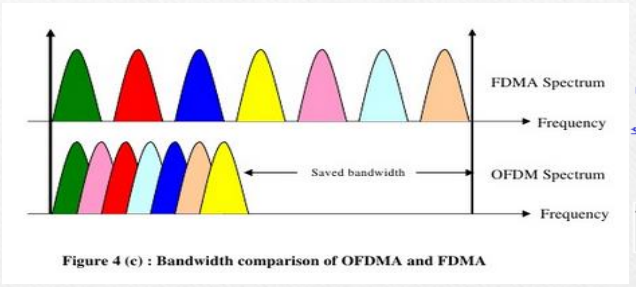
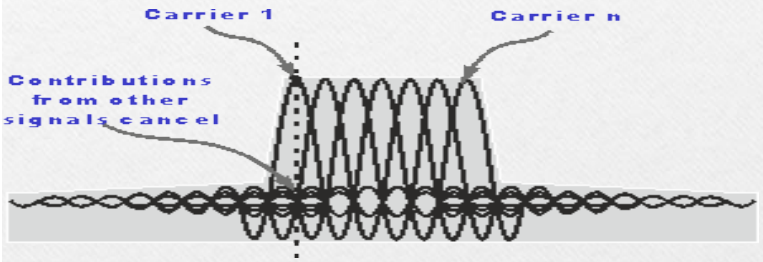


Figure 4 (c) : Bandwidth comparison of OFDMA and FDMA



- Encoding data onto multiple carrier frequencies (subcarriers)
- A variant of the traditional Frequency Division Multiplexing, FDM, where frequency band is sliced up into closely spaced orthogonal narrowband channels – this type of scheme results in bandwidth savings!
- Popular modulation scheme, used in latest 802.11n
- Achieves highest data rate at 54Mbps and 600Mbps in 802.11g/n standards
- Makes it possible to use embedded digital modulation methods for transmission i.e. PSK or QAM
- 52 subcarriers in total: 48 data subcarriers and 4 pilot subcarriers

8. OFDMA Basics

Data Rates[5]

	802.11A	802.11B	802.11G	802.11N
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Modulation	OFDM	CCK or DSSS	CCK, DSSS, or OFDM	CCK, DSSS, or OFDM
RF Band (GHz)	5	2.4	2.4	2.4 or 5
Number of spatial streams	1	1	1	1, 2, 3, or 4
Channel width (MHz) nominal	20	20	20	20, or 40

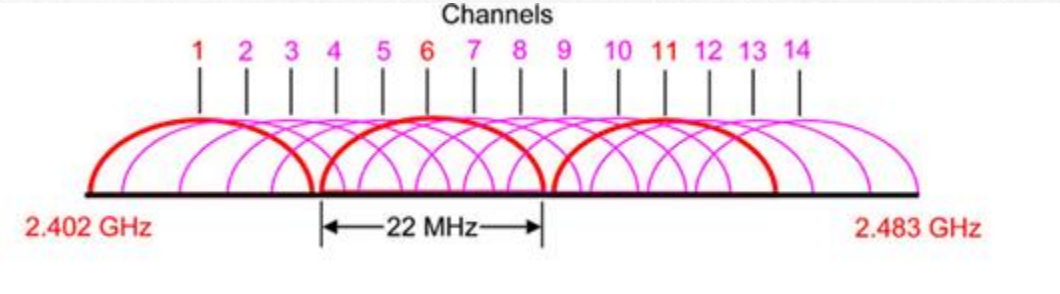
Summary of major 802.11 Wi-Fi Standards

- Currently 802.11n, ratified on Oct 2009, supports the highest data rate at approximately 600Mbps

Frequency Bands

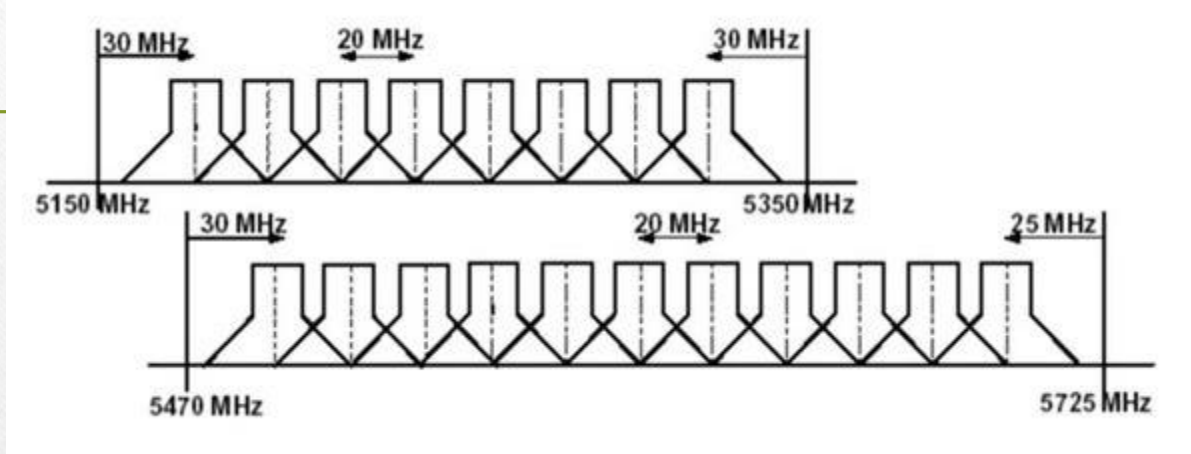
- 802.11 operates in two bands:
  - 2.4 GHz band
  - 5 GHz band

2.4GHz Frequency Band



- In North America, the 2.4 GHz ISM band is divided into 11 channels for 802.11
- Of the 11 channels, only 3 are non-overlapping (Channels #1, #6, and #11 are non-overlapping in the US); each having 22 MHz bandwidth

5GHz Frequency Band



- Operates on a larger frequency band
- Further, offers 23 non-overlapping 20MHz channels
- Less susceptible to interference

WLAN Drawbacks & Issues

- 2.4 GHz Band
  - Due to the limited channels available within the 2.4 GHz spectrum, it is crowded with Wi-Fi users
  - In addition, receives interference from various other sources operating in the 2.4 GHz ISM band i.e. cordless telephones, microwave oven, bluetooth, and wireless peripherals
- 5 GHz Band
  - Higher frequency causes system to be range-limited
  - RF propagation issues in the higher frequency band, as signals do not penetrate through solid objects as well as the 2.4 GHz does

Co-Channel Interference, CCI

- Co-Channel Interference, CCI, refers to two channels interfering with one another, induced by reusing the same frequency channel in adjacent cells
- Given only 3 non-overlapping channels, the 2.4 GHz WLAN is especially prone to this effect

Adjacent Channel Interference, ACI

- Adjacent Channel Interference is primarily due to overlapping channels interfering with one another
- Increasing the number of usable channels, which overlap one another, in a given system yields a greater ACI

Collision

- In the 2.4 GHz band, channel collision is inevitable
- Given limited available frequency spectrum, several users collide with one another in a given system, which in turn degrades throughput performance

Multiple Access Control, MAC

- In order to control collision as well as achieve greater capacity in the ISM band, 802.11 has adopted a multiple access method, CSMA
- To combat interference and collision, 802.11 utilizes the CSMA/CA protocol, sensing before transmitting

Carrier Sense Multiple Access, CSMA

- In order to combat collision, 802.11 uses CSMA/CA, collision avoidance scheme
- To combat interference occurring in adjacent overlapping cells CSMA 802.11 adopted CSMA protocol for control
- Helps avoid interference at the expense of degraded network performance (i.e. lower throughput)

CSMA Protocols

- 1-Persistent – Carrier senses channel and if the channel is not busy then sender transmits. If channel is busy, carrier waits a random amount of time and then retransmits
- Non-Persistent – Carrier senses channel and if channel is occupied, sender waits a specified amount of time before retransmitting
- P-Persistent – Carrier senses channel and if the channel is idle then sends with probability, P. If the channel is busy then waits a random amount of time before retransmitting

Privacy & Access Control

- Goal of 802.11 is to provide "Wired Equivalent Privacy" (WEP)
- WEP mechanism is usable worldwide

802.11 Wi-Fi Products & Services

- Wi-Fi integrates a plethora of devices into a network; making it possible for high-speed wireless networking
- Wi-Fi hotspots are frequently deployed by restaurants, hotels so as to provide guests with free internet service

AP Internal & External Antennas

- Access Points use either internal or external antennas
- Internal PCB antennas usually offer less gain (small gain, ~1-1.5 dBi gain) as compared to external antennas. They have a non-adjustable configuration
- External antennas offer a greater gain, (~5dBi gain) are tunable in terms of polarity, and upgradable

Embedded Wi-Fi Radios

- Texas Instruments, TI, is a major supplier of Wi-Fi transceivers
- These radios are embedded in a plethora of wireless devices including laptops, cellphones which conform to the 802.11 standard

VoIP over Wi-Fi

- VoIP over Wi-Fi (VoFI) uses IP-based signaling and encoding protocols
- These protocols are developed by ITU, IEEE, and others
- VoFI feature may be used in a WLAN office environment, creating a mobile communications setting
- 802.11n supports voice while 802.11ad enhances performance
- Drawbacks: Unlike data transmission, voice is susceptible to error i.e. unable to tolerate high packet loss

Future – WiGig Alliance (802.11ad)

- High-speed protocol in the works – will be the successor of 802.11ac
- 802.11ad supports Gigabit Wi-Fi chipsets achieving much faster data rates
- WiGig Alliance is the next generation of Wi-Fi which promotes the usage of the 60GHz frequency spectrum. WiGig Alliance was subsumed by Wi-Fi Alliance in March 2013
- 802.11ad chipsets are expected to be smart, small in size, and more efficient offering faster speeds operating in the 60GHz band, also uses beamforming yielding higher data rates
- 802.11ad products will be integrated into future mobile phones and tablets

Summary

- 802.11 protocol provides both MAC and physical layer specifications for WLAN
- Operates within the ISM band at 2.4GHz and 5GHz
- Wi-Fi Alliance, owner of Wi-Fi trademark, certifies 802.11 products for compliance
- Uses FHSS, DSSS, and OFDM digital modulation and spread spectrum schemes – increasing information capacity
- CCI, ACI, and collision affect system performance (resulting in low throughput)
- CSMA/CA protocol used to control channel collision, as well as provide multiple user access
- IP implementation for voice delivery within a Wi-Fi network, VoFI, already in use and is expected to grow in the future
- WiGig Alliance is the next generation of Wi-Fi, certifying and promoting latest 802.11ad standard that is currently underway, and is expected to support multi-Gbps data rates!

Reference List [1]

1. Pahlavan, Kaveh, and Prashanth Krishnamurthy. *Principles of Wireless Networks: A Unified Approach*. Upper Saddle River, NJ: Prentice Hall PTR, 2002. Print.
2. "802.11 MAC Entity: MAC Basic Access Mechanism Privacy and Access Control." Web. 1 Oct. 2014. http://www.ieee802.org/11/Tutorial/MAC.pdf
3. "802.11b Wireless LANs." *Wireless LANs*. Web. 1 Oct. 2014. http://web.stanford.edu/group/networking/NetConsult/wireless/wlan.html
4. "Wireless LAN 802.11 Wi-Fi." - *GHN: IEEE Global History Network*. N.p., n.d. Web. Oct. 2014. http://www.ieeeghn.org/wiki/index.php/Wireless_LAN_802.11_Wi-Fi#Standards_Summary
5. "IEEE 802.11 Standards Tutorial." *IEEE 802.11 Standards*. N.p., n.d. Web. Oct. 2014. http://www.radio-electronics.com/info/wireless/wi-fi/ieee-802-11-standards-tutorial.php
6. "EnggPedia - The Engineering Encyclopedia." Carrier Sense Multiple Access (CSMA). Web. Oct 2014. http://www.enggpedia.com/computer-engineering-encyclopedia/dictionary/computer-networks/1614-carrier-sense-multiple-access-csma
7. "Verizon 4G LTE: Two Datacards and a WiFi Hotspot Massively Reviewed." *RSS*. Web. Oct 2014. http://www.anandtech.com/show/4289/verizon-4g-lte-two-datacards-wifi-hotspot-massively-reviewed/2
8. "Ofdma Basics." *Ofdma Basics*. Web. Oct. 2014. http://www.slideshare.net/deepakecrbs/ofdma-basics
9. Verenkoff, Brian. Web. Oct. 2014. http://www.lmi.net/wp-content/uploads/Optimizing_802.11n.pdf
10. Leung, Kin K., and Byoung-Jo J" Kim. Web. Oct. 2014. http://www.ics.forth.gr/mobile/Bibliography/LoadBalancing/LB/Channel_Assign_80211_MultiCell.pdf

Reference List [2]

11. DiGiovanni, John. Web. Oct. 2014. https://net.educause.edu/ir/library/pdf/NMD0627.pdf
12. "Here's Why You Should Use 5GHz WiFi Instead of 2.4GHz - Pocketnow."*Pocketnow*. Web. 1 Oct. 2014. http://pocketnow.com/2014/01/23/5ghz-wifi
13. Clear Voice Over Wi-Fi in the Enterprise. Web. 1 Oct. 2014. http://a030f85c1e25003d7609-b98377aee968aad08453374eb1df3398.r40.cf2.rackcdn.com/wp/wp-clear-voice-over-wi-fi-in-the-enterprise.pdf
14. Chayat, Naftali. "Frequency Hopping Spread Spectrum PHY of the 802.11 Wireless LAN Standard." Web. 1 Oct. 2014. http://www.ieee802.org/11/Tutorial/FH.pdf
15. Boer, Jan. "Direct Sequence Spread Spectrum Physical Layer Specification IEEE 802.11." Web.
16. "Wireless Connectivity." Web. 1 Oct. 2014. http://www.ti.com/lit/sg/slab056d/slab056d.pdf
17. "WLAN Radio Frequency Design Considerations." Web. 1 Oct. 2014. http://www.cisco.com/c/en/us/td/docs/solutions/Enterprise/Mobility/emob41dg/emob41dg-wrapper/ch3_WLAN.pdf
18. "Is 5 GHz the Promised Land for Embedded Wireless Applications?" *Is 5 GHz the Promised Land for Embedded Wireless Applications*. Web. 1 Oct. 2014. http://www.digikey.com/en/articles/techzone/2013/feb/is-5-ghz-the-promised-land-for-embedded-wireless-applications
19. "OFDM Orthogonal Frequency Division Multiplexing Tutorial." *What Is OFDM*. N.p., n.d. Web. Oct. 2014. http://www.radio-electronics.com/info/rf-technology-design/ofdm/ofdm-basics-tutorial.php
20. "Network Analysis and Monitoring Blog." *Network Analysis and Monitoring Blog*. N.p., n.d. Web. Oct. 2014. http://blog.wildpackets.com/2012/12/11/best-practices-for-analyzing-voice-over-wi-fi-vofi-with-wildpackets.html
21. "To Address the Wide Variety of Mobile Users." *To Address the Wide Variety of Mobile Users*. N.p., n.d. Web. Oct. 2014. http://www.siscomm.com/docs/Univerge/univerge_mobile.htm
22. "Tensorcom Has Developed the Lowest-power, Multi-Gb/s 802.11ad 60 GHz SoCs." *Tensorcom – A Leader in Low-Power Wireless Chipsets*. N.p., n.d. Web. 19 Mar. 2015. http://www.tensorcom.com/