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**Certified Wireless Network Administrator (CWNA) PW0-106**

Chapter 6

Wireless Networks and Spread Spectrum Technologies

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## Chapter 6 Overview

- Industrial, Scientific, and Medical Bands (ISM)
- Unlicensed National Information Infrastructure Bands (UNII)
- 3.6 GHz band
- 4.9 GHz band
- Future Wi-Fi Frequencies
- Narrowband and Spread Spectrum
- Frequency Hopping Spread Spectrum (FHSS)
- Direct Sequence Spread Spectrum (DSSS)

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## Chapter 6 Overview (continued)

- Packet Binary Convolutional Code (PBCC)
- Orthogonal Frequency Division Multiplexing (OFDM)
- 2.4 GHz Channels
- 5 GHz Channels
- Adjacent, Nonadjacent, and Overlapping Channels
- Throughput vs. Bandwidth
- Communication Resilience



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## Industrial, Scientific, and Medical Bands

- 902 – 928 MHz (26 MHz wide)
  - Industrial Band
- 2.4 – 2.5 GHz (100 MHz wide)
  - Scientific Band
- 5.725 – 5.875 GHz (150 MHz wide)
  - Medical Band
- Defined by the ITU Telecommunication Standardization Sector (ITU-T)
- License-Free Bands
- Use is not restricted to band type

## 900 MHz ISM Band

- 902 – 928 MHz
- Early wireless used 900 MHz, but most newer wireless uses higher frequencies now
- Internationally could interfere with Global System for Mobile Communications (GSM) mobile phones
- Used by many consumer products, such as baby monitors and cordless home telephones





## 2.4 GHz ISM Band

- 2.4 – 2.5 GHz
- 100 MHz wide
- Most common Wi-Fi band
- Use for WLANs is defined by IEEE 802.11-2007 standard and 802.11n amendment
- Used by 802.11, 802.11b, 802.11g, and 802.11n wireless devices
- Also used by microwave ovens, cordless home telephones, baby monitors, and wireless video cameras

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## 5.8 GHz ISM Band

- 5.725 – 5.875 GHz
- 150 MHz wide
- Commonly confused with the UNII-3 band, which spans from 5.725 – 5.825 GHz
- Some countries allow the use of OFDM on Channel 165, however this is sparsely used
- Also used by microwave ovens, cordless home telephones, baby monitors, and wireless video cameras



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## Unlicensed National Information Infrastructure Bands

- Designated for use by IEEE 802.11a
- UNII-1, UNII-2, and UNII-3 were defined for use by 802.11a
- Each band is 100 MHz wide with 4 channels
- IEEE 802.11h designated the use of UNII-2E
- UNII-2E is 255 MHz wide with 11 channels

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# UNII

- UNII-1 (Lower UNII)
  - 5.150 – 5.250 GHz
  - 100 MHz wide
  - Typically used indoors
  - IEEE defined maximum power of 40 mW
- UNII-2 (Middle UNII)
  - 5.250 – 5.350 GHz
  - 100 MHz wide
  - Indoor or outdoor use
  - IEEE defined maximum power of 200 mW



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# UNII (continued)

- UNII-2 Extended
  - 5.470 – 5.725 GHz
  - 255 MHz wide
  - Indoor or outdoor use
  - IEEE defined maximum power of 200 mW
- UNII-3 (Upper UNII)
  - 5.725 – 5.825 GHz
  - 100 MHz wide
  - Typically outdoor point-to-point use
  - IEEE defined maximum power of 800 mW

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# UNII Summary

| Band | Name | Frequency | Channels |
|---|---|---|---|
| UNII-1 | Lower | 5.15-5.25 GHz | 4 |
| UNII-2 | Middle | 5.25-5.35 GHz | 4 |
| UNII-2 Extended | Extended | 5.47-5.725 GHz | 12 |
| UNII-3 | Upper | 5.725-5.825 GHz | 5 |



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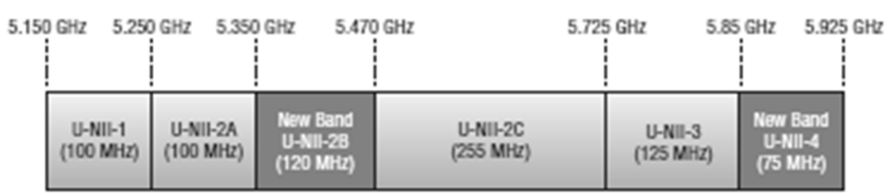
# Future U-NII bands

- Two new U-NII bands as shown
- U-NII-2 band would be renamed to U-NII-2A and the
- U-NII-2 Extended band would be renamed as U-NII-2C
- In addition to ten new channels gained from the proposed two new bands, U-NII-2A would gain an extra channel Unlicensed National Information Infrastructure Bands 207 and U-NII-2C would gain an extra channel in frequency space previously used as a guard bands.



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## New U-NII bands

| Old Name | New Name | Frequency | Channels |
|---|---|---|---|
| U-NII-1 | U-NII-1 | 5.15 – 5.25 GHz | 4 channels |
| U-NII-2 | U-NII-2A | 5.25 – 5.35 GHz | 5 channels |
| | U-NII-2B | 5.35 – 5.47 GHz | 6 channels |
| U-NII-2 Extended | U-NII-2C | 5.47 – 5.725 GHz | 13 channels |
| U-NII-3 | U-NII-3 | 5.725 – 5.85 GHz | 5 channels |
| | U-NII-4 | 5.85 – 5.925 GHz | 4 channels |



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## 3.6 GHz Band

- Specified by the 802.11y amendment
- 3.65 – 3.7 GHz
- Approved as a licensed band for use in U.S.
- Use is limited near certain satellite earth stations
- Designed for U.S. but made able to operate in other countries without having to ratify a new amendment

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## 4.9 GHz Band

- Defined in 802.11-2007 standard
  - 4.94 – 4.99 GHz
  - Defined for public safety organization in U.S.
  - Also approved in some other countries
- Defined in 802.11j-2004
  - 4.9 – 5.091 GHz
  - For use in Japan
  - Later incorporated in 802.11-2007 standard



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## Future Wi-Fi Frequencies

- 2.4 GHz ISM band is the dominant license-free frequency band
- Use of 5 GHz began to grow in 2006
- 5 GHz continues to grow due to:
  - Overcrowding of 2.4 GHz band
  - 5 GHz bands are wide and have more channels
  - 5 GHz can benefit from 802.11n channel bonding

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# Future Wi-Fi Frequencies (continued)

- 60 GHz
  - Proposed by 802.11ad draft amendment
  - Potential speeds of up to 7 Gbps
  - Ultrahigh frequencies will have difficulty penetrating walls
  - Likely to be used for bandwidth-intensive communications and indoor short distances
  - Tri-band radios will support 2.4 GHz, 5 GHZ, and 60 GHz with seamless handoff



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# Future Wi-Fi Frequencies - WiGiG

- In September of 2012, the Wi-Fi Alliance designated the WiGig certification to test interoperability of products that operate in the 60 GHz band
- Tri band radios should provide for seamless handoff between devices in the short coverage area of the 60 GHz band and the greater coverage area of either the 2.4 GHz or 5 GHz band

WiGig™ CERTIFIED by Wi-Fi Alliance

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## Future Wi-Fi Frequencies (continued)

- White-Fi
  - Proposed by 802.11af draft amendment
  - Describes the use of Wi-Fi in the unused television RF spectrum (also known as white space)
  - Will provide greater range because of lower frequencies below 1 GHz
  - Due to lower frequencies, data rates will be less than other Wi-Fi PHYs



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## Narrowband

- Narrowband uses very little bandwidth
- Intentional jamming or unintentional interference will likely cause disruption in the signal
- Typically transmitted using higher power
- Typically requires a license to limit the risk of interference between transmitters

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## Spread Spectrum

- Uses more bandwidth than is necessary to carry its data
- Spreads the data across the frequencies
- Less susceptible to intentional jamming or unintentional interference
- Typically transmitted using lower power
- Typically does not require a license
- Originally patented in 1942 by actress Hedi Lamarr and composer George Antheil for torpedo guidance



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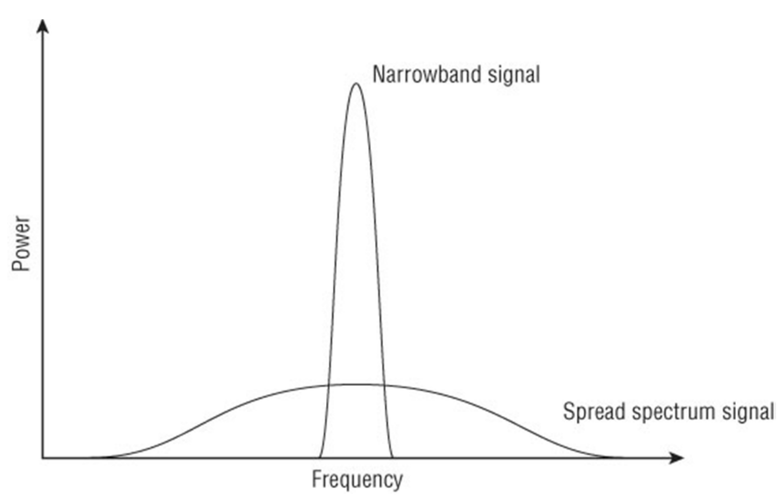
## Narrowband and Spread Spectrum



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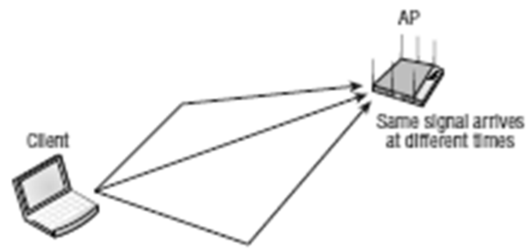
# Multipath Interference

- Prior to 802.11n, multipath was unwanted
- Occurs when reflected signal arrives at the receiving antenna after the primary signal
- Similar to how an echo arrives after the original sound is heard
- Delay between the main and reflected signals is known as the *delay spread*
- Intersymbol Interference (ISI) – When the delay spread is too great and the reflected signal interferes with the main signal



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# Multipath Interference (continued)

- With the introduction of 802.11n and MIMO, multipath is now a condition that can drastically improve the performance and throughput of a Wi-Fi network
- Enhanced digital signal processing techniques of 802.11n can take advantage of multipath

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## Frequency Hopping Spread Spectrum (FHSS)

- Defined in the original 802.11 standard in clause 14
- 2.402 – 2.480 GHz (79 MHz)
- Not used for Wi-Fi anymore (used by bluetooth)
- FHSS Process
  - Transmits data on a narrow frequency
  - Hops to another narrow frequency and transmits more data
  - Continue process using a defined hopping sequence



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## Frequency Hopping Spread Spectrum (FHSS) (continued)

- Hopping Sequence – predefined hopping pattern or set
- Dwell Time – Period of time that the transmitter stays on a channel and transmits data
- Hop Time – The time it takes for the tranmitter to change from one frequency to another
- Modulation – FHSS uses Gaussian frequency shift keying (FGSK). Two-level GFSK produced 1 Mbps and four-level GFSK produced 2 Mbps

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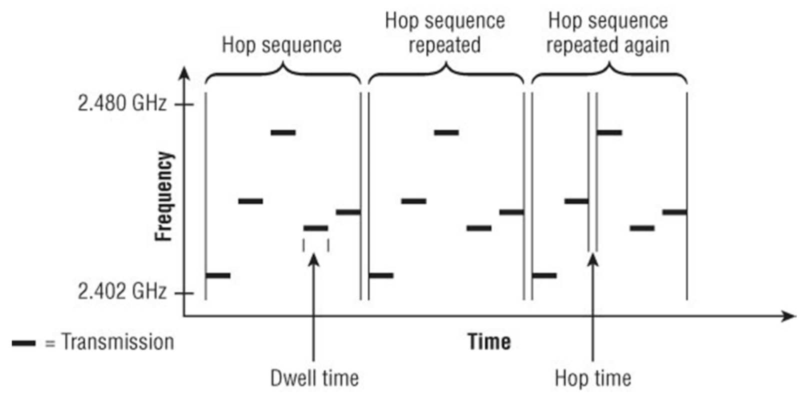
## FHSS Components



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## Direct Sequence Spread Spectrum

- Defined in the original 802.11 standard in clause 15
- 2.4 GHz ISM band
- High-Rate DSSS (HR-DSSS) was specified in the 802.11b amendment
- DSSS provided 1 and 2 Mbps
- HR-DSSS added 5.5 and 11 Mbps

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## Direct Sequence Spread Spectrum (continued)

- Added additional, redundant information to the data, known as *processing gain*
- Processing gain made signal more resistant to data corruption
- A bit of data is converted into a series of chips
  - Binary 1 = 1 0 1 1 0 1 1 1 0 0 0 chips
  - Binary 0 = 0 1 0 0 1 0 0 0 1 1 1 chips
- The chips are then spread across a wider frequency space – 22 MHz
- Known as *spreading* or *chipping*



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## Direct Sequence Spread Spectrum (continued)

- 802.11 used 11-chip *Barker code*
- HR-DSSS used faster more complex code, *Complementary Code Keying (CCK)*
- CCK uses 8-chip code
- Barker encodes 1 bit with 11 chips
- CCK can encode 8 bits using 8 chips

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## Direct Sequence Spread Spectrum (continued)

- Signal is modulated using one of two methods
- Differential binary phase shift keying (DBPSK) which utilizes two phase shifts, each representing either a 0 chip or a 1 chip
- Differential quadrature phase shift keying (DQPSK) utilizes four phase shifts, doubling the speed



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## Direct Sequence Spread Spectrum (continued)

| | Data Rate (Mbps) | Encoding | Chip length | Bits encoded | Modulation |
|---|---|---|---|---|---|
| DSSS | 1 | Barker | 11 | 1 | DBPSK |
| DSSS | 2 | Barker | 11 | 1 | DQPSK |
| HR-DSSS | 5.5 | CCK | 8 | 4 | DQPSD |
| HR-DSSS | 11 | CCK | 8 | 8 | DQPSK |

## Packet Binary Convolutional Code (PBCC)

- Defined in the 802.11b amendment
- Optional modulation technique
- Supports 5.5, 11, 22, and 33 Mbps
- Both the transmitter and receiver must support PBCC
- Implemented in the SOHO marketplace for a short time prior to ratification of 802.11g
- Rarely deployed in an enterprise environment





## Orthogonal Frequency Division Multiplexing (OFDM)

- Originally defined in the 802.11a amendment
- Used in 802.11a, 802.11g, and now 802.11n
- Technically not a spread spectrum technology
- Transmits across 52 subcarriers
- Each subcarrier is 312.5 KHz wide
- 48 subcarriers are used to transmit data
- Remaining 4 are know as pilot carriers – used as references for phase and amplitude by the demodulator to compensate for distortion

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## Orthogonal Frequency Division Multiplexing (OFDM) (continued)

- Convolutional coding – a form of error correction. It is a forward error correction (FEC) that allows the receiver to detect and repair corrupted bits
- The are many levels of convolutional coding
- Modulation uses binary phase shift keying (BPSK) and quadrature phase shift keying (QPSK) for the lower data rates
- The higher data rates use 16-QAM and 64-QAM (quadrature amplitude modulation)



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## 802.11a and 802.11g Data Rate and Modulation

| Data Rates (Mbps) | Modulation method | Coded bits per subcarrier | Data bits per OFDM symbol | Coded bits per OFDM symbol | Coding rate (data bits/ coded bits) |
|---|---|---|---|---|---|
| 6 | BPSK | 1 | 24 | 48 | 1 / 2 |
| 9 | BPSK | 1 | 36 | 48 | 3 / 4 |
| 12 | QPSK | 2 | 48 | 96 | 1 / 2 |
| 18 | QPSK | 2 | 72 | 96 | 3 / 4 |
| 24 | 16-QAM | 4 | 96 | 192 | 1 / 2 |
| 36 | 16-QAM | 4 | 144 | 192 | 3 / 4 |
| 48 | 64-QAM | 6 | 192 | 288 | 2 / 3 |
| 54 | 64-QAM | 6 | 216 | 288 | 3 / 4 |

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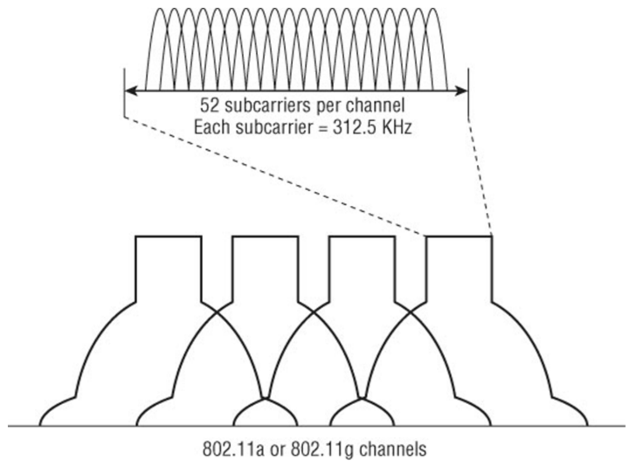
## 802.11 Channels and OFDM Subcarriers



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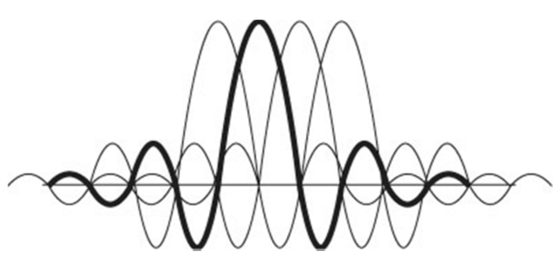
## 802.11 OFDM Subcarrier Signal Overlay

- The frequency of the subcarriers was carefully chosen so that the harmonics overlap and provide cancellation of most of the unwanted signals



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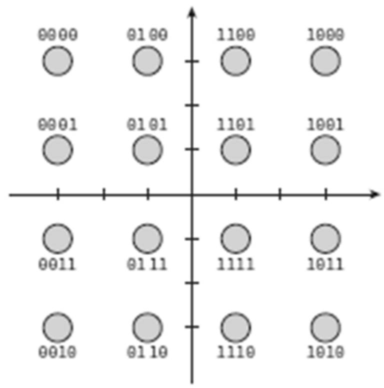
# 16 QAM constellation diagram



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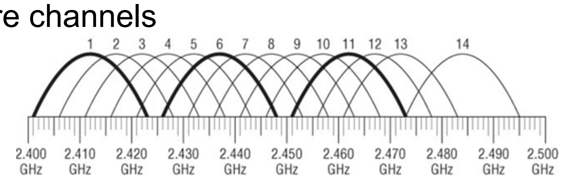
# 2.4 GHz Channels

- Divided into 14 channels by 802.11-2007 standard
- Local regulatory domains define allowed channels
- Each channel is 22 MHz
- Channel is reference by the center frequency (eg. Channel 1 = 2.412 GHz
- Distance between neighbor channels is 5 MHz
- Channels will not overlap if they are separated by 5 or more channels



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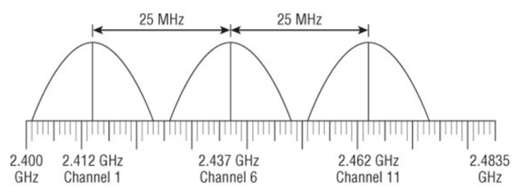
## 2.4 GHz Channels (continued)

- Some regulatory domains allow 11 channels (U.S.), while other allow more (European countries generally allow 13 channels)
- In an 11 channel environment, channel 1, 6, and 11 is the only three channel plan that does not overlap
- Channels need a minimum of 25 MHz separation between center frequencies to be nonoverlapping



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## 2.4 GHz Channels (continued)

| Channel ID | Center frequency (GHz) | US (FCC) | Canada (IC) | Many European countries |
|---|---|---|---|---|
| 1 | 2.412 | X | X | X |
| 2 | 2.417 | X | X | X |
| 3 | 2.422 | X | X | X |
| 4 | 2.427 | X | X | X |
| 5 | 2.432 | X | X | X |
| 6 | 2.437 | X | X | X |
| 7 | 2.442 | X | X | X |
| 8 | 2.447 | X | X | X |
| 9 | 2.452 | X | X | X |
| 10 | 2.457 | X | X | X |
| 11 | 2.462 | X | X | X |
| 12 | 2.467 | | | X |
| 13 | 2.472 | | | X |
| 14 | 2.484 | | | |

X = supported channel

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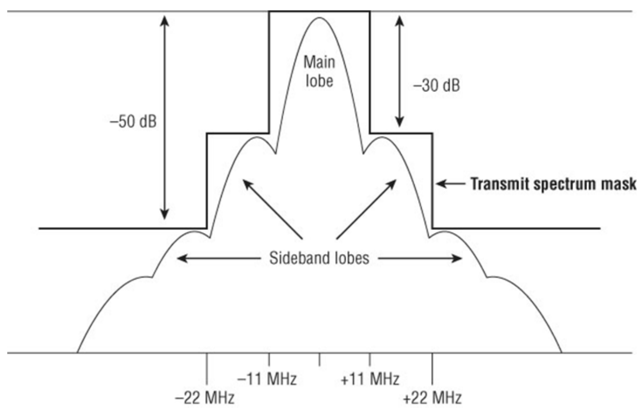
## IEEE 802.11b Transmit Spectrum Mask



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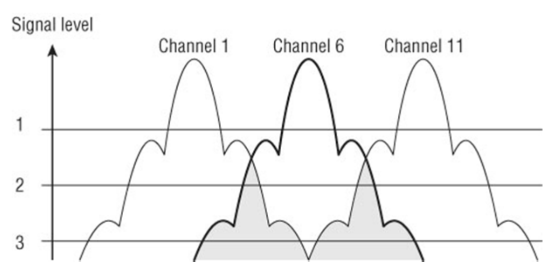
## Sideband Carrier Frequency Interference

- Sideband frequencies can cause interference
- Devices on different channels can cause interference if they are too close to each other



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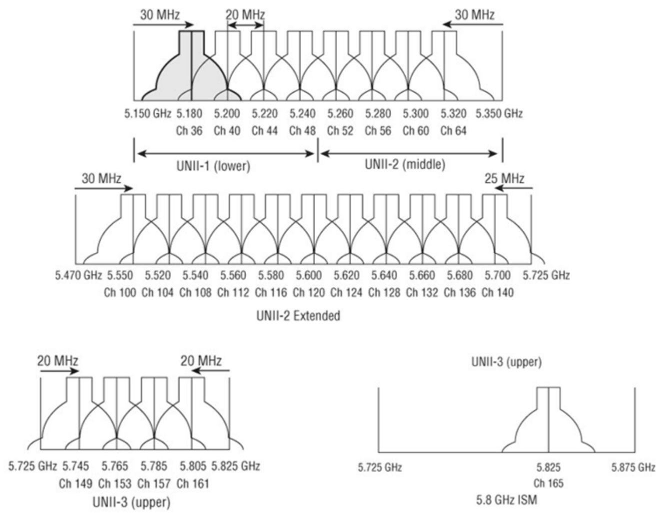
# 5 GHz Channels



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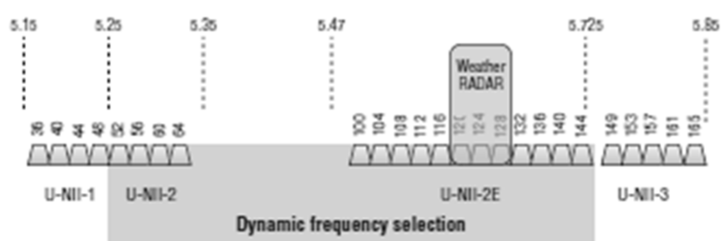
# U-NII channel overview

- As of April 2014, DFS rules for radar detection and avoidance have changed and the frequency band used for weather radar is now available for Wi-Fi radios.



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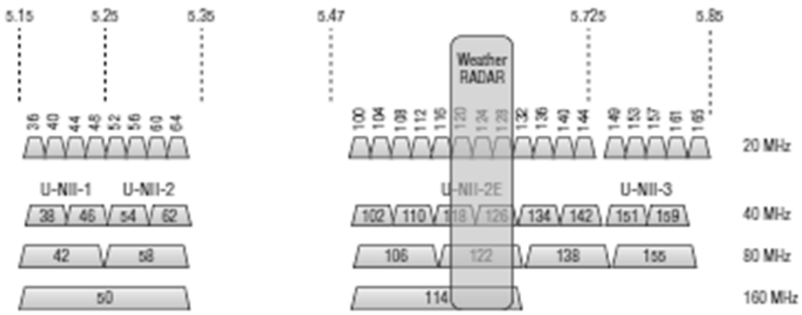
## U-NII 40 MHz, 80 MHz and 160 MHz channel overview



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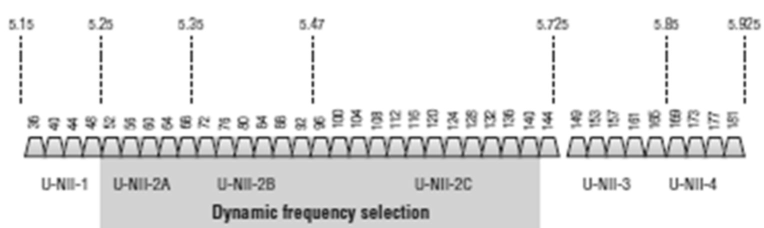
## Potential U-NII-1 through U-NII-4 20 MHz channels

- Should all these proposals be implemented and all the 5 GHz spectrum space be made available, there would be as many as thirty-seven 20 MHz channels that could be used by Wi-Fi radios



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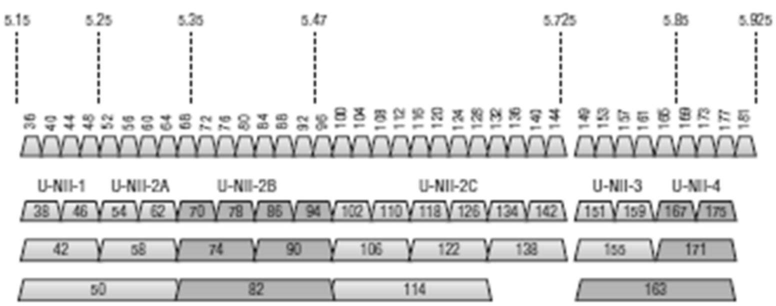
# Potential 40 MHz, 80 MHz, and 160 MHz channels

- If all the U-NII-1 through U-NII-4 spectrum is indeed made available, channel reuse patterns using larger channels can become a reality.



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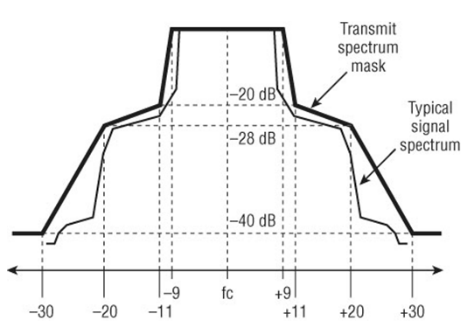
# 5.0 GHz Channels

- IEEE does not specifically define a channel width
- Spectral mask of OFDM channel is 20 MHz wide
- 23 UNII channels and 1 ISM channel



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## Adjacent and Overlapping Channels

| | DSSS (802.11) | HR-DSSS (802.11b) | ERP (802.11g) | OFDM (802.11a) |
|---|---|---|---|---|
| Frequency | 2.4 GHz | 2.4 GHz | 2.4 GHz | 5 GHz |
| Band | ISM | ISM | ISM | UNII |
| Adjacent | ≥ 30 MHz | ≥ 25 MHz | = 25 MHz | = 20 MHz |
| Overlapping | < 30 MHz | < 25 MHz | < 25 MHz | N/A |



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## Throughput vs. Bandwidth

- Data rates, also known as data bandwidth
- Due to half-duplex nature of 802.11, actual throughput it typically 50% or less of the data rate
- 54 Mbps link will have about 20 Mbps aggregate throughput
- Since 802.11 is a shared medium, 5 people using this AP will each experience about 4 Mbps throughput

## Communication Resilience

- Spread spectrum spreads the data across a range of frequencies
- This spreading makes it less susceptible to narrowband interference
- FHSS is more resilient than OFDM
- OFDM is more resilient than DSSS





## Chapter 6 Summary

- ISM and UNII Bands
  - ISM 902–928 MHz - Industrial
  - ISM 2.4000–2.5 GHz - Scientific
  - ISM 5.725–5.875 GHz - Medical
  - UNII-1 5.150–5.250 GHz - lower UNII
  - UNII-2 5.250–5.350 GHz - middle UNII (proposed as U-NII 2A)
  - UNII-2 Extended 5.470–5.725 GHz - Extended UNII ( proposed as u-NII 2C)
  - UNII-3 5.725–5.825 GHz - upper UNIi

## Chapter 6 Summary

- ISM and UNII Bands
  - U-NII-3 5.725 – 5.85 GHz—upper
  - Proposed U-NII-2B 5.35 – 5.47 GHz
  - Proposed U-NII-4 5.85 – 5.925 GHz





## Chapter 6 Summary (continued)

- Other bands
  - 4.94 – 4.99 GHz – US Public
  - 4.9 – 5.091 GHz – Japan
  - 60 GHz
  - < 1 GHz – White-Fi
- Spread Spectrum Technology
  - FHSS
  - Dwell Time
  - Hop Time
  - DSSS