Wi-Fi For Beginners Module 4

More RF

(Slide deck v4)

Introduction

Hello, my name's Nigel Bowden. Welcome to module 4 of the Wi-Fi for beginners podcast. This is a series of podcasts discussing the fundamentals of wireless LAN networking.

In each episode, we'll take a look at a different aspect of Wi-Fi to build your understanding and knowledge of wireless LAN networks.

Each episode is be accompanied by a set of slides describing the topics covered in that episode. Although you don't need to review these slides whilst listening to the podcast, they will be useful for reviewing the material we discuss and may provide some visual aids to more fully understand some of the concepts and equipment described.

All recordings and supporting material can be found at WiFiForBeginners.com

Aims of Podcast Series

- Present the fundamentals of Wi-Fi in a series of audio presentations
  - Hopefully in an easy-to-understand format
  - Useful to those on a daily commute, driving, running etc.
- Who is it aimed at?
  - Most likely IT professionals, students, people interested in career move
- Assumed knowledge:
  - Fundamentals of the 7 layer OSI model
  - Ethernet, switching and routing
  - IP addressing
  - Local Area Networks (LAN)
  - You have reviewed previous episodes! :)
- Wi-Fi in commercial/professional environment - not home

Who Am I?

- Nigel Bowden
- UK Based
- IT Industry for 30+ years
- Specializing in Wireless LANs for 5+ years
- Industry certifications:
  - CWNP: Certified Wireless Network Expert (CWNE #135)
  - Cisco CCNP R&S
  - Cisco CCNP Wireless
  - Miscellaneous other vendor specific certs
- Roles: Design, Consultancy & Deployment of WLANs (mainly Cisco)
- Prolific social media participant:
  - @WiFiNigel (Twitter)
  - WiFiNigel.blogspot.com (Blog)

In This Module

- Review
- RF System Basics
- CSMA/CA
- Concepts: Channels
- Wi-Fi Bands
- Unlicensed Spectrum

Review

- Quick review from Module 2:
  - AC/RF
    - cycling electric current - back and forth
    - one cycle per second: 1Hz
    - number of cycles per second is known as the “frequency”
    - electric & magnetic field created around wire - electromagnetic field
    - if frequency high enough, electromagnetic field can be detected at distance from the wire - RF transmission

Review

- Quick review from Episode 2:
  - Frequency measured in Hz
    - multipliers:
      - x 1,000 = KiloHertz (KHz)
      - x 1,000,000 = MegaHertz (MHz)
      - x 1,000,000,000 = GigaHertz (GHz)
  - Different bands based on frequency, with different characteristics:
    - Low Frequency
    - Medium Frequency
    - High Frequency
    - Very High Frequency
    - Ultra High Frequency
    - Super High Frequency

Review

- Quick review from Episode 2:
  - Frequency Characteristics:
    - In general terms, as frequency gets higher, distance propagated reduces and ability to pass through obstructions reduces (becomes more and more like light)
  - Light analogy for RF:
    - Very useful to think about an RF source (i.e. an AP) as a light source
      - ability to cover area dependant on how well it can be “seen”
      - also depends on obstructions
  - Free space loss:
    - RF signals levels naturally reduce over distance as they move through “space” (not outer space - through the air)

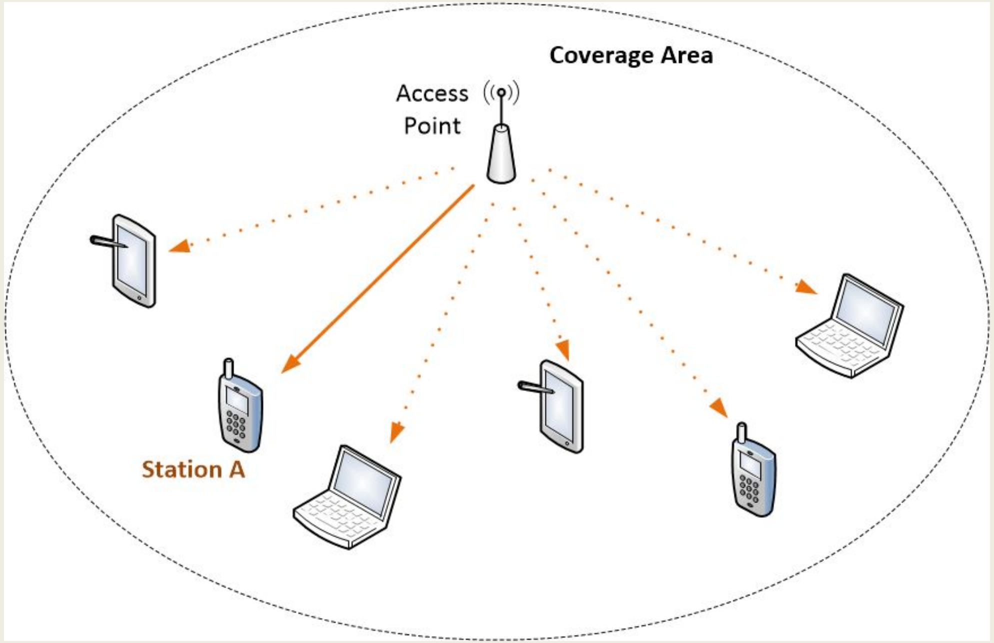
RF System Basics

- Need to look at the basics of a wireless system to understand some of the limitations we hit in Wi-Fi networks
- Two entities in an RF system:
  - Transmitter - station sending a signal
  - Receiver - one or more stations receiving that signal
  - “station”: any device accessing the RF medium
    - may be an AP or client on WLAN
- Basic system:
  - two stations can only hear each other if they are on the same frequency
    - if they are listening or transmitting on different frequencies, won’t hear each other
  -

RF System Basics

- Basic system:
  - one station will transmit information on the frequency they are using, the other station will receive the information
    - one station is using its radio as a transmitter, the other as a receiver
    - whilst one station is transmitting, the other station has to listen - cannot also transmit on same frequency - half duplex
  - In the coverage area of the station that is transmitting, the signal can also be heard by all other stations on the same frequency
    - they can hear the transmission of the station
    - they cannot transmit whilst the frequency is in use

RF System Basics



- Access point sends data to 'Station A'
- All other stations on same channel in coverage area also hear transmission

RF System Basics

- Basic system:
  - Only once transmitting station has finished transmitting can another start use the frequency, which is now free
  - Good analogy: walkie-talkie press to talk system
    - in building with walkie talkie system, all on same channel and only one can talk at any time. All other stations hear transmitting station
  - For radio systems where stations use the same frequency, it is inherently half duplex - only one station “talks” at a time
  - If two stations do transmit at the same time, all receivers in that area may receive both signals and end up with garbled/corrupted information
    - “co-channel interference” - very important concept in WLANs

CSMA/CA

- In Ethernet systems, we have concept of CSMA/CD
  - carrier sense, multiple access with collision detection
  - Listen on the wire, if no-one transmitting then send data (Carrier Sense)
  - Multiple stations on the same piece of wire can access the same media (wire) - in the old days! (Multiple Access)
  - As start sending data listen on the wire to see if there has been a collision (voltage spike) and stop if collision detected (Collision Detection)
- From our study of the basics of RF systems, we know that only one station in a wireless station can use a channel at any time.
  - Therefore wireless stations listen before they transmit to see if the medium (RF channel) is available (Carrier Sense)

CSMA/CA

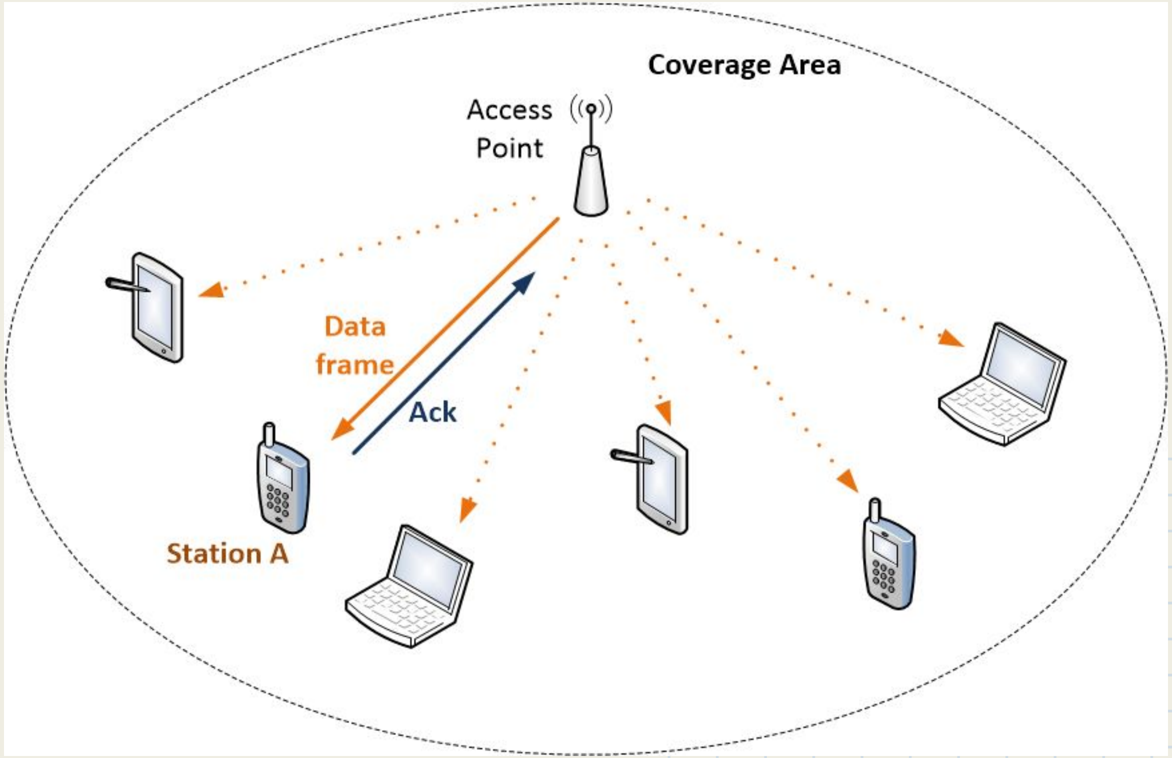
- Multiple stations in a wireless system can use the same channel (as long as they play nicely) - Multiple Access
- ...so far, same as Ethernet - CSMA
- However, radio system can only transmit <u>or</u> receive
  - Can't listen as they transmit to detect collisions
- Therefore, they use "Collision Avoidance" rather than "Collision Detection"
- CSMA/CA for Wi-Fi networks
- Try to avoid collisions by listening to the RF channel and then when have data to send, choosing a random number that acts as countdown timer
  - hopefully all stations who need to transmit have chosen different random numbers and only one station gets to zero and sends its frame

CSMA/CA

- As we can’t detect collisions, still need a mechanism to detect if sent frame was successful (e.g. did the frame sent from the iPad to an AP get there?)
- Wi-Fi networks require sent frame to be acknowledged
- APs and clients all have equal access, no priority for the AP even though all client communication via the AP
- This again adds <u>another</u> overhead to Wi-Fi compared to Ethernet
    - Overheads recap:
        - All transmissions half-duplex
        - Only one station at a time may transmit over the shared medium (RF channel)
        - Frames (Layer 2) sent need to be explicitly acknowledged by the receiving station

CSMA/CA

- No collision detection mechanism
- Frames need to be ‘ack’ed by receiving station



RF Contended Medium

- Re-cap:
  - Only one device on a channel may transmit at any time
  - If device (station) has frame to send:
    - checks if RF medium free
    - chooses random number countdown to try to avoid collisions
    - sends frame
    - awaits acknowledgment
- The RF channel is a contended medium
  - Each station must wait for its turn to use the channel
  - Only one station may “talk” at a time

RF Contended Medium

- All stations on a channel must share the available bandwidth provided by a channel
  - contended medium like old Ethernet hubs
  - contrast to Ethernet switch port where station may transmit/receive at any time
- For example, wireless client may connect at 450mbps, but will be shared with other client on an AP cell, not dedicated 450mbps
  - Also half duplex link, so generally around half of connection speed
- Significant different between switched Ethernet networks and RF WLANs
  - Ethernet stations have dedicated access & bandwidth
  - WLAN stations share access and bandwidth
- On busy WLAN, station may have significantly lower bandwidth compared to Ethernet network

Channels

- Radio systems do not operate on a single frequency
  - e.g. a frequency used by Wi-Fi in the 2.4GHz band is 2.412 GHz
    - this is the “centre frequency”
- In order to convey information through “modulation” need to use a range of frequencies either side of this “centre” frequency
- Previously mentioned modulation: simple modulation using two frequencies to represent one and zero - would need to be above and below this centre frequency, so we’re using more than just the centre freq
  - modulation more complex than this, but provides useful concept of why multiple freqs required
- The range of frequencies we need to use is called a “channel”. It usually has a lower and upper frequency which provides enough “channel width” for us to convey our information using that frequency

Channels

- Example:
  - channel one of 2.4GHz band: 2.401 - 2.423 GHz for WLANs
    - 22 MHz channel width used
    - centre frequency 2.412GHz
- Key takeaway: channel is small chunk of frequencies that we need to be able to convey information - single frequency not enough
- The chunk of frequencies we need is the “channel width”
  - as channel width increases, data rate/bandwidth of the channel generally increases
- In Wi-Fi, basic channel width is around 20 MHz, but these channels may be bonded in some 802.11 amendments (802.11n/ac) into wider 40MHz, 80MHz and 160MHz channels

Wi-Fi Bands

- Two main bands used for Wi-Fi networks:
  - 2.4GHz
  - 5GHz
- These bands are available for use in many parts of the world, but the number of channels available in each country may vary, depending on regional and national restrictions
  - some channels may already be in use by another service, so not available in some countries
    - licensed services
    - e.g. military, radar, weather systems
  - example
    - in UK, 13 channels available on 2.4GHz band (1 - 13)
    - in USA 11 channels available on 2.4GHz band (1 - 11)

Wi-Fi Bands

- 2.4GHz band often referred to as ISM band in WLAN textbooks
  - USA-specific reference (Industrial, Scientific & Medical radio band)
- 5GHz band often referred to as UNII band in WLAN textbooks
  - USA-specific reference (Unlicensed National Information Infrastructure radio band)
- 2.4GHz band usually around 11 to 13 channels
  - channel numbers 1,2,3,4,5….13
  - each channel only 5MHz of separation
  - need at least 20MHz for WLAN traffic
  - cannot use adjacent channels (e.g. 1 & 2) as too close together
  - need to use “non-overlapping” channels: 1, 6, 11
  - other channels used in same area generally cause “adjacent channel interference” (ACI)

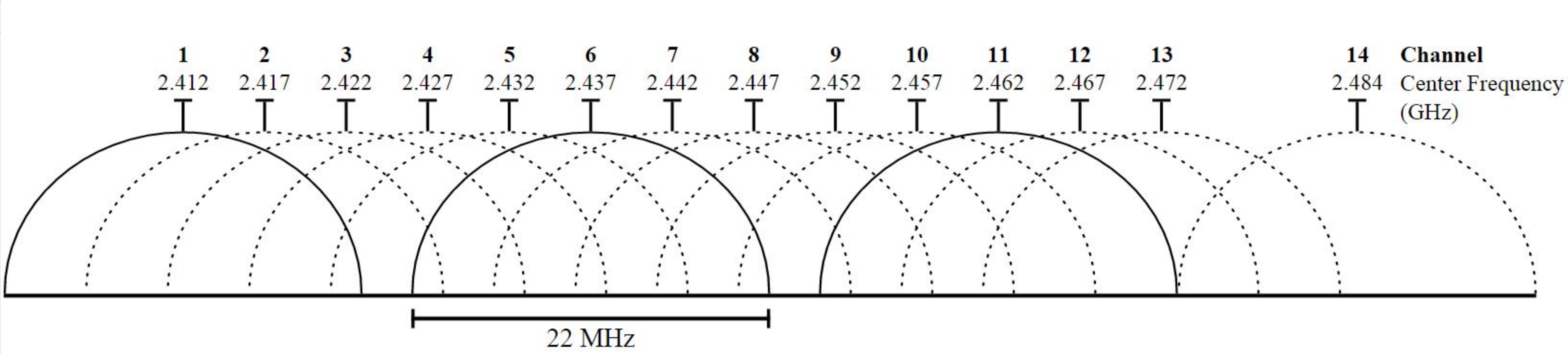
Wi-Fi Bands

- Regulatory bodies:
  - Global: ITU - International Telecommunications Union
    - Global management of RF spectrum (inc. WLAN bands)
      - Globe broken down into 3 regulatory regions:
        - Region 1 - Europe, Middle East & Africa
        - Region 2 - Americas
        - Region 3 - Asia & Oceania
      - Global treaties determine spectrum use in regions
  - In each region, country level RF regulatory bodies manage RF spectrum:
    - FCC (Federal Communications Commision) - USA
    - ARIB (Association of Radio Industries & Business) - Japan

Wi-Fi Bands

- In each region, country level RF regulatory bodies manage RF spectrum:
  - Ministry of Economic Development - New Zealand
  - ETSI/OFCOM - UK
- Important to know the regulations for <u>your</u> country
  - ensure equipment using correct channels, transmit powers, indoor/outdoor use & coexistence regulations
- Part of configuration of WLAN equipment (e.g. controllers and APs) is regulatory domain & country
    - essential to configure correctly
    - incorrect settings may break local law
    - incorrect settings may mean that clients cannot see some of your APs!

Wi-Fi Bands - 2.4GHz



2.4GHz Band Channels

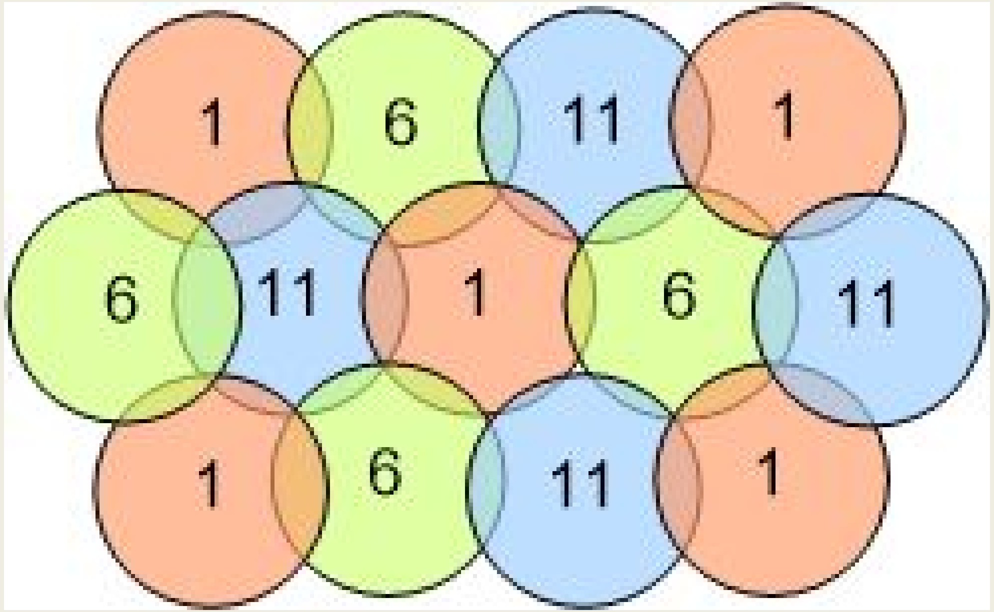
Wi-Fi Bands - 2.4GHz

- 2.4GHz band most heavily used (until recently), as was first to undergo mass adoption due to low-cost components
- Still heavily used today, with many lower-cost devices still only able to use 2.4GHz band
    - IoT devices using 2.4Ghz
- Additional issue with 2.4GHz band is that although there are up to 13 channels available, due to the channel spacing (5MHz), Wi-Fi communications requires that we span multiple channels
    - Generally have to use channels 1, 6 & 11 - only 3 usable channels
- With only 3 usable channels, difficult to have many APs in vicinity of each other and for them to remain isolated
    - co-channel interference is a big issue that affects performance badly

Wi-Fi Bands - 2.4GHz

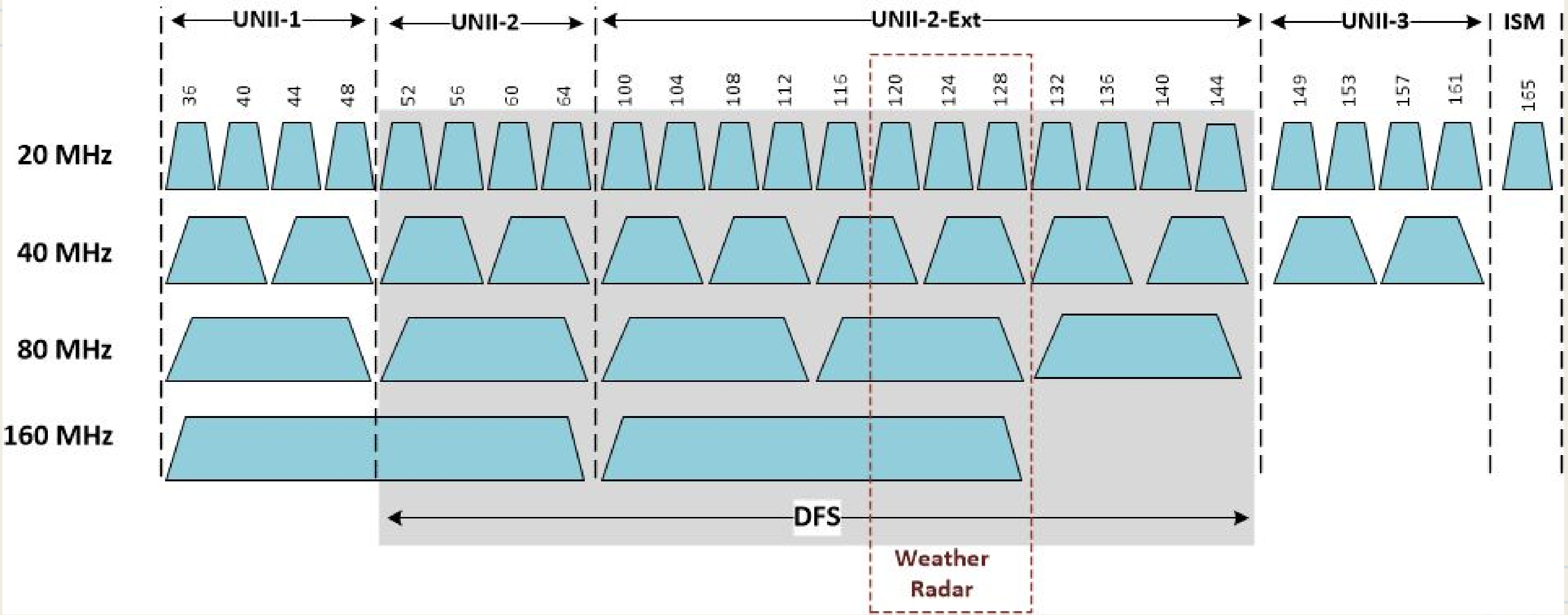
- 2.4GHz band usually around 11 to 13 channels
  - channel numbers 1,2,3,4,5….13
  - each channel only 5MHz wide
  - need at least 20MHz for WLAN traffic
  - cannot use adjacent channels (e.g. 1 & 2) as too close together
  - need to use “non-overlapping” channels: 1, 6, 11
  - other channels used in same area generally caused “adjacent channel interference” (ACI)
  - many other devices and services use 2.4GHz band making it very noisy

Wi-Fi Bands - 2.4GHz



2.4 GHz Channel Plan

Wi-Fi Bands - 5GHz



5GHz Band Channels (North America)

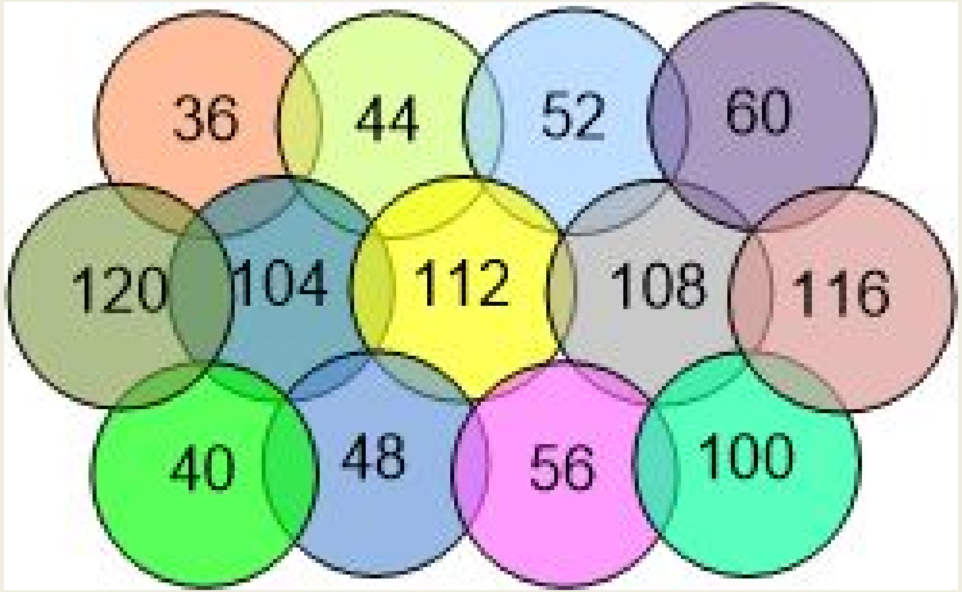
Wi-Fi Bands - 5GHz

- 5GHz band growing significantly in popularity as provides better performance and capacity
- We may have around 20 channels on the 5GHz band
  - compared to 11-13 on 2.4GHz), but we can use them all, not just 3!
  - each channel width in band is 20 MHz, so can use adjacent channels
  - channels number 36, 40, 44, 48… etc.
- More 5GHz channels means we can deploy many APs around a building, on different channels which do not interfere/contend with each other
  - less co-channel interference, better performance
- Always use 5GHz in preference to the 2.4GHz band for mission critical applications

Wi-Fi Bands - 5GHz

- Although 2.4GHz and 5GHz bands in similar area of spectrum, slightly different characteristics
  - remember, as frequency increases, more characteristics of light
- 5GHz less likely to get through obstructions than 2.4GHz
  - suffers higher attenuation
- Even in open space, 5GHz doesn't have the same coverage as 2.4GHz
  - 2.4GHz can cover up to twice the distance for the same power under ideal conditions (which is rare)
- Sounds like a disadvantage, but in modern Wi-Fi networks is a huge advantage
  - smaller distances and more containment by obstructions means less interference between neighbouring networks and other APs on same channel in a network

Wi-Fi Bands - 5GHz



5 GHz Channel Plan

Unlicensed Spectrum

- One important fact about the bands used by Wi-Fi is that they are “unlicensed spectrum”
- What does this mean?
  - Much of RF spectrum is “licensed”
    - need a permit or license to use
    - commercial radio (AM stations, FM stations, emergency services, cellular providers)
    - ensures tight control and lack of interference to other services
  - unlicensed spectrum means anyone (and everyone) can use the allocated frequencies, within certain restrictions (power settings etc.)
  - this is why Wi-Fi bands so popular
    - easy to use, easy to deploy, commoditized, mass market

Unlicensed Spectrum

- BUT - comes at a price…
- Due to lack of barriers to use, likely to suffer with Interferers on same band and channel
  - neighbouring networks (same channels)
  - other services and devices that use the band:
    - bluetooth devices, baby monitors, microwave ovens, security cameras, (LTE on 5GHz?) etc.
- 2.4GHz band has become so popular with Wi-Fi devices and non-Wi-Fi devices, starting to be called: “junk band”
  - not often a good choice when need performance in professional environments
    - limited channels
    - many interferers

RF Design

- Importance of good RF design cannot be stressed enough
- 802.11 operates at layer 1 & 2
- Layer 1 (physical - i.e. RF) relies on good RF design principles
  - need to understand RF behaviour:
    - propagation
    - interference
    - power levels
    - antenna choice
    - band choice
  - your country restrictions
- Imagine Ethernet running errors constantly due to poor cabling, other stations or interference..?

RF Design

- WLAN performance will always be poor without proper RF design
  - poor physical design = poor network design
  - no other features provided by WLAN equipment can mitigate or rescue a WLAN that has a poor RF design
- Some systems have ‘auto-RF’ systems to ‘tune’ the RF environment
  - typically change RF power & channel settings
  - these are still constrained by the environment they are deployed into and how the RF equipment has been deployed
  - DO NOT RELY ON AUTO-RF TO FIX POOR RF DESIGN - IT CAN’T!
- RF theory and design is THE study area that will differentiate you from other ‘wireless’ engineers

Summary

- Review
  - Frequency, EMF, RF Transmission
  - Frequency multipliers, Frequency bands (UHF, SHF etc.)
  - Light analogy & Free space loss
- RF System Basics
  - Transmitter & receiver on same freq
  - Half duplex, heard by all stations in coverage area
  - Walkie talkie analogy
  - Co-channel interference
- CSMA/CA
  - In WLAN, no collision detection
  - Avoid collisions with carrier sense & random countdown
  - Each frame ack'ed as transmitter cannot detect collision

Summary

- RF Contention
  - WLAN is contended medium
  - Stations share limited airtime
  - More stations, less bandwidth per station
- Concept: Channels
  - Cannot use single freq to convey data
  - Small range of freqs used to enable modulation and convey data
  - Lower to upper freq called channel - often 20MHz for WLANs
- Wi-Fi Bands
  - 2.4GHz and 5GHz bands used across globe
  - Specific details of use vary across globe (channels, power settings etc.)

Summary

- Wi-Fi Bands
  - ITU manage global spectrum with enforcement by regulatory bodies per country
  - 2.4GHz heavily used, only 3 usable channels, poor co-channel interference (CCI), high noise floor
  - 5GHz generally has far more usable channels, low CCI, better propagation for high density environments
- Unlicensed Spectrum
  - licensed spectrum subject to tight controls, limited services
  - unlicensed spectrum subject to interference from other networks, devices, services, but allows low-cost, rapid deployment
- RF Design
  - Bad RF design = bad WLAN performance