Wi-Fi In-Sights

Objectives of this Presentation

- Discuss the history of Ethernet
- Discuss wireline service level expectations
- Discuss the move from wireline to wireless
- Discuss wireless service level expectations
- Discuss RF coverage issues
- Discuss the different antenna / AP deployment models
- Discuss current technology best practices

Historical Perspective

CSMA / CD / CA Operations

- Originally intended for single shared medium (Coax Cable)
- Don’t talk if some else is talking (Carrier Sense)
- No central authority – anyone can talk (Multiple Access)
- Collision Detect and Collision Avoidance Mechanisms

Wireless Contention Mechanisms

- Super Frame Time Interval
- PCF – Point Coordination Function Time Period
  - Contention Free
  - Central Authority (Point Coordination)
  - controlled for a limited time
  - priority over DCF
- DCF – Distributed Coordination Function
  - Self policing (Distributed Coordination)
- Once active - data can span multiple frames
- Wi-FI Consortium does NOT verify PCF, only DCF

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Extending the LAN

- Repeaters (extend the wire – no delay)
  - longer wire, more chances for collision
- Bridges (extend the wire - store & forward)
  - reduces collisions between segments

Repeaters vs. bridges

- Repeaters – extend the collision domain
- Bridges – truncate the collision domain

Collisions vs. bandwidth

- Repeaters – one collision domain – bandwidth is function of number of stations on entire domain
- Bridges – multiple collision domains – bandwidth is a function of number of stations in any one segment

Half vs. Full Duplex

- Half-duplex – one lane shared road
- Ethernet coax / wireless media
- Full-duplex – two way separate lanes
- RJ-45 two-pair media – potential only

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The Wireline Switch Solution

- Hubs - RJ-45 media
- multi-point repeater
- extend the collision domain
- half-duplex only

- Switches – RJ-45 media
- multi-point bridges
- terminate the collision domain
- full-duplex possible

Privacy

- Hubs / Multi-point repeaters
  - none – shared medium
- Switches / multi-point bridges
  - privacy between any two stations

Bandwidth

- Hubs / multi-point repeaters
- 40% of base rate / number of stations

- Switches / multi-point bridges
- potentially 100% each way full duplex for each station

- 100 Mb – 100 stations Example;
- Hub – 400K / station
- Switch – 100 Mb per station – full duplex – 200 Mb equivalent
- In this example – switch provides up to 20 Gb of throughput, while hub only provides 400K
- Increasing base bandwidth does not change the ratio – rather possibly makes it worse due to increased contention to payload times

VLANs as broadcast domain limits

- Broadcast mechanism used for many functions
- Must be constrained to keep traffic loads reasonable
  - DHCP
  - ARP
  - proxy and gateway discovery
  - etc

Broadcast vs. Collision Domain

- Collision domain constrained by switch, not by hub
- Broadcast domain propagated by switch and by hub
  - required or many mechanisms fail
- Broadcasts may be detrimental
  - storms & unnecessary interruptions
  - privacy / discovery issues

VLANs as Broadcast Limiters

- Primary purpose of a VLAN
  - to limit the broadcast domain
- Routers required between VLANs
  - results in traffic segmentation (inside the switch – note for later wireless issue)

VLAN tagging

- Internal to Switch
- External to Switch – 802.1q trunks

End to End VLANs

- Simple
- Trunk Intensive (broadcast / multicast)
- Spanning Tree intensive

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Local VLANs

- Complex
- Limited to one (or very few switches)
- Spanning Tree simplified
- Introduces issues with L3

L3/L4 requirements for a switched LAN

- Highly segmented L2 network is good for L2 increases available bandwidth through fewer collisions and broadcasts
- Imposes much greater burden on L3 device
- Complicates L4 tests such as;
  - access-lists
  - traffic by application (port number)

MLS – Multi-Layer Switching

- Route / Test once
- Switch Many
- Header replacement

L4 Security with MLS

- Similar to L3 function
- Test Once – switch thereafter
- Track flows at detailed level – memory requirements could be high
- If change made to L4 test – must invalidate cache

Summary of the Historical Perspective

- Ethernet evolved from Aloha network
- may have been suitable for wireless, but
- highly evolved via switches for wireline
- MLS further optimizes the wireline solution
- switch models have no direct wireless equivalence for high density applications

Service Levels in a LAN

Traffic Types & Issues

- Time sensitive traffic
  - voice & video examples
  - voice – steady, low volume, long duration
  - not re-send able
- Best effort traffic
  - TCP/IP data
  - re-send able, bursty

Time Sensitive

- Voice and Video – major examples
  - Uses UDP mechanisms – not a “reliable” transport
  - Sequenced – but not resent
  - Loss or delay renders packets worthless
  - msec or worse sensitivity
    - loss, delay, jitter, seq

Best Effort Traffic

- General Data
  - Little to no timing sensitivity
  - TCP mechanisms – reliable transport
  - simple priority mechanisms for traffic classes when required
  - resent if lost
  - re-sequenced if out of order

Dealing with Loss

- Wireline has become hyper-reliable
- MTU and Window sizes maximize transmission
  - (longer runs between ack)
- Loss potential maximal at queue points
  - lack of buffer space

Traffic type Loss Issues

- Presumption of infrequent loss
- Real time – sophisticated DSP's interpolate frames in delay line
- Non-Real time – retransmits
- Presumption fails for wireless

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Prioritization at Queue Points

- Takes place at Serialization buffers in devices
- Place loss sensitive traffic first in queue
- Never drop real-time traffic
- Drop other traffic
- If infrequent, while done at expense of other traffic – losses are acceptable

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Sources of Delay

Fixed Delay

- Propagation
- Coder
- Serialization
- Initial Spanning Tree

Variable Delay

- Queuing
- Network congestion
- De-jitter buffers

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Fixed Delay Solutions

- Shorter segment lengths
- Smaller coder sample size
- Faster / higher frequency transmitters
- Optimized Spanning Tree – don't let it out of the box

Variable Delay Solutions

- Prioritization at queue points
- Uniform packet sizes (MTU, frame, cell)
- Faster L3 decision mechanisms
- Faster L3 forwarding mechanisms
- Adaptive de-jitter buffers

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Jitter Defined

- Variations in delay
- Wreaks havoc on end-users
- At worst becomes complete drop-out – equivalent to loss

Dealing with Jitter

- Use small uniform frame sizes
- If possible, reduce mix of real-time with other traffic types
- If not, allow for efficient interleave of real-time traffic with other traffic

Bandwidth Reservation

- Reservation protects from over-subscription
  - Protects traffic classes from each other
  - Protects traffic in any one class from itself

Bandwidth Reservation

- RSVP – requires active participation of every member of network
- Gatekeeper – simplified - general rules – one authority

Available QoS Mechanisms

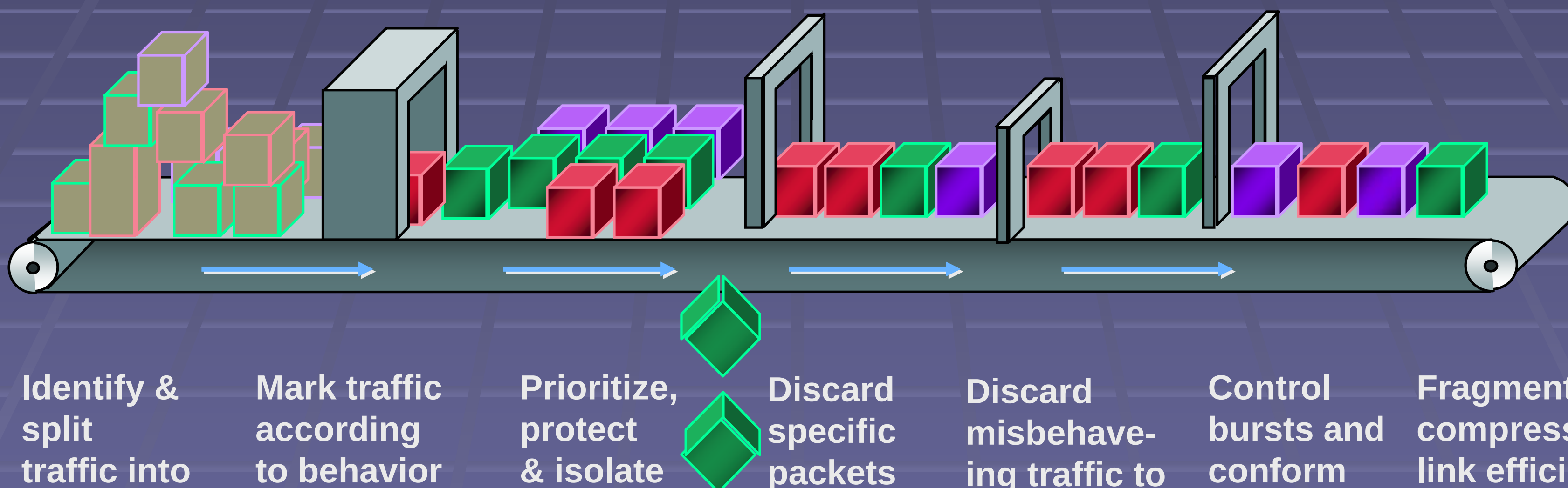
Signaling, Provisioning, & Classification

Congestion Management

Congestion Avoidance

Traffic Conditioning

Link-Efficiency Management



- Identify & split traffic into different classes
- Mark traffic according to behavior and business policies
- Prioritize, protect & isolate traffic based on markings
- Discard specific packets to avoid network conges-tion
- Discard misbehave-ing traffic to maintain network integrity
- Control bursts and conform traffic
- Fragment and compress for link efficiency

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Mixing Traffic Types

- Separate real-time vs. general data traffic
- Use VLANs
- Where merged – prioritize and queue

Summary of Service Level Issues

- All traffic is not the same
  - File transfers are long duration payloads, high bandwidth, uniform bit rate, non-real time
  - Credit card transactions are short and bursty, variable bit rate, low bandwidth, non-real time
  - Voice is long duration, low bandwidth, uniform bit rate, real time
  - Video is long duration, high bandwidth, variable bit rate, real time
  - Other categories possible

- Separate & prioritize the traffic
- set different transport medium characteristics for each traffic type

The Move to Wireless LANs

The move to Wireless

- Wi-Fi – 802.11 (b/g/a)
- Consumer Spec not Industrial
- Intended as a “last hop” extension to LAN
- Not-intended as backbone
- Presumed few users

802.11 b/g radios

- Share unregulated 2.4 GHz freq
- Back off to least common denominator
- One b node spoils the g bunch
- 3 possible “clear” channels
- Interference from
  - microwave ovens
  - bluetooth devices
  - cordless phones

802.11 a radios

- Unregulated 5 Ghz freq
- Almost no interference from other devices (for now)
- 12 “clear” channels

802.11 in Industry

- Issues:
  - Original 802.11 is a frequency hopping specification
  - Limited number of stations
  - Wi-Fi spec does not test PCF function
  - Interference
  - Large area coverage interference even between non-overlapping channels
  - Still suitable for low volume / large area coverage

VLANs within one radio channel

- Compared to wireline switch VLAN;
  - Does not provide broadcast limit
  - No privacy between VLANs
  - Simply marks traffic for wireline upstream

Security Issues

- Current key systems are too simple
- Reuse can occur in as little as a few hours
- Easily sniffed vs. wireline device tap
- Mac address spoofing
- DoS (jamming) easy – but easily located

Wireless Capacity Issues -1

- Wireless shared channel vs. wireline private pipes
- Half duplex by nature vs. full-duplex
- DCF contention assumes everyone “plays nice”
- Signal levels change available bandwidth based on distance of end-point from AP
- Retransmissions or low signal levels for 2.4Ghz radios lower bit rate from 11, to 5.5, 2, or 1 Mb/s – blocks all stations

Wireless Capacity Issues – 2

- For 5Ghz these values are 54, 48, 36, 24, 18, 12, 9, or 6 Mb/s
- Wireline switches essentially non-blocking vs. physical bandwidth limits
- Traffic mix can greatly impact real-time traffic
- Too many planners based on “ideal” conditions which rarely exist

Wireless QoS

- Upstream QoS does not currently exist in DCF
- Downstream QoS exists if the AP is smart enough
- Everyone waits for the busy medium, then SIFS, PIFS, or DIFS time (short, priority, distributed)

Downstream QoS

- AP can be QoS aware
  - Prioritizes traffic
  - Segments large flows
  - Can broadcast Contention Window by COS/TOS for endpoints to use – not required to comply
  - Cisco IP Phones will take advantage of this if enabled on the AP

Upstream QoS

- DCF – non existent – end point can choose to honor the CW parameters sent by AP, but even then a real-time frame might have to wait for other traffic
- PCF – absolute polling at discretion of AP – but PCF time interval limited in duration after each beacon – if DCF overruns- PCF must wait

Summary of the Wi-Fi intro

- Wi-Fi designed for limited end-station consumer use
- Fails in high density applications that require high throughput or real-time traffic
- Treat wireless bandwidth as a scarce resource which can not be remedied by “engineering”

RF Primer

Signal Levels and Throughput

2.4 Ghz adapters	-94 dBm @ 1 Mbps -91 dBm @ 2 Mbps -89 dBm @ 5.5 Mbps -85 dBm @ 11 Mbps
5-GHz client adapters - more sensitive due to lower power levels	-85 dBm @ 6 Mbps -84 dBm @ 9 Mbps -82 dBm @ 12 Mbps -80 dBm @ 18 Mbps -77 dBm @ 24 Mbps -73 dBm @ 36 Mbps -69 dBm @ 48 Mbps -68 dBm @ 54 Mbps

Cross Talk vs. Throughput

2.4-GHz client adapters	35 dB adjacent channel rejection
5-GHz client adapters	16 dB @ 6 Mbps adjacent channel rejection 15 dB @ 9 Mbps adjacent channel rejection 13 dB @ 12 Mbps adjacent channel rejection 11 dB @ 18 Mbps adjacent channel rejection 8 dB @ 24 Mbps adjacent channel rejection 4 dB @ 36 Mbps adjacent channel rejection 0 dB @ 48 Mbps adjacent channel rejection -1 dB @ 54 Mbps adjacent channel rejection

Transmit Levels

2.4-GHz transmit levels	**100 mW (20 dBm)** **50 mW (17 dBm)** **30 mW (15 dBm)** **20 mW (13 dBm)** **5 mW (7 dBm)**
5.0-GHz transmit levels – note lower max power vs. 2.4 GHz	**40 mW (16 dBm)** **25 mW (14 dBm)** **20 mW (13 dBm)** **13 mW (11 dBm)** **10 mW (10 dBm)**

Issues:

- Hot spots vs. Uniform coverage
- Over-powered signals

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SNR vs. Throughput

- No data published – bit error rates varied
- Implied is a minimum 5dB difference between signal and noise – and at that level the throughput would be minimal relative to the overall signal level
- Implied – a 45 dB difference between signal and noise is considered excellent – and at that level the throughput would be maximal – relative to the signal level itself
- As the overall noise floor raises, throughput drops
- Based on cross-talk numbers, one can infer a relationship between SNR and throughput

Multipath vs. Throughput

2.4-GHz client adapters	**500 ns @ 1 Mbps** **400 ns @ 2 Mbps** **300 ns @ 5.5 Mbps** **140 ns @ 11 Mbps**

- Slower speeds tolerate a longer duration multipath distortion

Range vs. Throughput

- Sample distances – of course this is really signal level vs. throughput converted to distance

2.4-GHz client adapters	Outdoor **2000 ft (609.6 m) @ 1 Mbps** **1500 ft (457.2 m) @ 2 Mbps** **1000 ft (304.8 m) @ 5.5 Mbps** **800 ft (243.8 m) @ 11 Mbps** Indoor **350 ft (106.7 m) @ 1 Mbps** **250 ft (76.2 m) @ 2 Mbps** **200 ft (61 m) @ 5.5 Mbps** **150 ft (45.7 m) @ 11 Mbps**
5-GHz client adapters	Outdoor **1200 ft (365.8 m) @ 6 Mbps** **700 ft (213.4 m) @ 18 Mbps** **120 ft (36.6 m) @ 54 Mbps** Indoor **200 ft (61.0 m) @ 6 Mbps** **150 ft (45.7 m) @ 18 Mbps** **70 ft (21.3 m) @ 54 Mbps**

Antenna / AP Coverage Scenarios

- Several possible approaches
  - Discrete - Cells (macro / micro)
  - Distributed - Straight Line
  - Sectorized
  - Dumb client problem

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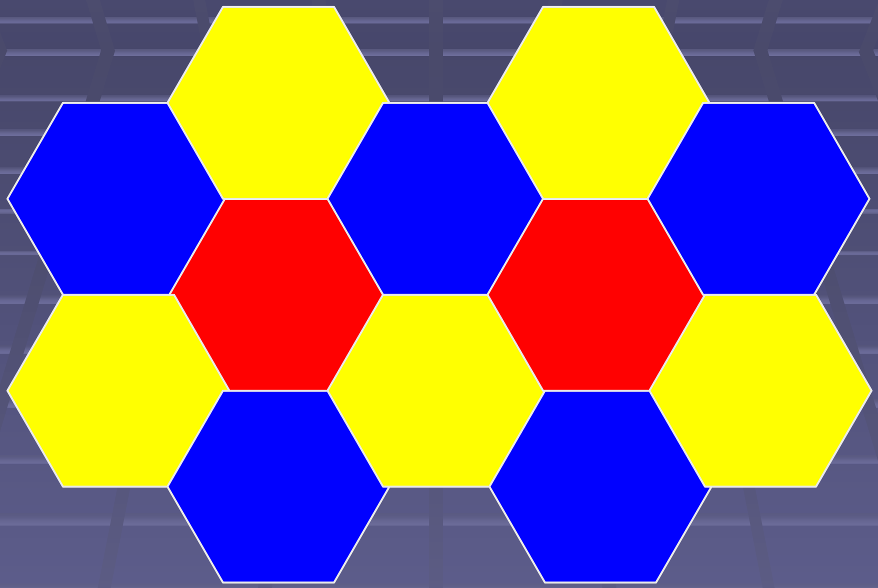
Discrete Cells



- Size / number of cells depends on number of endpoints
- Cell size also dependent on power levels
- Cell re-use limited by number of clear channels (a vs b/g)
- Complicates roaming users

Distributed

- Antenna is central - snaked line
- Wide but thin coverage – close to ideal
- End points presume cell coverage – need power levels set
- For any given coverage area, three channels possible for b/g, a not presently allowed by FCC rules
- This limits number of endpoints / throughput by traffic type
- One way to handle this is to differentiate traffic by channel
- Simplifies roaming users

Sectorized Antennas

- Variation of the discrete AP
- Changes problem from one of end points per cell diameter – to number of end points per beam reach angle

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Dumb Client Problem

- Unlike cell phones, client does not report RF status
- End point has insufficient intelligence and knowledge of overall network to make good choices
- Will remain with first AP even when better one is available
- PropagateNet has a possible solution AutoCell if everyone would adopt it or similar

Antenna Summary

- Each has strengths and weaknesses
- Underlying problem is one of 802.11 Wi-Fi architecture
- Client is dumb – so smart antenna only partially resolves problem
- AP & Antennas alone will not resolve the issues

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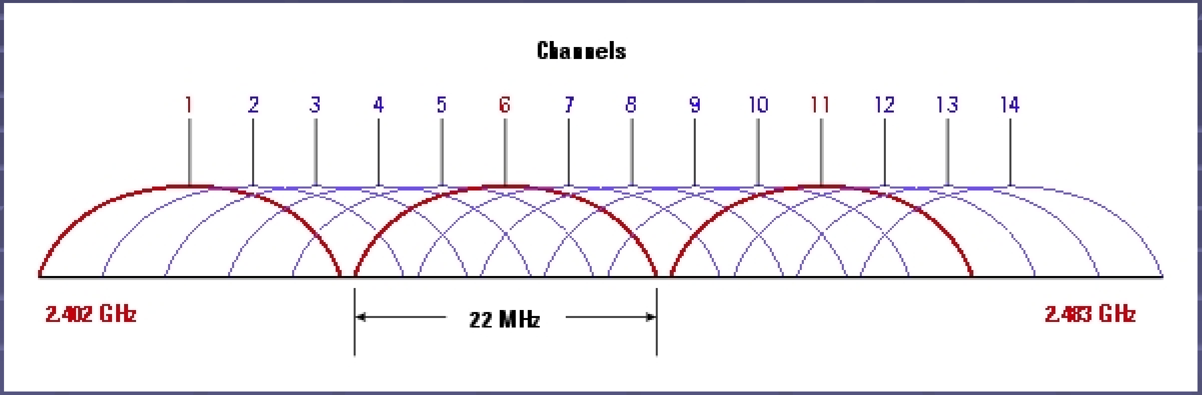
Channel Re-Use and Interference

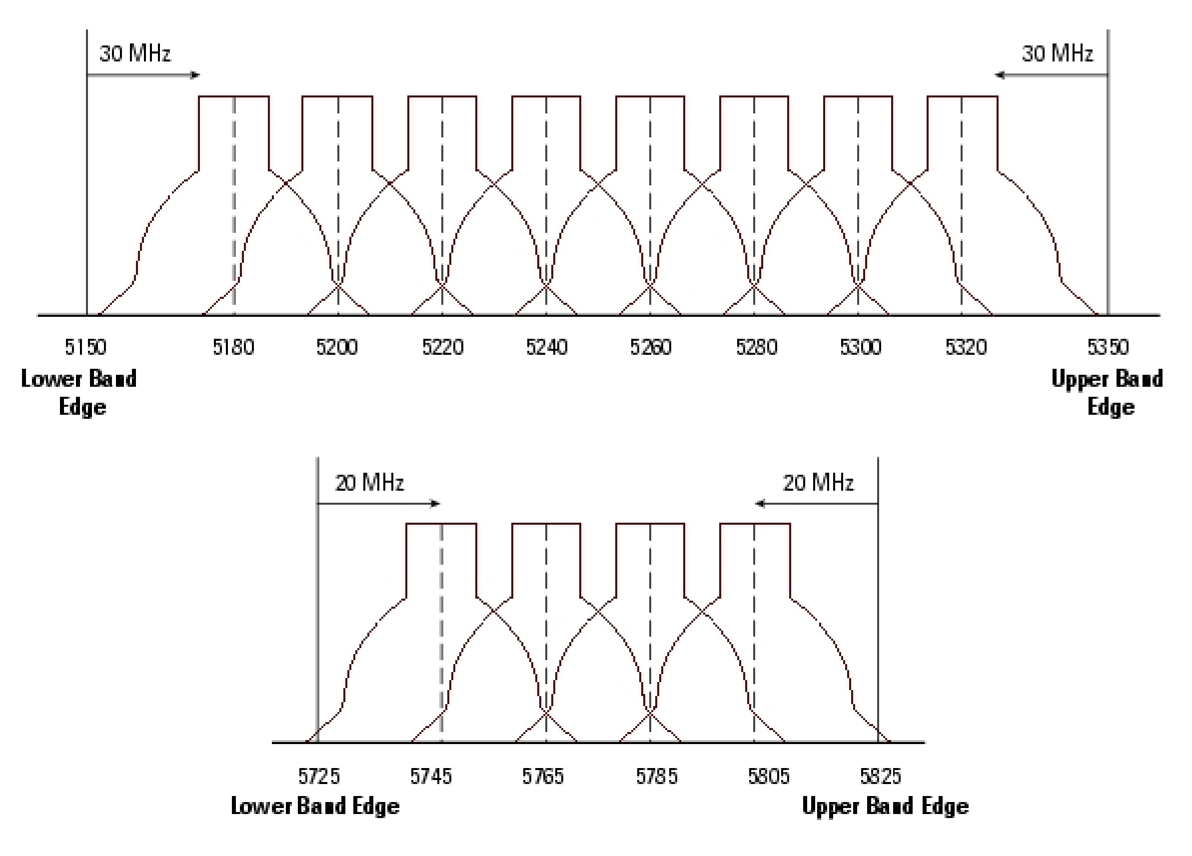
- Due to underlying 802.11 architecture, there is a practical limit on number of end points per channel
- How to best re-use channels ?

802.11 b/g channels



- 14 channels
- 2.412 through 2.484 GHz
- 22 MHz width
- 5 MHz spacing
- 1-11 allowed in NA, 14 elsewhere (ie Japan)
- Every 5 channels – clear (1, 6, 11 in NA)

802.11a Channels



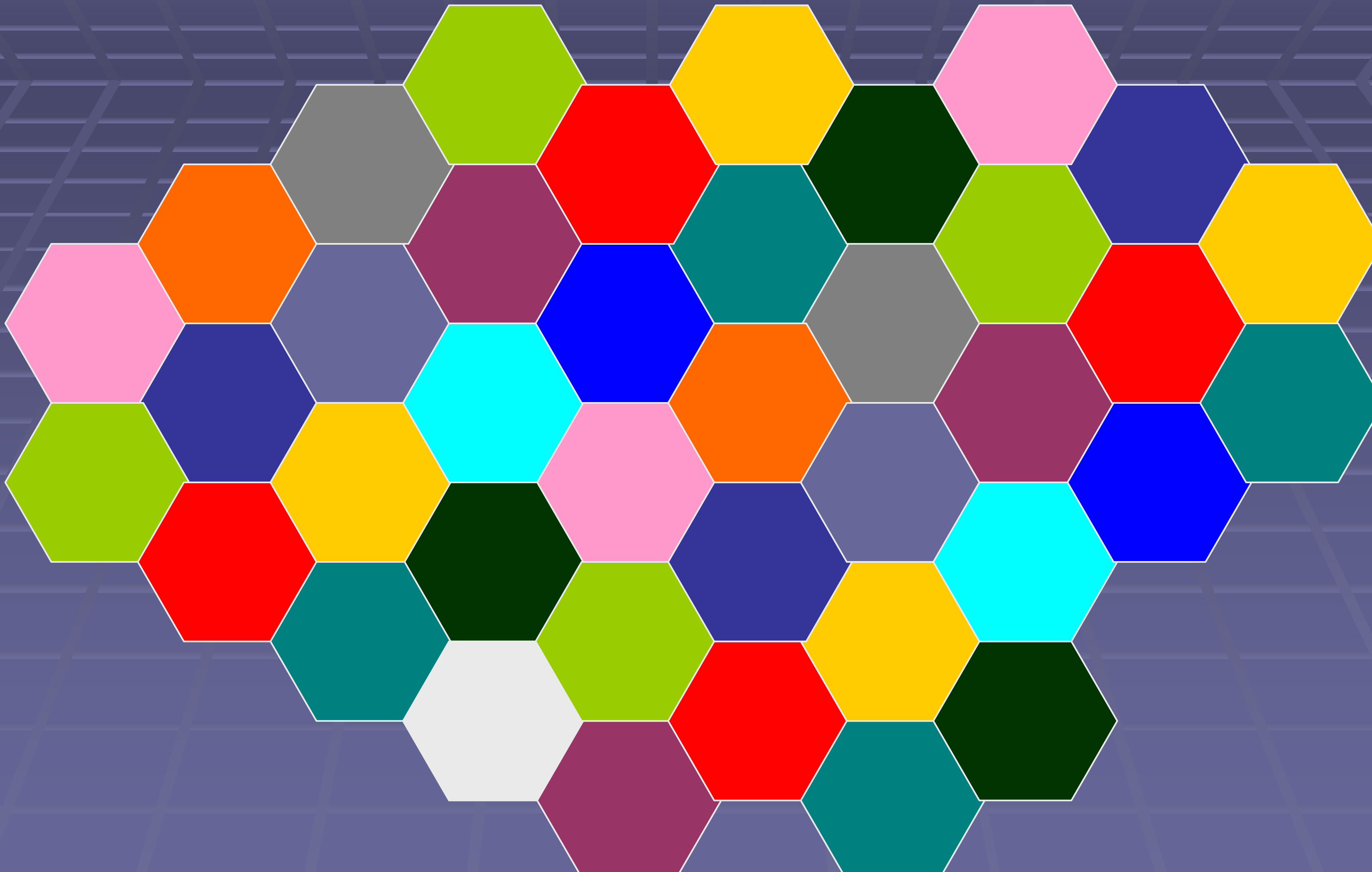
- 3 bands (low, mid, upper), with 4 channels each, 20 MHz spacing
- Considered non-interfering, but they do overlap – signal coverage differs from 2.4 GHz
- Should not place adjacent channels side by side in cells, but more useable than 802.11b/g
- Only available in discrete antenna per FCC rules

802.11a Channels

Regulatory Domain	Frequency Band	Channel Number	Center Frequencies
USA	**UNII lower band 5.15-5.25 GHz**	**36**	**5.180 GHz**
		40	**5.220 GHz**
		44	**5.230 GHz**
		48	**5.240 GHz**
USA	**UNII middle band 5.25-5.35 GHz**	**52**	**5.260 GHz**
		56	**5.280 GHz**
		60	**5.300 GHz**
		64	**5.320 GHz**
USA	**UNII upper band 5.725-5.825 GHz**	**149**	**5.745 GHz**
		153	**5.795 GHz**
		157	**5.785 GHz**
		161	**5.805 GHz**

Channel Information for the Curious

802.11a Channel Reuse



Summary of RF Intro

- Determine available throughput
  - Signal level
    - affected by power
    - attenuated by distance
    - attenuated by obstructions
  - Noise level
    - sufficient level below useable signal
  - Net result - throughput

Summary of RF Intro (continued)

- Given available throughput
  - Divide in number of stations
  - Compensate for traffic type
  - Net result – number of stations per AP / Antenna

Plan cell re-use

Iterate until acceptable solution found

or

Use a distributed antenna and plan traffic types

Discrete vs. Distributed Wireless

Discrete Deployment

- Advantages
  - discrete cells
  - ability to effectively limit users per cell

- Challenges
  - many cells = many APs = $$$
  - complex underlying wireline network
  - mobility between cells can be a challenge
  - inability to separate traffic by type due to cell layout

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Discrete Deployment Best Use

- High density, relatively fixed users, uniform traffic type, non-real time traffic

Distributed Antenna

- Advantage
  - fewer APs
  - less complex network
  - enhances mobility
  - easier to separate traffic types / reserve channels

Challenges
  - fewer APs = fewer end points per AP

Distributed Best Use

- Relatively few end points consisting of mixed traffic types which need separation by channel
- Highly mobile end-points

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Sectorized Antenna

- Advantage
  - over discrete deployment
  - fewer APs
- Challenges
  - same as for discrete
  - further complicated by possibility of too many end-points in one sector – antenna insufficiently narrow cast

Comparison of Deployment Models

- Each has advantages and challenges
- Design to traffic and end-point requirements
- As underlying protocols improve, advantage goes to distributed antenna

Current Best Practices

Application Mix / Use

- Given only three channels
- Given a distributed antenna
- Define three traffic types
  - Real-time, low volume (ie voice)
  - Best effort – short, bursty (ie – scanners / transaction devices – web form fill in)
  - Best effort – other (ie – file transfer, browser)
- Limit / control access with ACS system

QoS

- Separate Traffic - different channels
- Limit broadcasts – each AP on own wireline VLAN
- MLS on wireline switches to minimize delay
- Priority queues on wireline side to minimize loss
- Set MTU sizes appropriately on VLANs

VoWLAN

- Limited Use
- Separate channel from other traffic
- Expect issues if more than 5-6 handsets in use on any one channel at one time. If truly separate, may improve.
- Works best with distributed antenna because of minimal cell hopping
- If many stations, better choice – install 1.9GHz digital POTS station and hook to VoIP network via analog gateways
- Limitations are inherent in base 802.11 – nothing to do with choice of antenna

VLAN Design

- Each AP channel is it's own wireline VLAN
- Never mix VLANs on any one channel
- Use MLS to route between VLANs
- Control end-point registration via ACS or similar means

Summary of Recommendations

- Segment and separate traffic types
- Each AP channel it's own VLAN
  - resist the temptation to re-use VLANs
  - limit broadcast traffic
  - optimize MTU sizes – thus uniform frame sizes
- Limit power levels on clients to reduce interference
- Use a distributed antenna for overall use, plus discrete APs to handle local high density traffic
- Engineer the wireline network – don't default

Questions

- Q&A Session