Much Ado About Wireless Backhaul

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LigoWave Networks, Inc.

@EmperorWiFi

Much Ado About Wireless Backhaul
About the Bard

- Veteran in Wireless Backhaul
  - Debugged my first mesh network after being at a WISP for only two weeks (spoiler: first of far too many lessons in self-interference)
  - Designed, deployed, and/or troubleshot dozens of mesh and point-to-multipoint deployments in the last 10 years, working for service providers and AP manufacturers
- Current Role: Director of Business Development at LigoWave Networks, Inc.

CWNE #171
Blog: http://emperorwifi.com

"O God, I could be bound in a mesh network, and count myself @EmperorWiFi of infinite bandwidth – were it not that I have bad dreams." – *Hamlet (Act 2, Scene 2) {Adapted}*

Approaching Wireless Backhaul Design
Understand Your Requirements and Constraints

Requirements

- Usage
- Coverage
- Capacity
- Control and Monitoring
- Integration and Infrastructure

Constraints

- Budget
- Aesthetics
- Mounting / Wiring Restrictions
- Electrical Power

https://akinjidepetersdotcom.files.wordpress.com/2015/01/requirement.gif

http://image.sportsmansguide.com/adimgs/l/1/112010_ts.jpg

"There is no darkness but ignorance."
– Twelfth Night (Act IV, Scene 2)

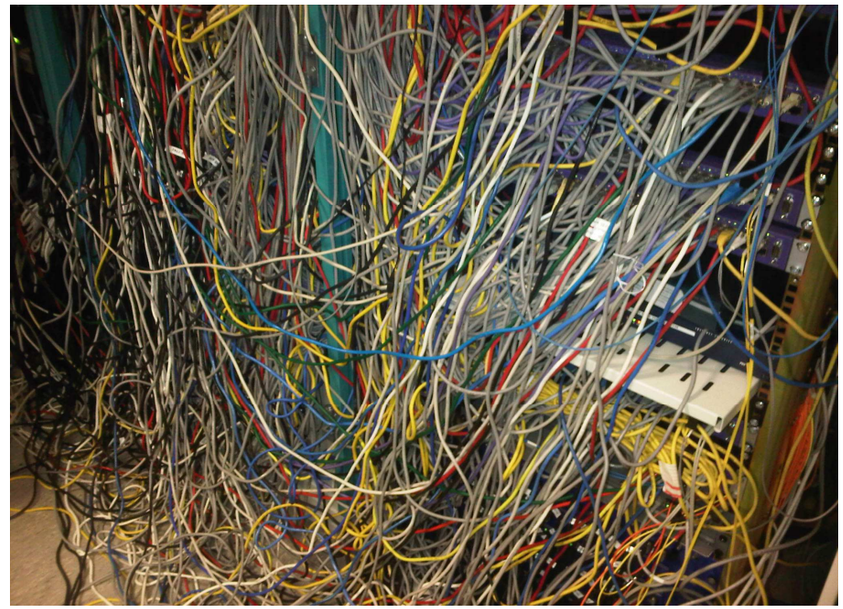
Approaching Wireless Backhaul Design
Understand Your Design Parameters and Goals

Design Parameters

- AP Model and Antenna
- AP Locations
- Channel
- Transmit Power

Design Goals

- Maintain Functional Independence
- Minimize Complexity



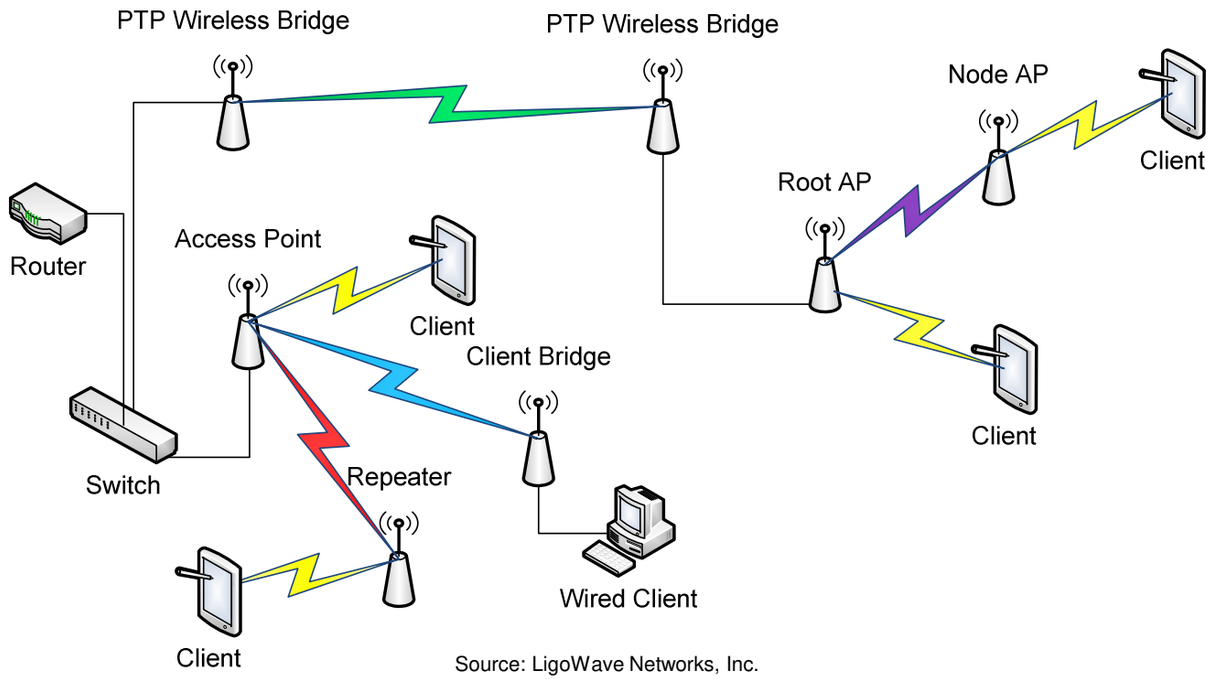
http://blog.quindorian.org/wp-content/uploads/2016/08/cable-mess1.jpg

"See first that the design is wise and just: that ascertained, pursue it resolutely; do not for one repulse forego the purpose that you resolved to effect."

– Attributed to William Shakespeare

Defining Wireless Backhaul
Selecting Your Network's "Operational Mode"

- Conventional Wired APs
- Client Bridge
- Repeaters
- Point-to-(Multi)point Bridges
- Mesh



Source: LigoWave Networks, Inc.

"All the word's a network. And all the APs and clients merely players; They have their exits and their entrances, and one AP in its time connects many clients."

– As You Like It (Act 2, Scene 7) {Adapted}

Approaching Wireless Backhaul Design
Avoiding Self Interference

- All repeater, point-to-(multi)point, and mesh radios in a group need to be on the same channel.
- Every time an AP intercommunicates with client devices, that consumes airtime for neighboring APs
- This self-interference further lowers airtime capacity, by causing more retries.

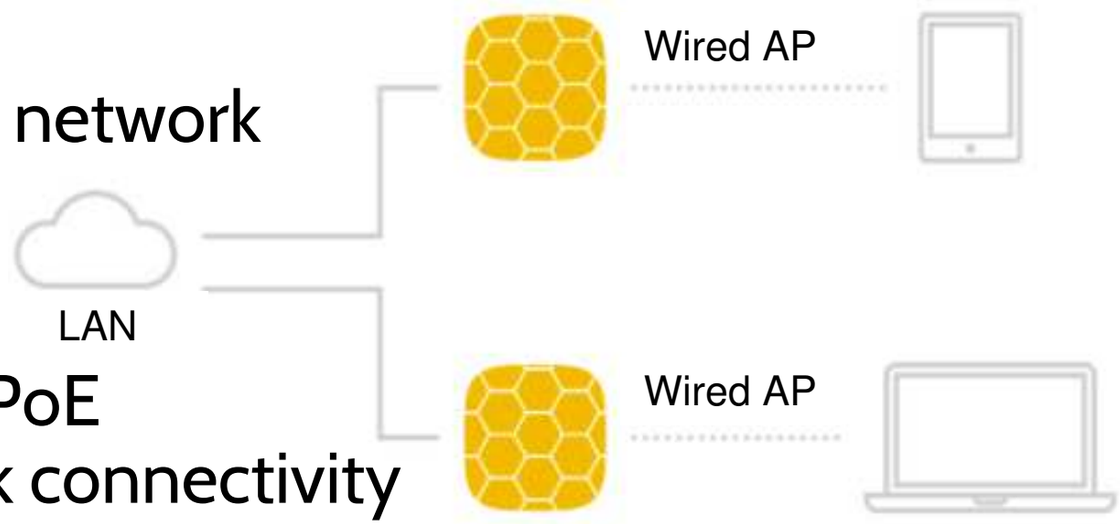
https://theviewfromsarisworld.files.wordpress.com/2016/10/john_gilbert_-_hamlet_in_the_presence_of_his_fathers_ghost.jpg?w=840

"I am the ghost frame, doomed for a certain period of time to propagate the earth at night, while during the day I'm trapped in the fires of purgatory until I've interfered with neighboring APs. If I weren't forbidden to tell you the secrets of RF physics, I could show you RF interference that would slice through your soul, freeze your blood, make your eyes jump out of their sockets, and your hair stand on end like dipole antennas. But mortals like you aren't allowed to see RF waves in the air." – Hamlet (Act 1, Scene 5){Adapted}

– As You Like It (Act 2, Scene 7) {Adapted}

Types of Wireless Backhaul
Conventional Wired AP Network

- Connect wireless clients to a wired network
- A wireless client device only has a single *hop* to the wired network
- Each dual-band AP is wired into a PoE switch for both power and network connectivity
- APs can be either be managed centrally or operate in standalone mode



Source: LigoWave Networks, Inc.

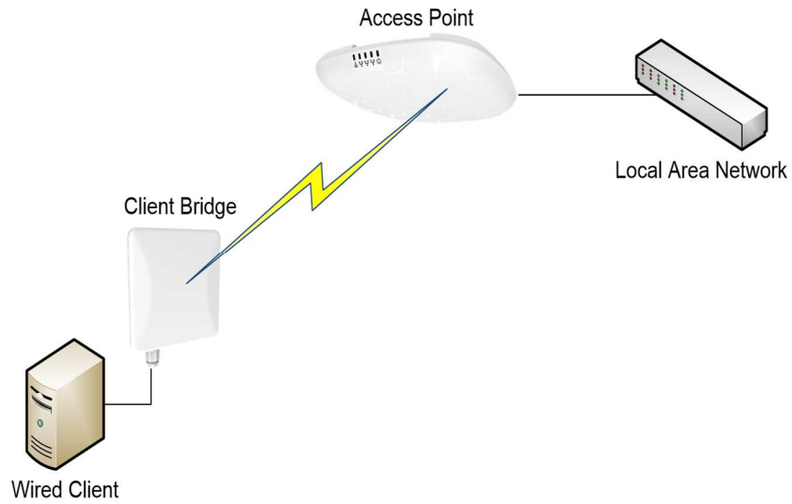
"I would my Wi-Fi had the speed of your tongue, and so good a continuer."
– Much Ado About Nothing (Act 1, Scene 1) {Adapted}

Types of Wireless Backhaul
Best Design Practices for Wired APs

- Place APs as close as possible to clients
- Place APs as far apart from each other
- Set your channels and transmit power properly
- Facilitate how network shall get used
  - Client Types
  - Coverage Areas
  - User Density

"There's something roaming in the state of Denmark."
– Hamlet (Act 1, Scene 4) {Adapted by Hälge, the Swedish WiFi Moose}

Types of Wireless Backhaul
Client Bridge



Source: LigoWave Networks, Inc.

- Connect wired clients to a wireless network
- The Client Bridge converts a wired Ethernet connection into a single-band wireless client
- The Client Bridge connects to an AP as a wireless client device
- If multiple wired devices are behind the client bridge, the network will see them all with the same MAC address (i.e. the WLAN MAC address of the Client Bridge)
- Client Bridges are configured in standalone mode

"Once more unto the breach of Wi-Fi networks, dear friends, once more;"
– Henry V (Act 3, Scene 1) {adapted}

Types of Wireless Backhaul
Repeaters

- Connect wireless APs and clients to a wireless network
- The repeater spends half of its time servicing wireless clients, the other half to provide backhaul
- Lose 50% of the bandwidth capacity per hop on repeater band, so generally only used in non-enterprise environments to fill coverage gaps
- Repeaters are configured in standalone mode, may be dual-band APs

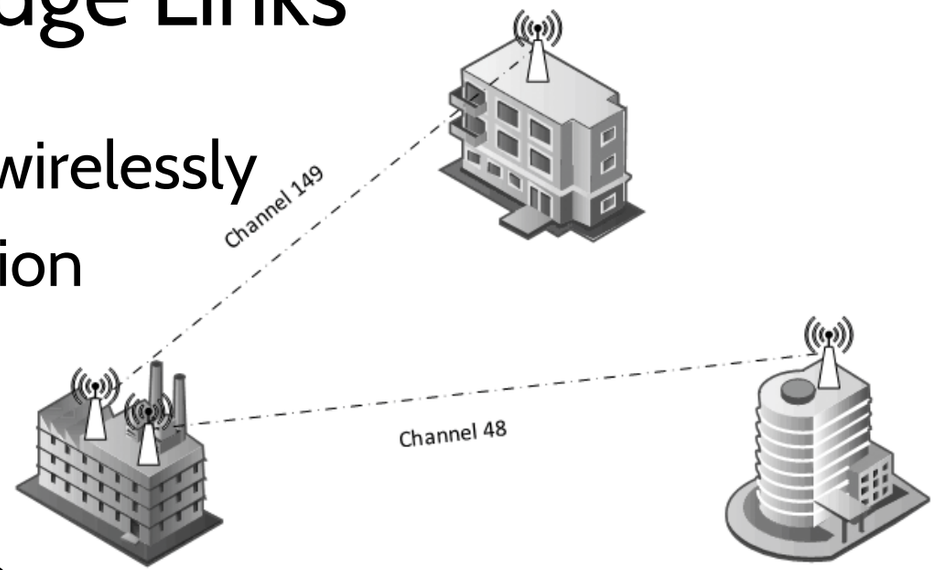
Source: CWDP Certified Wireless Design Professional Official Study Guide, 2015.

"Why, i'faith, methinks the Wi-Fi signal is too low for a high praise, too spotty for a fair praise, and too slow for a great praise."

– Much Ado About Nothing (Act 1, Scene 1) {Adapted}

Types of Wireless Backhaul
Point-to-(Multi)Point Wireless Bridge Links

- Connect multiple wired networks together wirelessly
- Act as a "wireless wire"; all Layer 2 information (i.e. MAC address, VLAN, etc.) preserved
- Ethernet frame is encrypted, encapsulated in a wireless frame, transmitted, de-encapsulated, decrypted, and passed on
- Single band APs traditionally configured in standalone mode, some vendors now enable cloud monitoring and management.

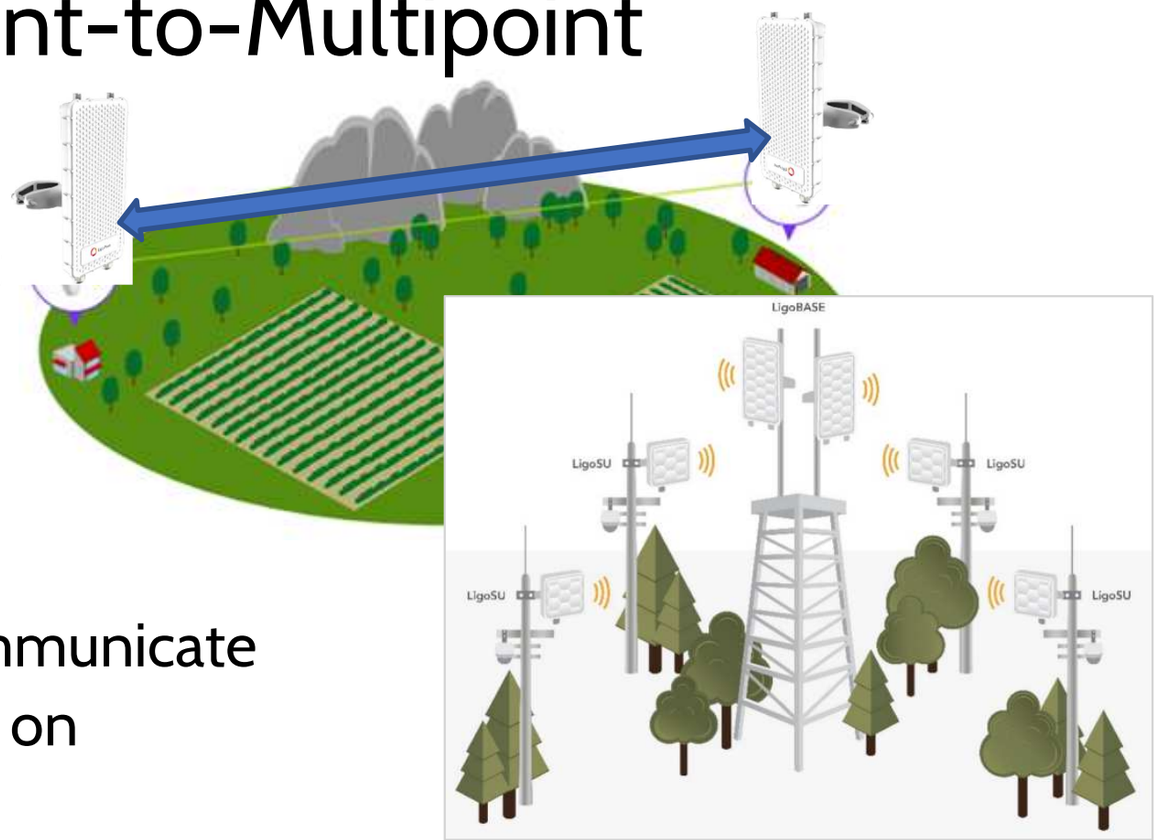


Source: CWDP Certified Wireless Design Professional Official Study Guide, 2015.

"Your antenna, sir, would cure deafness."
– The Tempest (Act 1, Scene 2) {adapted}

Types of Wireless Backhaul
Point-to-Point (PTP) vs. Point-to-Multipoint

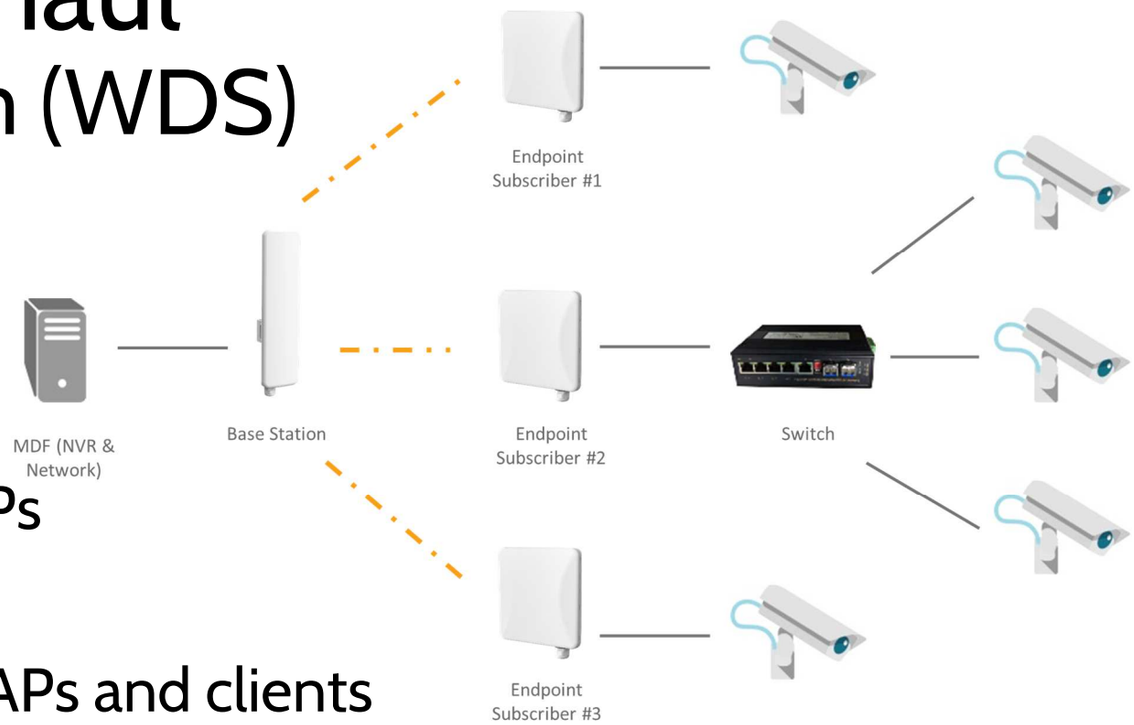
- PTP: Point-to-Point
  - Neighboring links on independent channels
- PTMP: Point-to-Multipoint
  - All links in PTMP group share the same airtime; must be on the same channel in order to intercommunicate
  - Neighboring PTMP group links are on independent channels



"Words are easy, like the wind; faithful subscribers are hard to find."
– The Passionate Pilgrim (attributed to William Shakespeare) {adapted}

Types of Wireless Backhaul
Wireless Distribution System (WDS)

- WDS Bridge
  - Endpoints configured identically
  - Each AP must specify the WLAN MAC addresses of the connected APs
- WDS Access Point / Station
  - Configured similar to conventional APs and clients
  - SSID broadcast from base station
  - Scalable to large numbers of PTMP remote stations

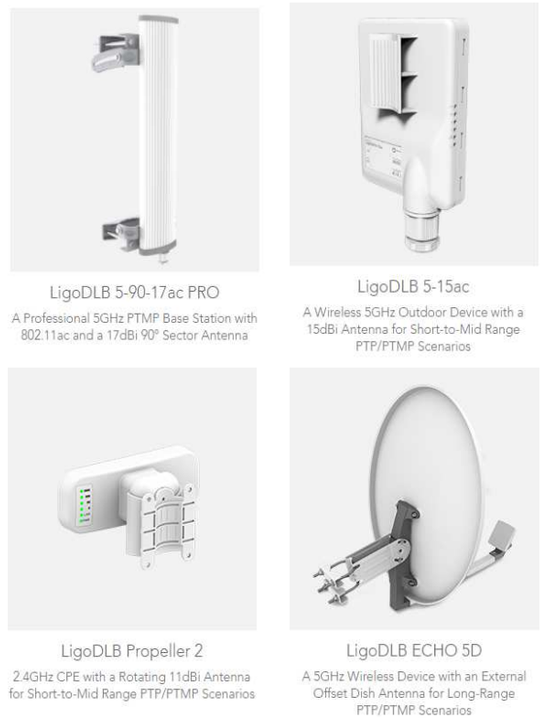


Source: LigoWave Networks, Inc.

"Love all clients, trust a few subscribers, do wrong to none."
– All's Well That Ends Well {adapted}

Types of Wireless Backhaul
Vendor Specialization in PTP / PTMP

- Dedicated AP Models
  - Integrated directional antennas for PTP and PTMP applications
- Hardware acceleration for QoS
- Proprietary wireless protocols
  - Generally TDMA-based, often with QoS modifications
  - Minimizes CSMA/CA and other Wi-Fi overhead
- Design and Installation Tools
- Centralized Cloud Management

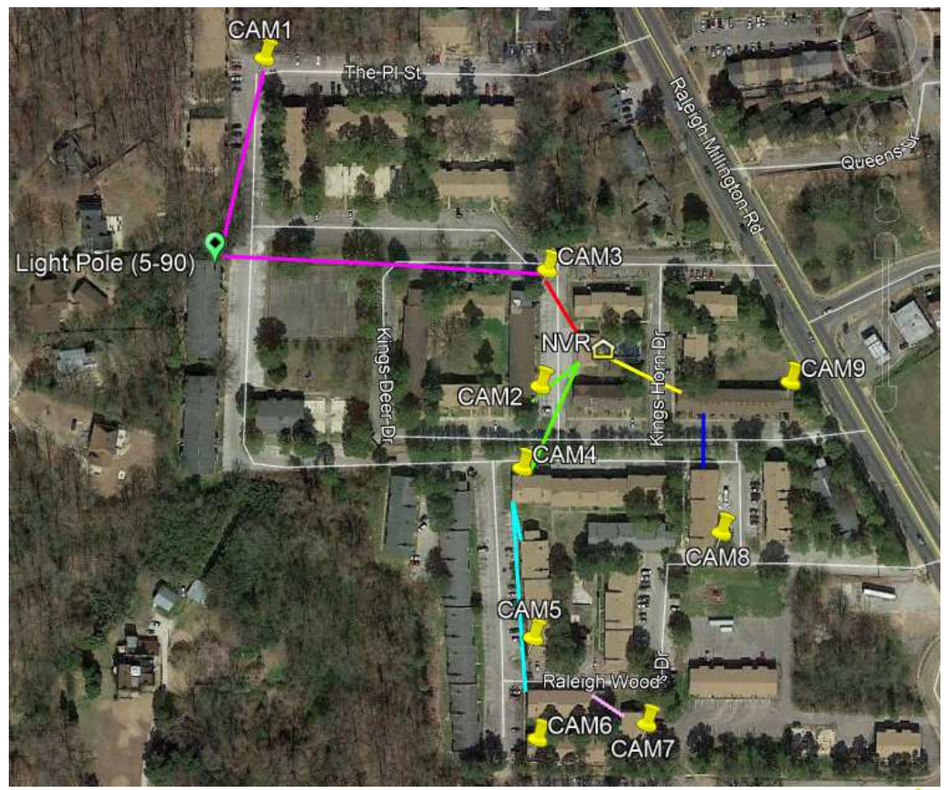


Source: LigoWave Networks, Inc.

"Some are born great, some achieve greatness, and some have greatness thrust upon them." – Twelfth Night (Act 2, Scene 5)

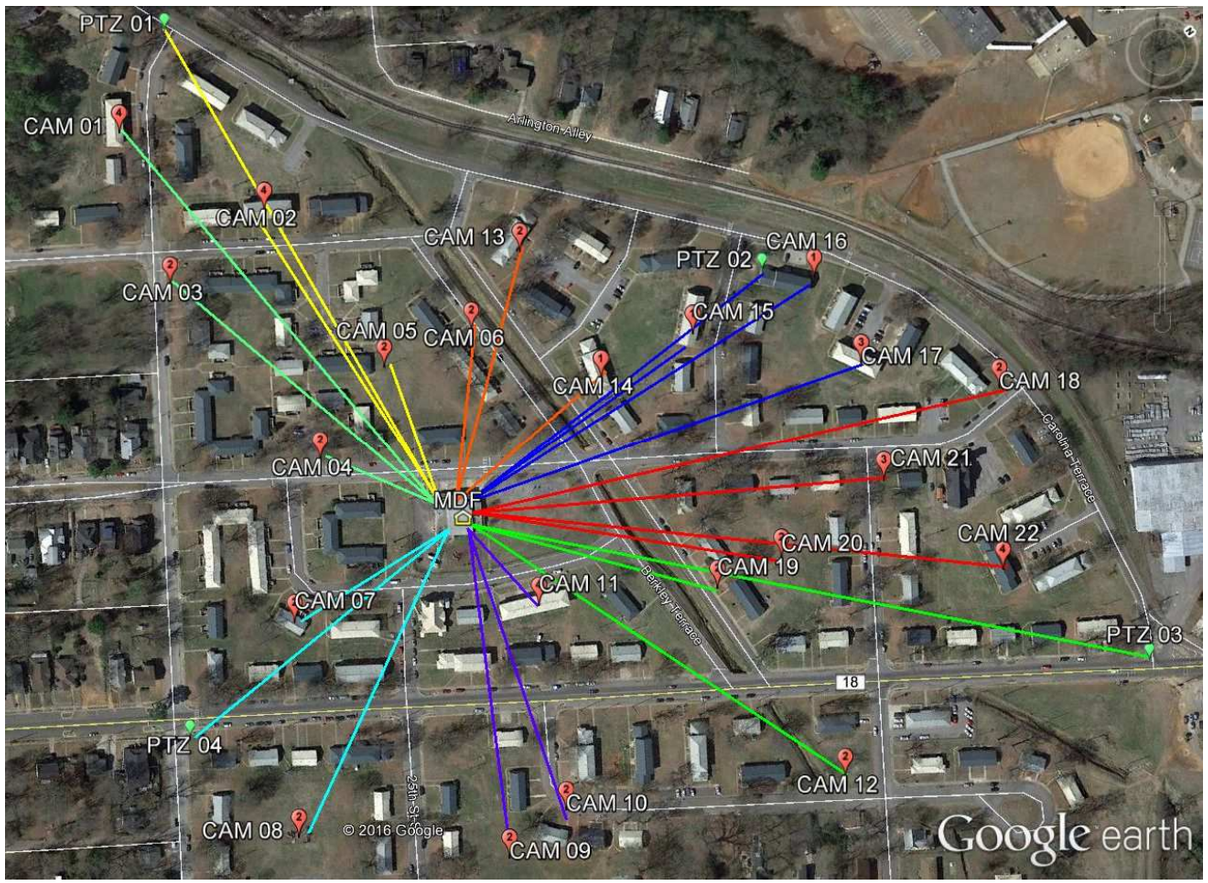
Point-to-Multipoint Example
Wireless Surveillance

- Mix and match standard components
- Tailor design to specific needs of property
- 9 camera locations at various locations at residential property
- Limited line of sight between buildings
- 15 ***LigoDLB 5-15ac***
- 1 ***LigoDLB 5-90ac***



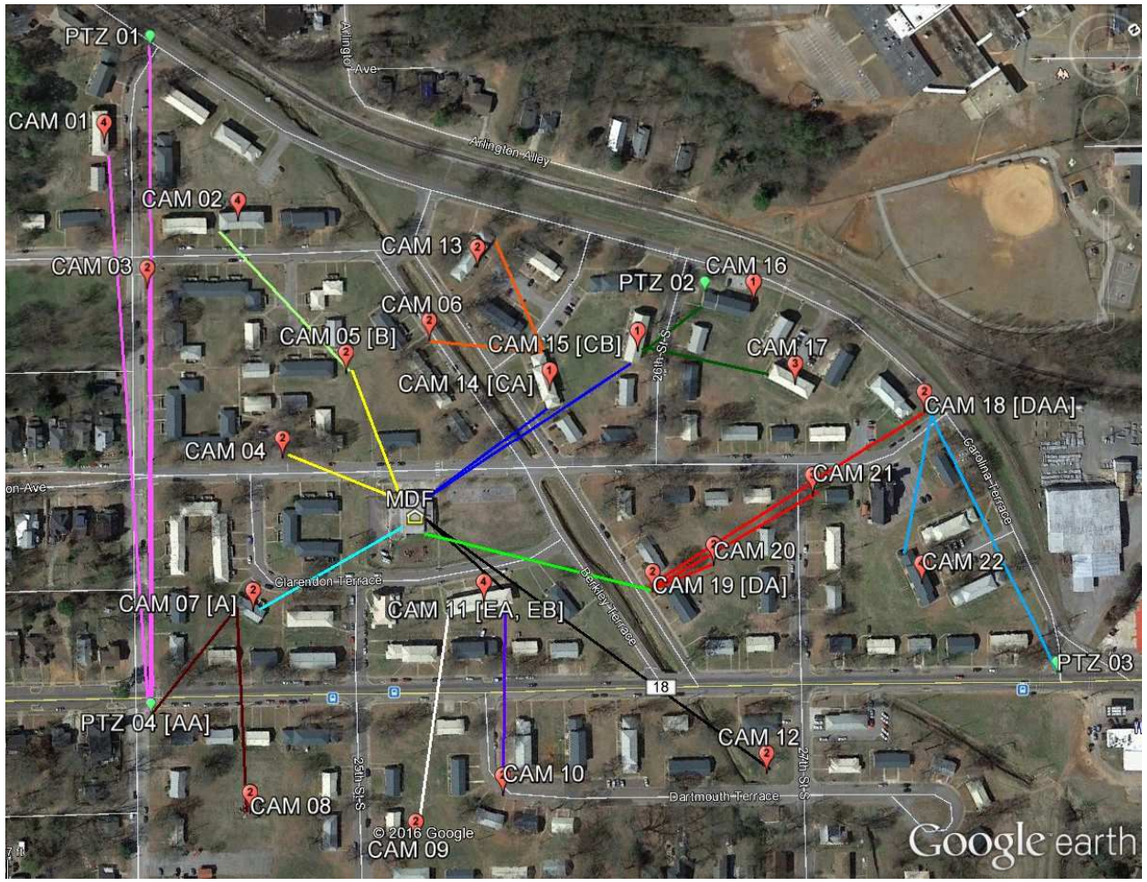
Source: LigoWave Networks, Inc.

Point-to-Multipoint Example
You Cannot Always Get Line of Sight: Ideal



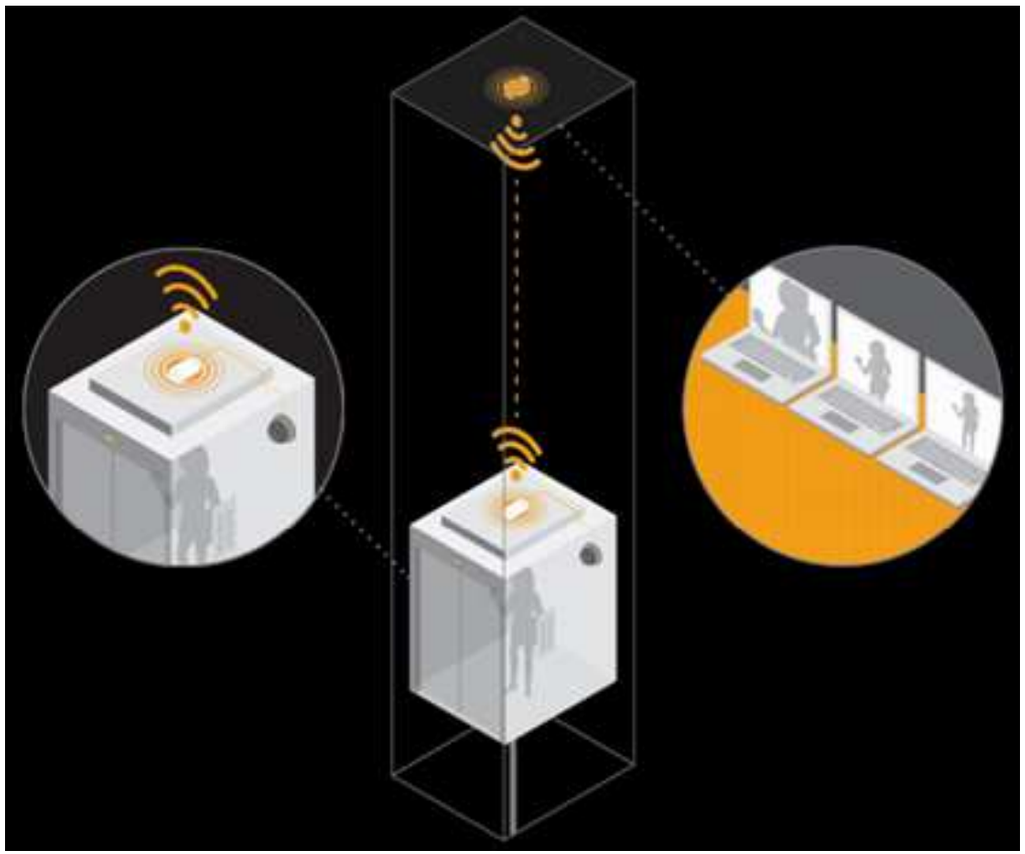
- RF Visibility to All Locations
  - Main distribution frame (MDF) higher than endpoint locations
  - Have structure at main distribution frame (MDF) to isolate neighboring links
  - No trees or buildings in path
- Example: 32 LigoWave *LigoDLB 5-15ac* (cameras at endpoints)

Point-to-Multipoint Example
You Cannot Always Get Line of Sight: Actual



- Lack RF Visibility to Most Locations
  - Must set up *relay points* that are intermediate distribution frames (IDFs)
  - Accommodate environment by working around trees and buildings (e.g. following roadways)
  - Channelization critical
- Example: 38 LigoWave *LigoDLB 5-15ac* (cameras at endpoints)

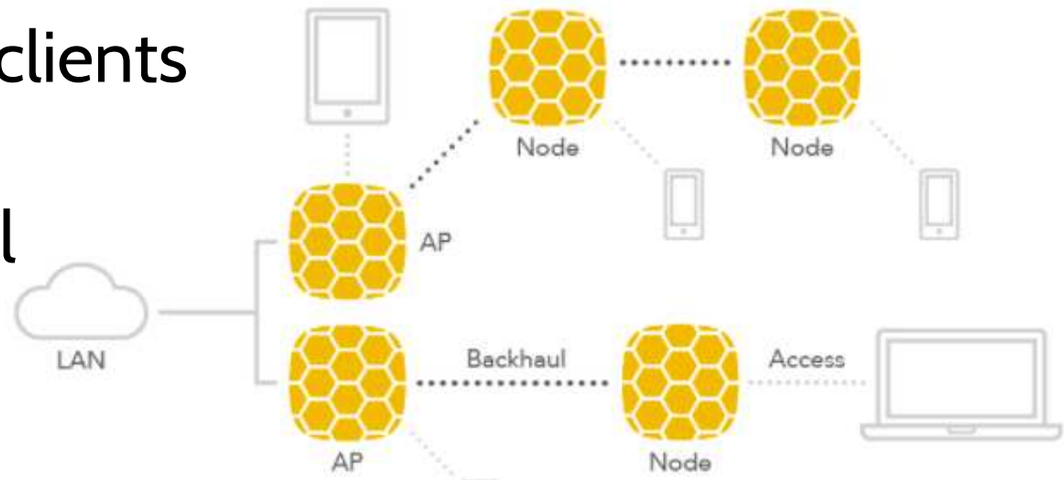
Point-to-Multipoint Example
Elevators



- Demand for IP surveillance cameras and Wi-Fi APs inside elevator cabs
- Newer elevators have CAT5e running cable, older elevators do not
- Shaft is a large steel box
- Single root node on top of elevator shaft talks to endpoint on top of each elevator cab
- Motion of elevator compensated for automatically in the link
- MIMO compensates for reflections in elevator shaft

Types of Wireless Backhaul
Mesh Network: Wi-Fi Without Wires

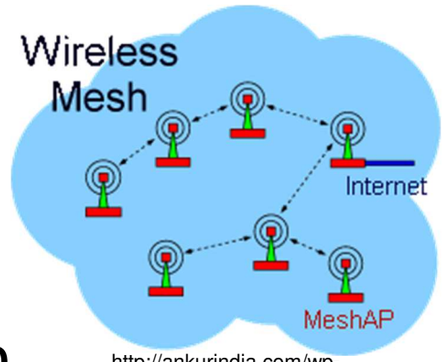
- Mesh provides both Wi-Fi service to clients and wireless backhaul to wired AP
- Automatically calculates the "optimal path" through the network, and can adapt to changes
- Designed for large scale networks where wiring is impossible or cost-prohibitive



EasyMesh™ illustration for LigoWave Infinity APs

"What a piece of work is mesh! How noble in reason, how infinite in faculties, in form and moving, how express and admirable in action, how like an angel in apprehension, how like a God! The beauty of no wire! The paragon of backhaul!" – Hamlet (Act 2, Scene 2) {Adapted}

Types of Wireless Backhaul
Mesh Network: Terminology

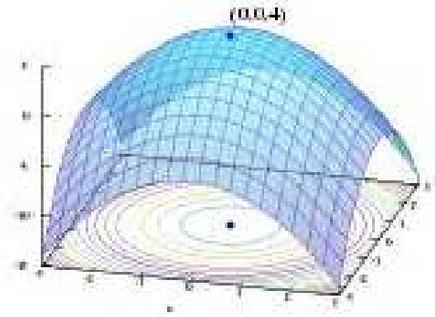


http://ankurindia.com/wp-content/uploads/2018/01/wm4.gif

- **Root APs:** AP with a "wired" connection to the wired switch infrastructure network, via Ethernet, fiber, or PTMP backhaul
- **Node AP:** AP without a wired Ethernet connection. Wireless backhaul is established to a root AP or other node AP. Each wireless link is a ***hop***
- Always use dual-band APs
  - Single-band APs: Simultaneous Wireless Backhaul and Client Access
  - Dual-band APs use 5 GHz for simultaneous Wireless Backhaul and Client Access. 2.4GHz radio is only for Client Access.

"Neither a node AP nor a root AP be, For node oft loses both itself and friend, And root dulls the edge of client performance." – Hamlet (Act 1, Scene 3) {Adapted}

Types of Wireless Backhaul
Mesh Network: Calculating the Path



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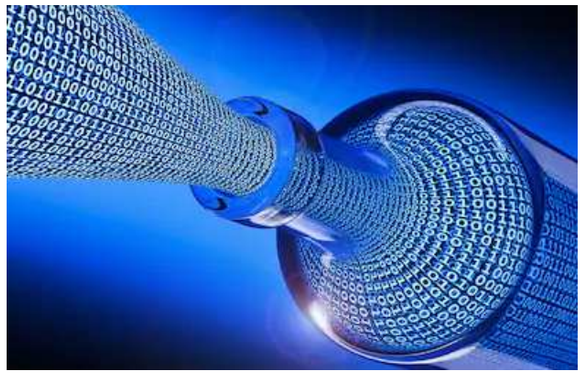
- Remote APs calculate "best path" route through the network, adapt to changes in environment (e.g. APs going offline)
- Algorithm is proprietary to each vendor, but generally includes optimizing the following:
  - **Minimize hops:** Minimize latency by minimizing total number of hops to a root node
  - **Maximize signal:** Select links with the strongest RSSI to maximize data rates in the link
  - **Balance load:** Account for number of clients and bandwidth consumption at each AP
- ***Note, these parameters can be conflicting, leading to counter-intuitive and sub-optimal solutions.***

"There are more things in mesh optimization, Horatio, than are dreamt of in our philosophy."" – Hamlet (Act 1, Scene 5) {Adapted}

Types of Wireless Backhaul
Mesh Network: Throughput Tradeoffs

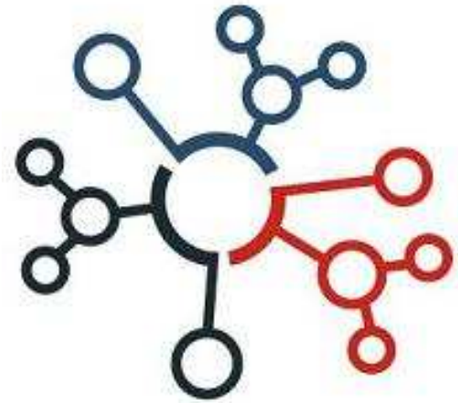


https://image.shutterstock.com/image-photo/3d-illustration-bottleneck-260nw-722637007.jpg

- Conventional "wired" Wi-Fi dedicates all wireless airtime to client access, as all backhaul is wired
- Mesh utilizes wireless airtime for both wireless backhaul and client access
- Mesh therefore results in reduced throughput and client capacity (50% per hop)
- ***Avoid mesh in performance-critical applications***
- Mesh should only be used in scenarios where running Ethernet cabling is unfeasible (physically impossible or cost-prohibitive)

"You cannot, sir, take from me any thing that I will more willingly part withal: except my throughput, except my throughput, except my throughput."
– Hamlet (Act 2, Scene 2) {Adapted}

Types of Wireless Backhaul
Mesh Network: Designing Mesh Correctly

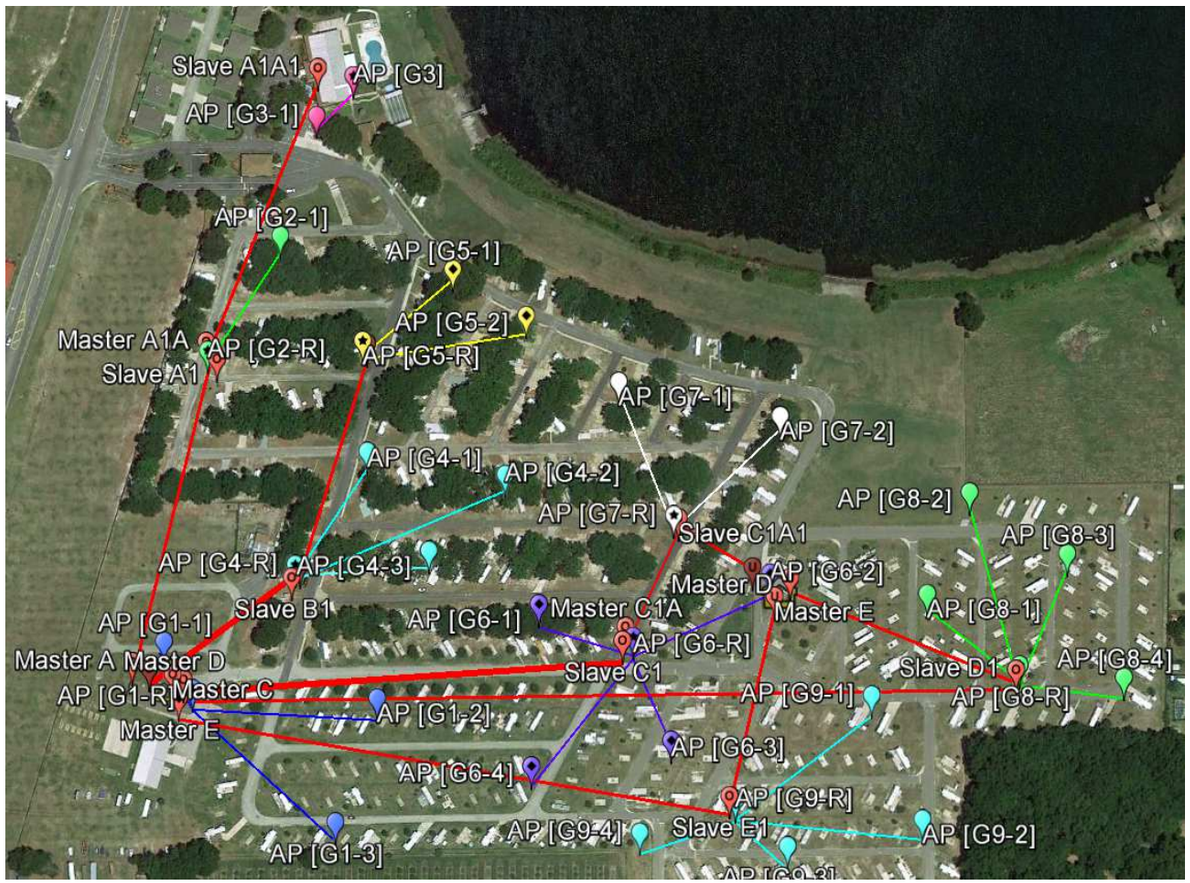


https://www.kom.tu-darmstadt.de/fileadmin/_migrated/pics/SW_Cluster_Logo_01.jpg

- Cluster the mesh APs
  - Space root APs roughly evenly throughout the property
  - Ensure up to four remote nodes APs are nominally one hop away from a root AP (***i.e. at least 20% of AP are root APs)***
  - Use dedicated wiring or separate wireless bridge backhaul links to create additional root APs
- Backhaul channelization
  - Set each root AP and each wireless bridge link to a static & non-overlapping channel; ***Each mesh cluster is on a separate channel***
  - Set all node APs to auto channel; ***Allows for self-healing if a root node goes offline***

"Mesh, the undiscovered country, from whose bourn no Wi-Fi engineer returns."
– Hamlet (Act 3, Scene 1) {Adapted}

Mesh Network Example
RV Park



- Markers represent APs, colors represent nominal mesh clusters
- Red: Point-to-(multi)point backhaul links to create additional root APs
- Each mesh cluster root AP and backhaul link on fixed 5 GHz channel to avoid self-interference
- Node APs on auto-channel
- Modern RV parks make mesh impractical; need PTMP link to each AP

Design Tips for Wireless Backhaul
Select the Right Wi-Fi Technology

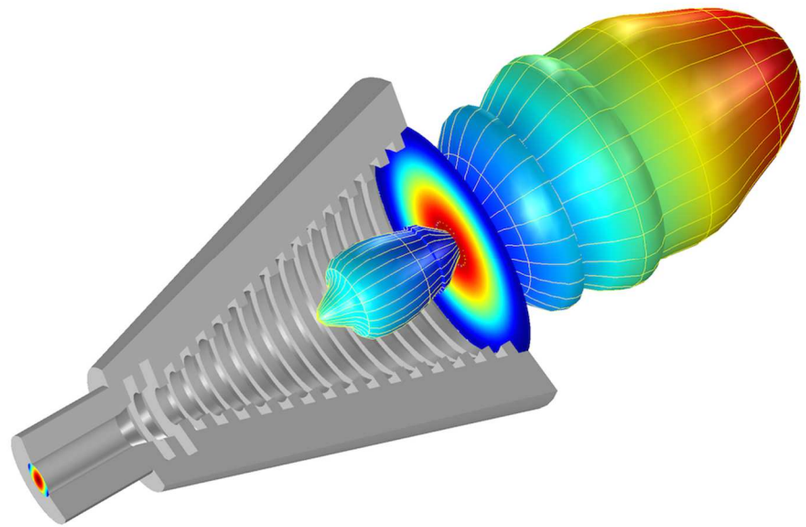
- 802.11ac Wave 1 2x2:2
  - Wireless backhaul all dual stream, achieve their separation via polarization
  - Few reflections, so little MIMO, in outdoor environments
- 802.11ac Wave 2
  - Lots of APs, but virtually no client devices
  - Utilized for massive PTMP (Cambium)
- 802.11ax
  - Beginning to see APs, but will there ever be client devices?
  - Potential for massive PTMP in surveillance and WISP applications

http://4.bp.blogspot.com/-ExcpuJqYkUY/VqtJaxdX89I/AAAAAAAAAkc/56fwNIiFhvI/s1600/Cara%2BMenentukan%2BPilihan%2Byang%2BTepat.jpg

"If you can look into the seeds of time, and say which grain will grow and which will not, speak then unto me." – Macbeth (Act 1, Scene 3)

Design Tips for Wireless Backhaul
Select the Right Antenna

- Directional Antennas
  - Higher gain = more focused transmit & receive
  - Still have to monitor sidelobes / backlobes
- Internal Antennas
  - Easy integration, but limits choices
- External Antennas
  - High gain dish / grid for long distances
  - Horn antennas (eliminates side lobes, good for co-located base stations)



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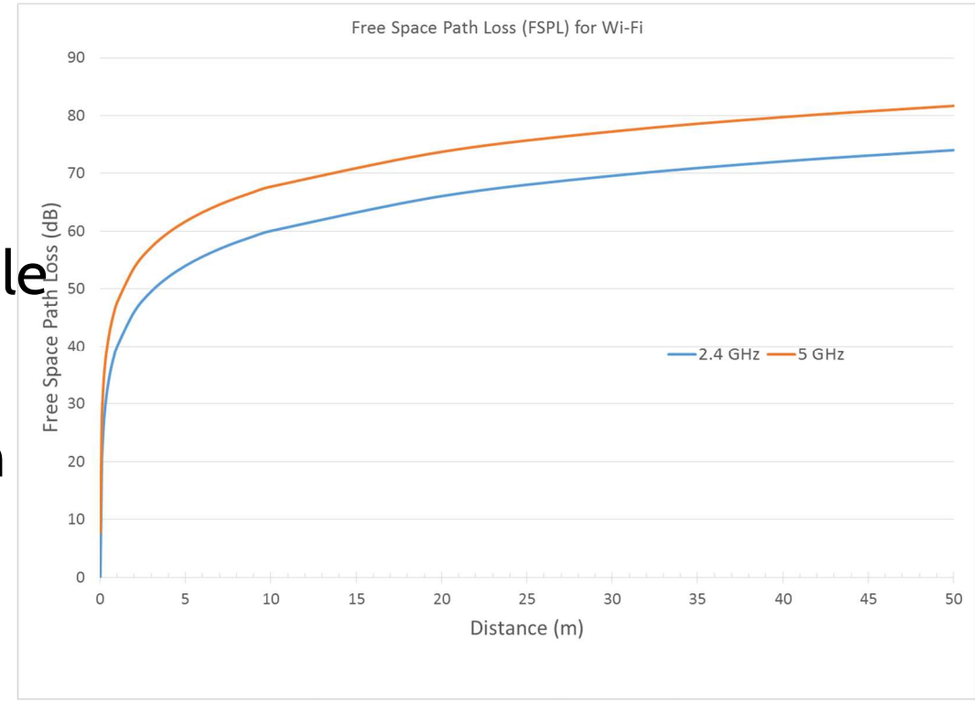
"Mend your speech a little, lest you may mar your fortunes."
– King Lear (Act 1, Scene 4)

Design Tips for Wireless Backhaul
Understand Your Link Budget

- Free Space Path Loss (FSPL)
  - Lose 6 dB as distance doubled
  - Guideline: -70 dB @ 50 ft, -110 dB @ 1 mile
- Fresnel Zone
  - Diffraction of signal by objects in the path
  - Area in which signal must be kept clear
- Earth Bulge
  - Over 7 miles, the Earth is no longer flat

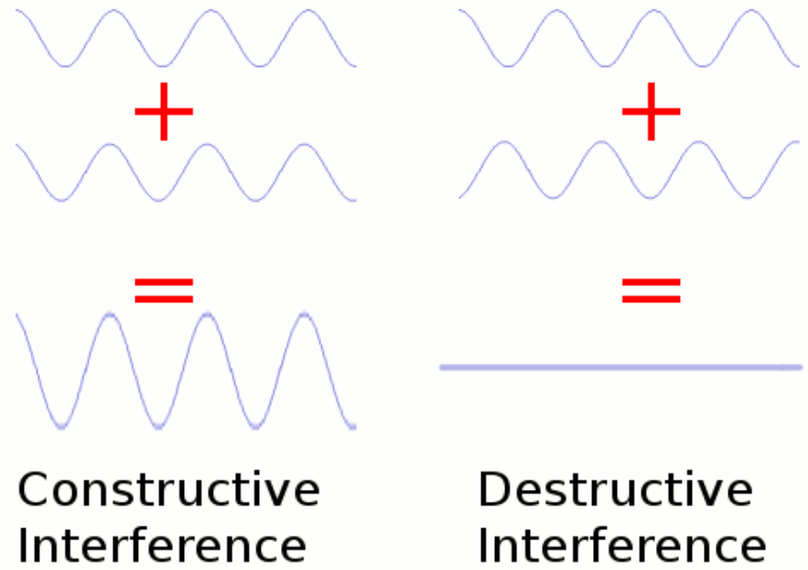


Source: Imperial Network Solutions LLC

"When signals die, there are no packets seen; The heavens themselves blaze forth the death of wireless links." – Julius Caesar (Act 2, Scene 2) {Adapted}

Design Tips for Wireless Backhaul
Interference is The Enemy

- Self Interference: Your own APs
  - Completely under designer's control
  - Select fixed channels, Tx power, and antennas
- External Interference: Neighboring APs
  - Completely NOT under designer's control
  - Requires careful channel selection (even DFS) and AP / antenna locations



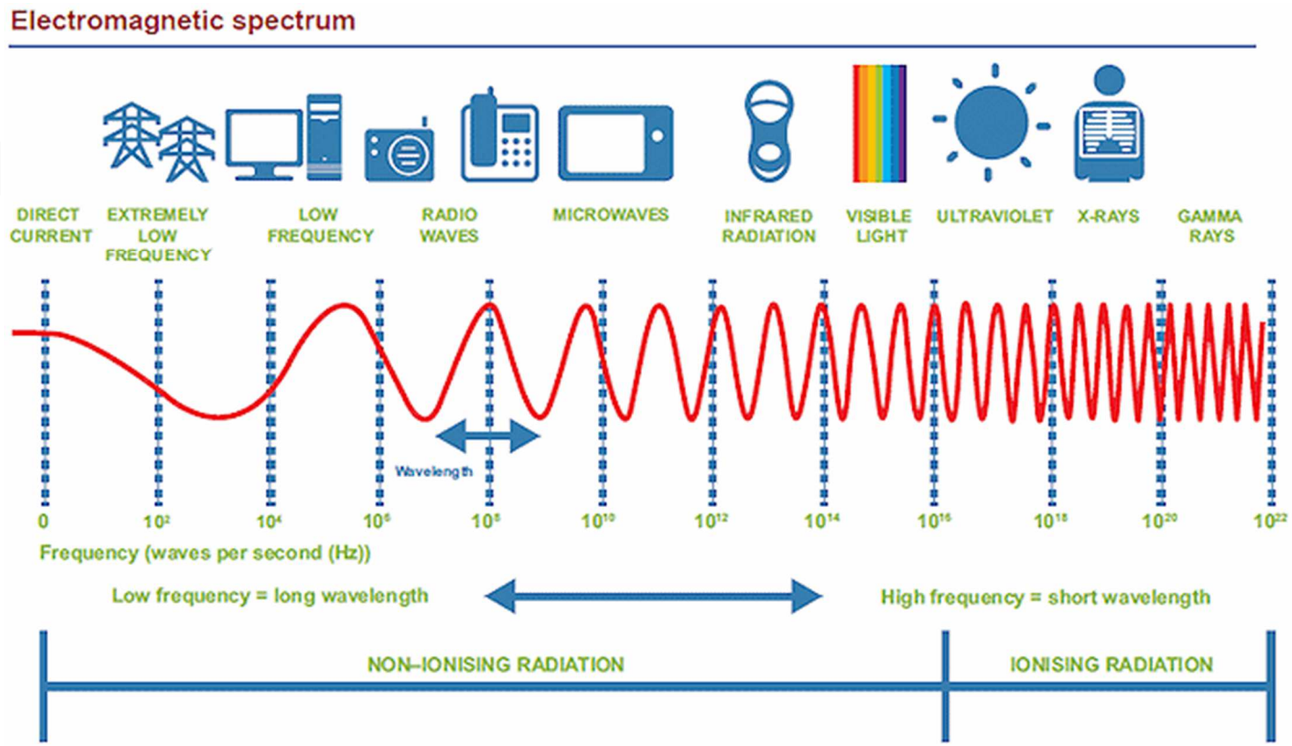
http://ffden-2.phys.uaf.edu/212_spring2011.web.dir/michael_hirte/waveinterference.jpeg

"Silence is the perfectest herault of joy. I were but little happy if I could say how much."
– Much Ado About Nothing (Act 2, Scene 1)

Design Tips for Wireless Backhaul

Know Your Frequencies

- 2.4 GHz and 5 GHz: Infested with Wi-Fi
- Unlicensed Frequencies
  - 80 GHz, 60 GHz (802.11ad), 24 GHz, 3. 5 GHz (CBRS), 900 MHz (ISM)
- Licensed Frequencies
  - 6 GHz, 11 GHz



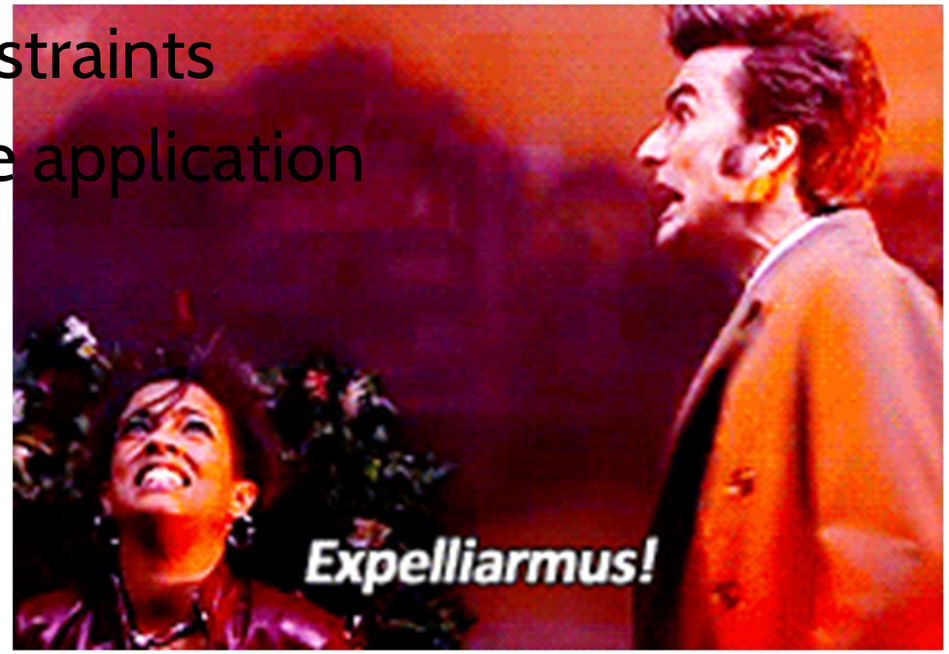
https://justitarchive.files.wordpress.com/2016/05/electromagnetic_spectrum_mthr.gif

"Come, and take choice of all my library, And so beguile thy sorrow."

– Titus Andronicus (Act 4, Scene 1)

Conclusions

- Understand your requirements and constraints
- Select the right wireless backhaul for the application
  - Wired Access Points
  - Client Bridges
  - Repeaters
  - Point-to-(Multi)Point Links
  - Mesh
- Guard against self-interference



Doctor Who, “The Shakespeare Code”
http://33.media.tumblr.com/tumblr_lzitd1LsTk1qjkmbno4_250.gif

“Betwixt Dravidian shores, in Linear 5, 930167.02, and strikes the bosom grove of Rexel 4. Corradiating crystal, Activate!" – Love Labour’s Won (Final Scene)