TOMORROW starts here.
High Density WiFi Networks for Stadiums and Large Public Venues

BRKEWN-2007

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Josh Suhr, Cisco Services, Network Consulting Engineer
TAMING THE BEAST: Dispatches from the front lines of HD WIFI
Agenda

- Design Tips
- Configuration Best Practices
- Enemies of HD Wi-Fi
- Case Study: Big Game
Design Tips
Designing for Efficient RF Relationships

- How clients hear AP’s
- How AP’s hear clients
- How AP’s hear each other
Antenna Selection: Public-Facing Areas

In most high-density areas use directional antennas

AIR-ANT2566P4W-R=
Dual-Band MIMO, 6/6 dBi Gain

• Dual-Band patch
• 802.11n 4x4:3SS
• Used for seating area augmentation, concourses, and other high density areas

AIR-ANT2513P4M-N=
Dual-Band MIMO, 13/13 dBi Gain

• Dual-Band High Gain Patch
• 802.11n 4x4:3SS
• For seating primary coverage
New Stadium Antenna: AIR-ANT2513P4M-N

AIR-ANT2513P4M-N
- Antenna designed for outdoor (stadium) operation with 3702P AP
- Antenna unit has 2 vertically polarized and 2 horizontally polarized ports
- Improved articulating mount, included for use with flat surfaces and masts, permits ease of adjustment in both horizontal and vertical planes
New Stadium Antenna: 2.4GHz Comparison

**Diff View (top diagram)**
- Shows comparative power differences

**Survey View (bottom diagrams)**
- Slightly tighter 2.4GHz beamwidth than AIR-ANT25137NP-R
- -65 RSSI cutoff shown

**KEY:**

![Diagram showing power differences and AP location](image-url)
Diff View (top diagram)
- Shows comparative power differences

Survey View (bottom diagrams)
- Much tighter 5GHz beamwidth than AIR-ANT25137NP-R
- -65 RSSI cutoff shown

KEY:

[Diagram showing comparative analysis]
Non-Seating Areas RF Design Approach

- Concourses should receive coverage while directing energy away from seating
- Suites can be a mixture of patch or omni antennas
- Protect seating areas from unnecessary energy and protect the suites from high RF duty cycle in the seating areas

- Omnis can be deployed where attenuation is used to advantage in Suites
- Omnis require high data rates, low power, and protection from seating areas
- 5GHz band preferred for private Wi-Fi applications
Antenna Placement
Seating Area Coverage

- Proper placement is **critical** to success
- Wi-Fi is a 2-way street!
  - Clients need to hear our transmissions, but we need to hear their transmissions too
- Maximize angle of incidence
  - Ideal placement: above the targeted seats, aimed downward or back
- Know your seats-per-cell target
  - Design should be based on more than that
- Max distance 20m from furthest client when possible; target 12m-15m for best results
Antenna Placement
Seating Area 2.4GHz Channel Plan Example

- Utilize physical features and geometry to reduce unintended coverage
- Segment RF between seating areas and the rest of venue
- Incorporate existing/legacy WLAN constellations to reduce interference
Antenna Placement
Seating Area Coverage: Challenging Areas

Avoid long shots like this

Don’t try to cover clients through concrete!
Antenna Placement
Seating Area Coverage: Challenging Areas

- Creative options may be required for low seating rows
  - Handrails
  - Front walls (aimed away from playing surface)

- Ensure compliance with minimum distances to bodies - >20cm
Antenna Placement
Press/Media Areas and Conference Halls

- Omnis are not ideal for open areas where high capacity is needed
- Create smaller cells with directional antennas mounted above, aimed directly downward
- Understand RRM implications of this type of design
Maximize the Spectrum
Avoiding Excessive Management Traffic

- **Always aim for 1 SSID**
  - **Especially** in seating areas

- **Why?**
  - Each SSID requires a separate Beacon
  - Each SSID will beacon at the minimum mandatory data rate

- Each broadcast SSID will respond to null probe requests
  - **Exponential** amounts of airtime wasted

---

<table>
<thead>
<tr>
<th>Network Configuration</th>
<th>Value</th>
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<tbody>
<tr>
<td>Average Beacon Size (bytes)</td>
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<tr>
<td>Beacon Interval (ms)</td>
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<td>Number of SSIDs per AP</td>
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<tr>
<td>Number of Nearby APs</td>
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<table>
<thead>
<tr>
<th>Basic Data Rate</th>
<th>Bandwith Utilization</th>
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<tr>
<td>1 Mbps</td>
<td>69.12%</td>
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<tr>
<td>2 Mbps</td>
<td>34.56%</td>
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<tr>
<td>5.5 Mbps</td>
<td>12.57%</td>
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<td>11.52%</td>
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<td>9 Mbps</td>
<td>7.68%</td>
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<td>11 Mbps</td>
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<td>12 Mbps</td>
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<td>36 Mbps</td>
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<tr>
<td>48 Mbps</td>
<td>1.92%</td>
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<td>54 Mbps</td>
<td>1.28%</td>
</tr>
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</table>

Results in bps: 691,200
Maximize the Spectrum
Integrate Legacy WLANs

- Efficient HD WLANs are deployed holistically – one infrastructure

- Benefits?
  - Provide consistent configuration management
  - Improve airtime efficiency throughout the venue
  - Legacy management traffic that once chewed up 30-40% of airtime typically drops to < 1% of airtime
  - Allows greater airtime availability
Maximize the Spectrum
Leveraging PHY Rate Tuning

- Size your cells to allow elimination of low rates (i.e., <12mbps)
- Eliminate 11b rates
- Recommend NOT disabling any MCS rates due to interoperability issues with some clients
  - Disabling MCS rates, especially 0-7, can cause significant client issues
1mb Data Rates & Client Performance

iPerf Test #1: Client (first-generation iPad) connected at 1mb data rate

The 24mb PHY connection resulted in 17x as much data being moved across the Wi-Fi network in the same amount of time.

iPerf Test #2: Client (first-generation iPad) connected at 24mb data rate
Client-Induced Interference: What is it?

Common Assumptions
- 75% of fans will have a Smartphone
- 30% of Smartphone users will utilize Wi-Fi
- But what is everyone else doing?
Client-Induced Interference
What does it look like and how can we mitigate?

- Client-induced interference: damaging on 2.4GHz
- Probe requests sent on all channels
  - Many frames on overlapping channels, driving noise floor to be higher/worse
- Getting these devices on your network can help
  - Probe frequency diminishes significantly on an associated device
Maximizing the Spectrum
Ease-of-Use & Client Induced Interference

- Ask yourself - how difficult is it to get on your WiFi network?
- Ease-of-use directly impacts airtime efficiency
- Low take rate = lots of probe request noise (1mb, max power, all channels)
  - Results in Client Induced Interference
- Design for seamless end-user experience
- A device on the network is far less damaging than a device off the network!
Maximizing the Spectrum
Client Induced Interference: 2.4GHz Probing Behavior

For example:

iPhone 5s – iOS v7.0.3
Unassociated:
• Sends 4 probe requests per “learned” network, per channel every 3-6 seconds on channels 1 – 11

Associated:
• Very few probe requests for any network on any channel – almost no client induced interference at all!
Develop an RF Policy

Employ an effective **RF policy** to manage **non Wi-Fi interference** as it occurs

Understand Your Clients

- Identify your target client device types and their key specs
- Test them for yourself!
- Most smartphone radios will have **much** poorer sensitivity than your survey kit’s NIC
  - On average in our testing, 10dB worse!
- Understand popular clients in your market
- Recognize device behavior changes in software updates
Know Your Noise Floor

- **RSSI vs. SNR**
- Clients have varying sensitivity to noise
- Get a feel for your noise floor during peak usage
  - Packet captures with a NIC that you trust (MacBook Pro, etc.)
  - Fluke AirCheck
  - Spectrum Expert
  - Metageek Chanalyzer for Clean Air

### Sample receiver sensitivity table for CB21AG NIC

<table>
<thead>
<tr>
<th>Data Rate</th>
<th>2.4 GHz Min RSSI</th>
<th>2.4 GHz Min SNR</th>
<th>5 GHz Min RSSI</th>
<th>5 GHz Min RSSI</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>-94</td>
<td>4</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>2</td>
<td>-91</td>
<td>6</td>
<td>N/A</td>
<td>N/A</td>
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<td>5.5/6</td>
<td>-89</td>
<td>8</td>
<td>-85</td>
<td>5</td>
</tr>
<tr>
<td>11/12</td>
<td>-82</td>
<td>10</td>
<td>-82</td>
<td>7</td>
</tr>
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<td>24</td>
<td>-77</td>
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<td>18</td>
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<td>48</td>
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<tr>
<td>54</td>
<td>-71</td>
<td>24</td>
<td>-68</td>
<td>20</td>
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</table>

### Sample sensitivity table for MCS rates

<table>
<thead>
<tr>
<th>Data Rate</th>
<th>2.4 GHz Min RSSI</th>
<th>2.4 GHz Min SNR</th>
<th>5 GHz Min RSSI</th>
<th>5 GHz Min RSSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.430</td>
<td>-82</td>
<td>11</td>
<td>-79</td>
<td>14</td>
</tr>
<tr>
<td>28.960</td>
<td>-79</td>
<td>14</td>
<td>-76</td>
<td>17</td>
</tr>
<tr>
<td>43.390</td>
<td>-77</td>
<td>16</td>
<td>-74</td>
<td>19</td>
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<tr>
<td>57.8120</td>
<td>-74</td>
<td>19</td>
<td>-71</td>
<td>22</td>
</tr>
<tr>
<td>86.7180</td>
<td>-70</td>
<td>23</td>
<td>-67</td>
<td>26</td>
</tr>
<tr>
<td>115.6240</td>
<td>-66</td>
<td>27</td>
<td>-63</td>
<td>30</td>
</tr>
<tr>
<td>130.270</td>
<td>-65</td>
<td>28</td>
<td>-62</td>
<td>31</td>
</tr>
<tr>
<td>144.4300</td>
<td>-64</td>
<td>29</td>
<td>-61</td>
<td>32</td>
</tr>
</tbody>
</table>

Data is intended to be an example only.

Rx sensitivity capabilities will vary based upon the receiver in use.
Wireless Services Block

- **Access**
  - SVI Here
  - Switched Link
  - Dual physical links appear logically as a single link
  - Diverse Fiber Paths
  - Redundant Supervisors
  - Redundant Line Cards

- **Core/Distribution**
  - Routed Link
  - Swtiched Link
  - Routed Link

- **Data Center**
  - Services Block

- **L3 to Access**
  - Fully Redundant Core
  - Routed Layer 3 Links to Access Layer & Service Blocks
  - VLANs terminated in Access Layer Switches
  - Routed L3 Links to Service Blocks
  - Highest Reliability

- **L2 to Access**
  - Fully Redundant Core
  - Switched Layer 2 Etherchannel Links to Access Layer (vPC or MEC)
  - 802.1q trunk with VLANs terminated in Core Switches
  - Routed L3 Links to Service Blocks
  - Highest Reliability

- **Single Chassis**
  - Redundant Core with Single Chassis
  - Switched Layer 2 Etherchannel or Routed L3 Links to Access Layer
  - Routed L3 to the Service Blocks
  - High Reliability
Stadium Wi-Fi Configuration Best Practices
Use RF Profiles for Fine-Tuning

- Stadiums are not “one size fits all” from an RF perspective
- Tuning control must be granular
  - Long vs. short seating sections, etc.
  - Accommodate specific devices – 11b rates only where needed
- Before WLC v7.2: Physical Controller Groups
- v7.2+: RF Profiles
Config Tip: RF Profiles

- Provides granular administrative control over:
  - Min/Max TPC values
  - TPC Thresholds
  - Mandatory, Supported, and Disabled PHY Rates (per band)
- RF Profiles are separate for 2.4 GHz or 5GHz bands
  - Profiles are applied to AP Groups
  - All AP’s in the group will assume these RF Profile settings
- More capabilities in 7.4
Understanding RRM: Using WLCCA

- Don’t assume that RRM is broken just because it doesn’t look “right”
- Use the WLCCA to identify and understand neighbor relationships
- Often exposes unintended consequences of the physical installation
Optimizing RRM: TPC

- Calculates Tx power on a per-AP, per-radio basis for every member of the RF group
- Calculations run at 10-minute intervals
- TPC updates are iterative
- Use TPC Thresholds & Min/Max for power level tuning
  - TPC Thresholds for general adjustments
  - Finer adjustments can be made with Min/Max if needed
  - RF Profiles provide granular control

When tuning, be sure you know which WLC is your group leader
Optimizing RRM: DCA

- Exercise caution when setting DCA lists for 5GHz
- Watch DFS frequencies
- Consider eliminating DFS channels for Ticketing AP’s
  - But – DCA lists must be set per WLC
- One possible strategy: on pre-production network, enable DFS channels and watch NCS for DFS events
Enemies of HD Wi-Fi
Rogue APs

- Press/media are prime instigators
- For a recent major sports event, many dedicated DSL modems were installed at the last minute, all of which had 2.4GHz WiFi turned on by default
- MiFi's, Eye-Fi's, and hotspot-enabled smartphones are everywhere
- Low PHY rates, max power
- Often on overlapping channels due to least-congested channel selection
- Causes exponential OTA traffic due to probe requests/responses and beacons

Looks like it belongs… but it doesn’t
Adhoc Rogues

- Adhoc rogues – even in 2014, still a significant problem
  - Beacons, probe requests, probe responses all occupy airtime
  - Users perpetuate the issue by attempting to connect
  - Examples: "MEDIA" SSID in press area at Recent Big Football Game; FPW still very prevalent

- Mitigation: user education and ease-of-use
Non-WiFi Interferers

- Video cameras, wireless audio (Coachcomm, Zaxcom), lighting, pyro, and cryo systems, etc.
- Ever look at a Fluke meter and see zero AP's where you’d expect to see dozens? Non-WiFi Interferers often drown out 802.11 altogether.
- Mitigation: remove them altogether or change frequency if possible
Probe Requests & Responses

- Often #1 frame types in HD
- Especially in smaller enclosed venues
  - NBA, NHL, etc.

Why?
- Stadium is full of mini AP’s with omni antennas (smartphones) probing at 1mbps
- Our radios are high quality and ultra sensitive
- We hear probe requests from client devices far outside our own cell

- Responses can be streamlined to some degree through tuning
Bad Client Behavior

- Pro tip: profile new OS and hardware behavior
- Clients sometimes do things they shouldn’t
- Example: Virtual NAV abuse
  - Does this client device really need to reserve 11,330 microseconds of channel time to Tx a CTS frame? Probably not
Client Chatter

- IPv4: mDNS (Bonjour)
  - In packet captures, look for UDP packets to destination 224.0.0.251 on UDP/5353
  - iOS devices primarily responsible – but some frames also observed from Android devices

- IPv6: mDNS, Link-Local Multicast
  - In packet captures, look for DHCPv6 and ICMPv6 advertisements
  - Android devices primarily responsible – but also some frames from iOS devices

mDNS Packet Example
At one sports event in 2012, Multicast DNS (mDNS/Bonjour) lookups from iOS devices made up **22.5% of all packets** captured on channels 1, 6, and 11 during halftime.

- UDP Multicast to 224.0.0.251 on UDP/5353
Client Chatter: SSDP

- **SSDP** (automated discovery protocol) discovery frames have grown quickly in prevalence as Digital Living Network Alliance (DLNA) services are implemented on more smartphone OS platforms.
- Appears as multicast traffic to 239.255.255.250 on UDP/1900.
Client Chatter: IPv6

- Smartphone OS’s are increasingly chatty with IPv6 discovery/broadcast messages
- DHCPv6
  - Common destination address is ff02::1:2 (all nodes on the local network segment)
- ICMPv6 Nadv
  - Common destination address is ff02::1 (all DHCP servers and relays on local site)
- Check MAC header – if exit from DS, you didn’t hear this directly from the client device and the WLAN is propagating it
Client Chatter: Mitigation

- IPv6
  - Use WLC ACL’s if necessary
  - If no valid need for IPv6, turn it off
    - IPv6 “killswitch” is available in 7.3+
    - WLC CLI: “config ipv6 disable”
  - Consider VLAN ACL’s on switched infrastructure to block propagation of IPv6 advertisements from wired side

- mDNS, SSDP
  - Use WLC ACL’s
  - See the Cisco Wireless LAN Apple Bonjour Deployment Guide for more info
Case Studies: Data to Drive Your Decisions
Case Study: 5GHz Adoption Rates

Stats from a recent sporting event:

- Total Unique Clients: **28,801**
- Total Potential Clients (MSE Probing Clients detected): **55,000**
- **54%** of unique clients connected at 5GHz (11n)
- Legacy A/G clients dwindling rapidly

*Note: Devices which connected to both 2.4 and 5GHz appear once for each protocol.*
Case Study: Top Over-The-Air Protocols

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Description</th>
<th>Packets</th>
<th>Bytes</th>
</tr>
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<tbody>
<tr>
<td>Probe Resp</td>
<td>802.11 Management Probe Response</td>
<td>1,503</td>
<td>407,461</td>
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<tr>
<td>Ack</td>
<td>802.11 Control Acknowledgment</td>
<td>742</td>
<td>10,388</td>
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<td>Beacon</td>
<td>802.11 Management Beacon</td>
<td>651</td>
<td>130,778</td>
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<td>ICMPv6 Neighbor</td>
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<td>605</td>
<td>71,934</td>
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<td>802.11 Management Probe Request</td>
<td>599</td>
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<td>ARP Request</td>
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<td>337</td>
<td>26,274</td>
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<td>CTS</td>
<td>802.11 Control Clear to Send</td>
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<td>802.11 Block ACK</td>
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<td>802.11 Management Action</td>
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<td>RTS</td>
<td>802.11 Control Request to Send</td>
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</tr>
</tbody>
</table>

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Cisco Public
Case Study: Bandwidth Over Time, “Vanity” Event

400,000,000 bps = 400Mbps

Very high output utilization: photo uploads, etc.
Case Study: Rogue APs

From a recent large sporting event:

- **964** Total detected rogue AP’s at -70dBm or higher, including:
  - 200+ MiFi portable hotspots
  - 10+ GoPro live-streaming cameras
  - 30+ Eye-Fi SD Cards
Case Study: Adhoc Rogues

From a large sporting event in 2013:

- Adhoc Rogues
  - 2,752 total detected adhoc rogues, including:
    - “Free Public WiFi”: 1,563
    - “MEDIA”: 595
- “MEDIA” adhoc wildfire ignited & thrived in the Press area
  - Publicize your networks
## Case Study: Creation vs. Consumption

From a recent large sporting event:

<table>
<thead>
<tr>
<th>Category</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate WiFi Traffic (GBytes)</td>
<td>369.9 GB</td>
<td>1.125 TB</td>
</tr>
<tr>
<td>Upstream (Out of the Stadium) (Gbytes)</td>
<td>144.6</td>
<td>683.4</td>
</tr>
<tr>
<td>Downstream (Into Stadium) (Gbytes)</td>
<td>225.3</td>
<td>441.5</td>
</tr>
<tr>
<td>Peak WiFi Throughput IN (Mbps)</td>
<td>75</td>
<td>185.16</td>
</tr>
<tr>
<td>Peak WiFi Throughput OUT (Mbps)</td>
<td>42</td>
<td>396.09</td>
</tr>
</tbody>
</table>
Case Study: Cisco Live Orlando 2013

Data from the first three days of Cisco Live Orlando 2013

- 673 AP’s
- 19,505 unique WiFi devices joined
- 13,000+ max concurrent associations
- 800+ mbps peak throughput
- 43.7% 5GHz (11n), 53.5% 2.4GHz (11n)
Essential Tools
Data-Gathering Tools

WLCCA

- Device Data
  - AP Nearby Info
  - Global Miss

- Device Data
  - Controllers
    - WLC-WLAN-1
    - WLC-WLAN-2
    - WLC-WLAN-3
    - WLC-WLAN-4
    - RF Summary-All controllers

- Access Points
  - Configuration
  - RF Summary
  - ClearAir Persistent Devices
Data-Gathering Tools
WLC Config Analyzer (WLCCA)

- The WLC Config Analyzer (WLCCA) is an extremely valuable tool when tuning large venues

- WLCCA helps us determine:
  - **Configuration consistency** across multiple WLC’s
  - **RF Problem Finder** – determine likely “problem” RF areas
  - **AP Neighbors** – how do AP’s hear each other? Too well, not well enough?
  - Additional views of **CleanAir data**
  - RRM overview with the RF Summary

Download at https://supportforums.cisco.com/docs/DOC-1373
Data-Gathering Tools

WLCCA

Prime & MSE
Data-Gathering Tools
Cisco Prime Infrastructure and MSE

- Up-to-date CPI placement maps are helpful in tuning
- Use these maps in conjunction with WLCCA
- Allows for easy area overview comparisons of AP channels, CU, and power levels
- Easy reference point for number of Associated Clients per radio
Data-Gathering Tools

**WLCCA**

**Prime & MSE**

**OmniPeek and/or Wireshark**
Data-Gathering Tools
OmniPeek and Wireshark

- **OmniPeek/Wireshark**
  - For packet captures of the WLAN, including beacons and other management traffic
  - Helpful for troubleshooting of problems at the source

- **OP-specific features:**
  - Shows breakdown by data rates - very helpful for determining cause of high CU
  - Can do multi-channel aggregation - all three 2.4GHz channels at once (3 NICs) - “Triple Blendy”
Data-Gathering Tools

WLCCA

Prime & MSE

OmniPeek and/or Wireshark

Survey & Analysis
Data-Gathering Tools
AirMagnet Survey & WiFi Analyzer Pro

- **Ekahau Site Survey Pro**
  - Design & Verify
  - Determine **differences in coverage** that occur as a result of tuning changes

- **Airmagnet WiFi Analyzer Pro**
  - Provides **in-depth 802.11-based protocol analysis**
  - Realtime tool, useful during events
Data-Gathering Tools

WLCCA

Prime & MSE

OmniPeek and/or Wireshark

Survey & Analysis

Fluke AirCheck
For quick coverage and cell size checks, use a mobile device (i.e. Fluke AirCheck)
- This **does not replace a site survey** but can allow for more immediate discovery of obvious concerns with the installation – disconnected antennas, for example.
Data-Gathering Tools

WLCCA

Prime & MSE

OmniPeek and/or Wireshark

Survey & Analysis

Fluke AirCheck

Metageek Chanalyzer & CleanAir
Data-Gathering Tools
Metageek Chanalyzer Pro with Cisco CleanAir

- Provides a view of real energy on a channel
- Identify interferers of all types
- Critical part of the “big picture” during live events
Data-Gathering Tools

WLCCA

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Survey & Analysis

Fluke AirCheck

Metageek Chanalyzer & CleanAir

MetaGeek EyePA
Data-Gathering Tools
Eye P.A. – Useful Eye Candy

Packet captures are great but what’s the real story being told?
Data-Gathering Tools

WLCCA
Prime NCS & MSE
OmniPeek and/or Wireshark
Survey & Analysis

Fluke AirCheck
Metageek Chanalyzer & CleanAir
MetaGeek EyePA

YOUR BRAIN = SUCCESS
Key Takeaways

- Design the RF environment with **appropriate antennas and sensible physical placements**
- Employ **HD-focused WLC feature configurations** such as RF Profiles for more flexible and robust designs
- **Understand the key outside factors** that may impact a live HD WLAN, including enemies of performance
- Get comfortable with Wi-Fi analysis and optimization tools to **make informed, data-driven decisions**
Call to Action…

Visit the World of Solutions:-
  - Cisco Campus
  - Walk-in Labs
  - Technical Solutions Clinics

- Meet the Engineer

- **Lunch Time Table Topics**, held in the main Catering Hall

- **Recommended Reading**: For reading material and further resources for this session, please visit [www.pearson-books.com/CLMilan2014](http://www.pearson-books.com/CLMilan2014)
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