# WiFi. Best practices.

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Born and raised a Chicago native, My family migrated to Indianapolis 10 years ago to pursue a dream and open my own Apple consulting business.

We specialize in education and small to medium sized businesses and are a business consultancy focusing on integrating technology solutions for our client base.

When I don't have my face buried in Apple devices I can be found watching my kids play various sports and cooking s'mores over a campfire.

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# Before we start…

Huge shout out for curriculum to:
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# Let's Talk About

- Wi-Fi overview
- WLAN design principals
- Planning for high density
- Troubleshooting

# Wi-Fi Fundamentals

802.11 principles and standards

# 802.11 Standards

| Standard | Frequency | Supported Data Rate | Modulation | Date release |
|---|---|---|---|---|
| 802.11 | 2.4GHz | 1, 2 Mbps | FHSS, DSSS | 1997 |
| 802.11b | 2.4GHz | 1,2,5.5, 11 Mbps | DSSS | Sept 16th, 1999 |
| 802.11a | 5GHz | 6,9,12,18, 24,36,48,54 | OFDM | Sept 16th, 1999 |
| 802.11g | 2.4 GHz | 1,2,5.5,6,9,11,12,18,24,36,48,54 | DSSS, OFDM | June 2003 |
| 802.11n | 2.4 / 5 GHz | Up to 600Mbps | All previous, plus HT-OFDM | Sept 11th, 2009 |
| 802.11ac | 5 GHz | Up to 6.93 Gbps | OFDM | Draft |

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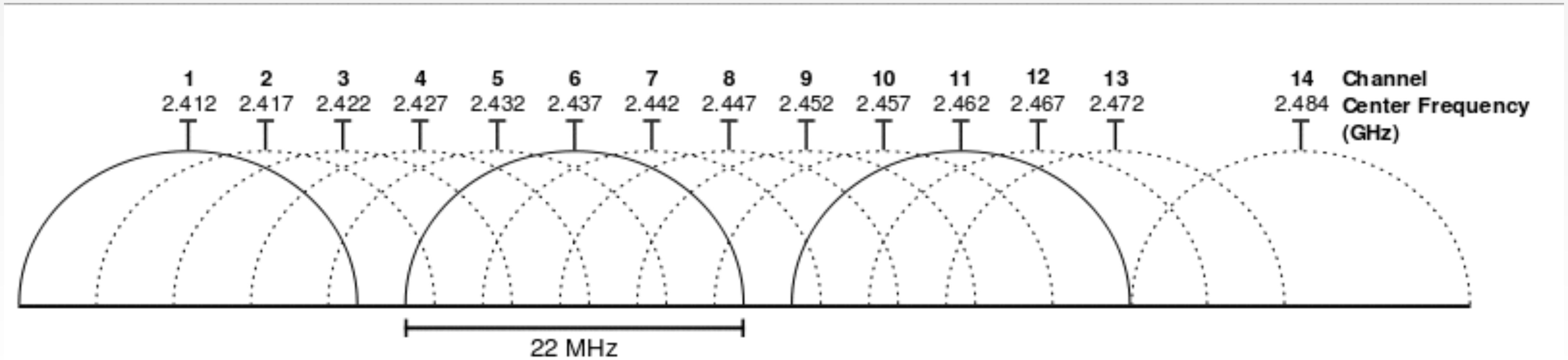
# 2.4 GHz Spectrum

- Only 3 non-overlapping channels (1, 6 and 11)
- Propagates better through obstructions like walls (is this a good or bad thing)
- Widely adopted frequency for millions of devices e.g. smart phones
- Heavily congested frequency
- 40MHz channels is not feasible

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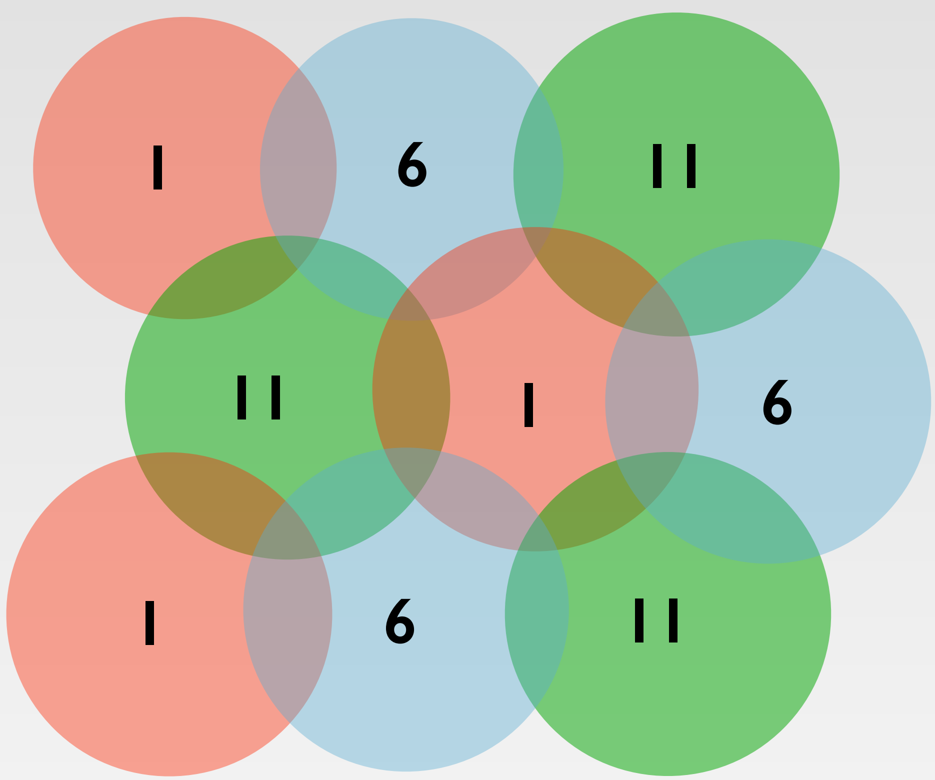
# 2.4 GHz Channel Planning

- Goal: As little interference as possible with non-overlapping channels

- Reality: Not gonna happen

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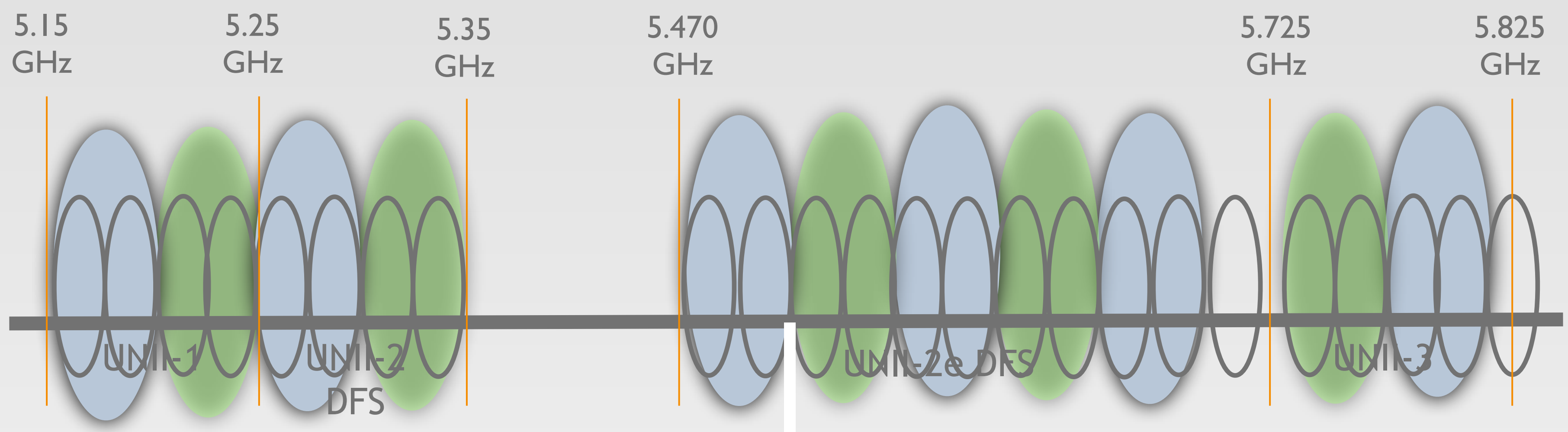
# Why Channels 1, 6, and 11 Suck

- Lots of APs on these channels in urban environments
- Most of those APs are far away from our AP
- Most of those APs are using 1mbps for beacon/mgmt
- Constant sea of 1mbps beacons and probe responses
  - Very low rx power at our AP
  - Irrelevant to our AP
  - Can easily 'overpower' them for our own clients
- Leaving 1,6,11 can fix this problem!

# 5 GHz Spectrum




NON-DFS CHANNELS

| Channels | Width |
|---|---|
| 36, 40 | 40MHz |
| 44, 48 | 40MHz |
| 149, 153 | 40MHz |
| 157, 161 | 40MHz |

- 24 non-overlapping 20 MHz channels
- 11 non-overlapping 40 MHz channels
- Only 4 non-DFS channels for bonding
- Creates channel planning problems similar to 2.4 GHz
- 5 GHz isn't a panacea, RF management is still king

# 5 GHz: The Future of Wi-Fi

- 5GHz band has 6-7 times the available bandwidth of 2.4GHz in most countries.
- Large number of channels allows frequency reuse factors of 4,7,9, or 12+ (compared to 3 for 2.4)
- **Allows for much denser AP placements**
- 8 to 20x the mbps/m2 of 2.4 GHz band (!)

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# 802.11n

- Multiple Transmit/Receive chains (MIMO)
  - Uses Tx:Rx notation, e.g. 3x3
  - Fewer errors, more robust, multi-path is an advantage
- Spatial multiplexing
  - Send different data on different paths = twice the throughput!
  - Streams indicator notation: 3x3:3

| | Minimum Tx/Rx Chains | Spatial Streams | Maximum Link Speed |
|---|---|---|---|
| Single stream | 1x1 | 1 | 150 Mbps |
| 2 stream | 2x2 | 2 | 300 Mbps |
| 3 stream | 3x3 | 3 | 450 Mbps |
| 4 stream | 4x4 | 4 | 600 Mbps |

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# TxBF vs. Multiple Spatial Streams

- TxBF: Transmit Beam Forming
  - Introduced with 802.11n, chip-based beam-forming is used to direct RF signals towards a desired area. Multiple antennas are used to send multiple copies of the same data
- Chip-based beam-forming does not work well with spatial multiplexing
  - Lose streams in favor of TxBF

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# 802.11 MCS Rates Your Best Friend

| MCS Index | Type | Coding Rate | Spatial Streams | Data Rate (Mbps) with 20 MHz CH | | Data Rate (Mbps) with 40 MHz CH | |
|---|---|---|---|---|---|---|---|
| | | | | 800 ns | 400 ns (SGI) | 800 ns | 400 ns (SGI) |
| 0 | BPSK | 1 / 2 | 1 | 6.50 | 7.20 | 13.50 | 15.00 |
| 1 | QPSK | 1 / 2 | 1 | 13.00 | 14.40 | 27.00 | 30.00 |
| 2 | QPSK | 3 / 4 | 1 | 19.50 | 21.70 | 40.50 | 45.00 |
| 3 | 16-QAM | 1 / 2 | 1 | 26.00 | 28.90 | 54.00 | 60.00 |
| 4 | 16-QAM | 3 / 4 | 1 | 39.00 | 43.30 | 81.00 | 90.00 |
| 5 | 64-QAM | 2 / 3 | 1 | 52.00 | 57.80 | 108.00 | 120.00 |
| 6 | 64-QAM | 3 / 4 | 1 | 58.50 | 65.00 | 121.50 | 135.00 |
| 7 | 64-QAM | 5 / 6 | 1 | 65.00 | 72.20 | 135.00 | 150.00 |
| 8 | BPSK | 1 / 2 | 2 | 13.00 | 14.40 | 27.00 | 30.00 |
| 9 | QPSK | 1 / 2 | 2 | 26.00 | 28.90 | 54.00 | 60.00 |
| 10 | QPSK | 3 / 4 | 2 | 39.00 | 43.30 | 81.00 | 90.00 |
| 11 | 16-QAM | 1 / 2 | 2 | 52.00 | 57.80 | 108.00 | 120.00 |
| 12 | 16-QAM | 3 / 4 | 2 | 78.00 | 86.70 | 162.00 | 180.00 |
| 13 | 64-QAM | 2 / 3 | 2 | 104.00 | 115.60 | 216.00 | 240.00 |
| 14 | 64-QAM | 3 / 4 | 2 | 117.00 | 130.00 | 243.00 | 270.00 |
| 15 | 64-QAM | 5 / 6 | 2 | 130.00 | 144.40 | 270.00 | 300.00 |
| 16 | BPSK | 1 / 2 | 3 | 19.50 | 21.70 | 40.50 | 45.00 |
| ... | ... | ... | ... | ... | ... | ... | ... |
| 31 | 64-QAM | 5 / 6 | 4 | 260.00 | 288.90 | 540.00 | 600.00 |

Not just data rates 1, 2, 5.5 and 11 any more; Are you using a single, dual or three stream device for testing. What do your performance numbers mean?

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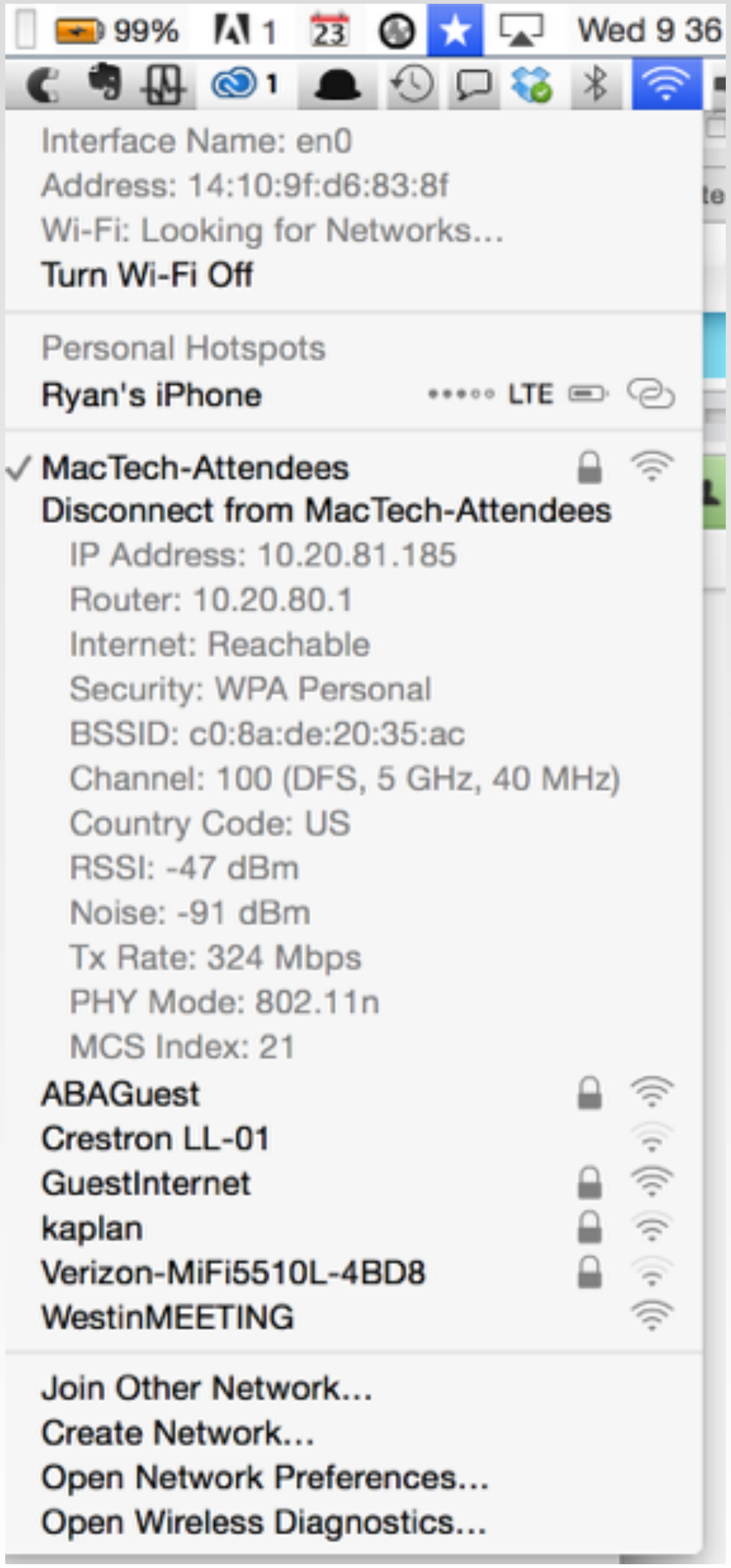
# Check Your MCS

- SNR and MCS will tell the real story
- RSSI is meaningless – don't even bother with it
- Data rates change over time, a one time glance guarantees nothing in the next second!

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# 802.11ac

- The trigger for 5GHz everywhere
- Led by Apple and other consumer specialists
  - In-home device sync, video, backup, etc
  - "Gigabit Wi-Fi" on retail shelves
- 11ac's best feature is that it is 5GHz only
- 11ac Apple devices
  - Newest Macbooks
  - Airport Extreme
  - All 802.11n devices receive a speed boost!

# 802.11ac Performance

- Wave 1 (now)
  - Wider channels (80-160 MHz)
    - Vs. 20-40 MHz for 802.11n
    - Modulation: up to 256 QAM
    - Throughput around 1.3Gbps

- Wave 2 (2015+)
  - More spatial streams (up to 8)
  - Multi-user MIMO (Phase 2)
    - Multiple stations transmit/receive simultaneously
    - Throughput around 3Gbps

# WLAN Design

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# Define Network Requirements

- Coverage area
- Applications
- Type of devices and performance
  - All 1x1? 3x3:3?
- Number of expected devices
- Number of simultaneous devices

# How Much? How Far?

- Everyone wants to know how far an AP can go…
- Answer: It depends.
- Factors:
  - Obstructions (walls, windows, etc.)
  - Construction material (dry wall vs. steel doors)
  - Interference (SNR)
  - How many devices?
  - Minimum application requirements

# Determining AP Capacity

- Determined by number of clients and their airtime consumption

```
Airtime = bandwidth required/max. throughput * 100
AP capacity = airtime * base capacity
```

- 1 Mbps streaming video on tablet w/max throughput of 40 Mbps:

```
1 Mbp/40 Mbps * 100 = 2.5%
2.5% airtime = maximum 40 devices per radio
70% base capacity = 28 devices per radio
```

- Always plan to leave some capacity for future growth.

# Adding Up the Costs

- Take the actual client throughput …
  - TCP: 40%-60% of data rate (PHY)
  - UDP: 60% of data rate (PHY)
- And subtract …
  - Loss from contention/congestion
    - Dependent on number of simultaneous clients
  - Loss from RF interference
    - Dependent on number of networks on same channel as well as errors from adjacent channels
    - Non-802.11 noise

| | Throughput Loss | Achievable Rate |
|---|---|---|
| **TCP protocol** | ~50% (overhead) | 75 Mbps |
| **In a clean environment** | Very little | ~70-75 Mbps |
| **In a busy network** (congestion only, no CCI) | Significant (~25%) | ~50 Mbps |
| **Some outside interference** (CCI/adjacent/non-802.11) | Significant (~25%) | ~37 Mbps |
| **With heavy interference** | Huge | ?? |

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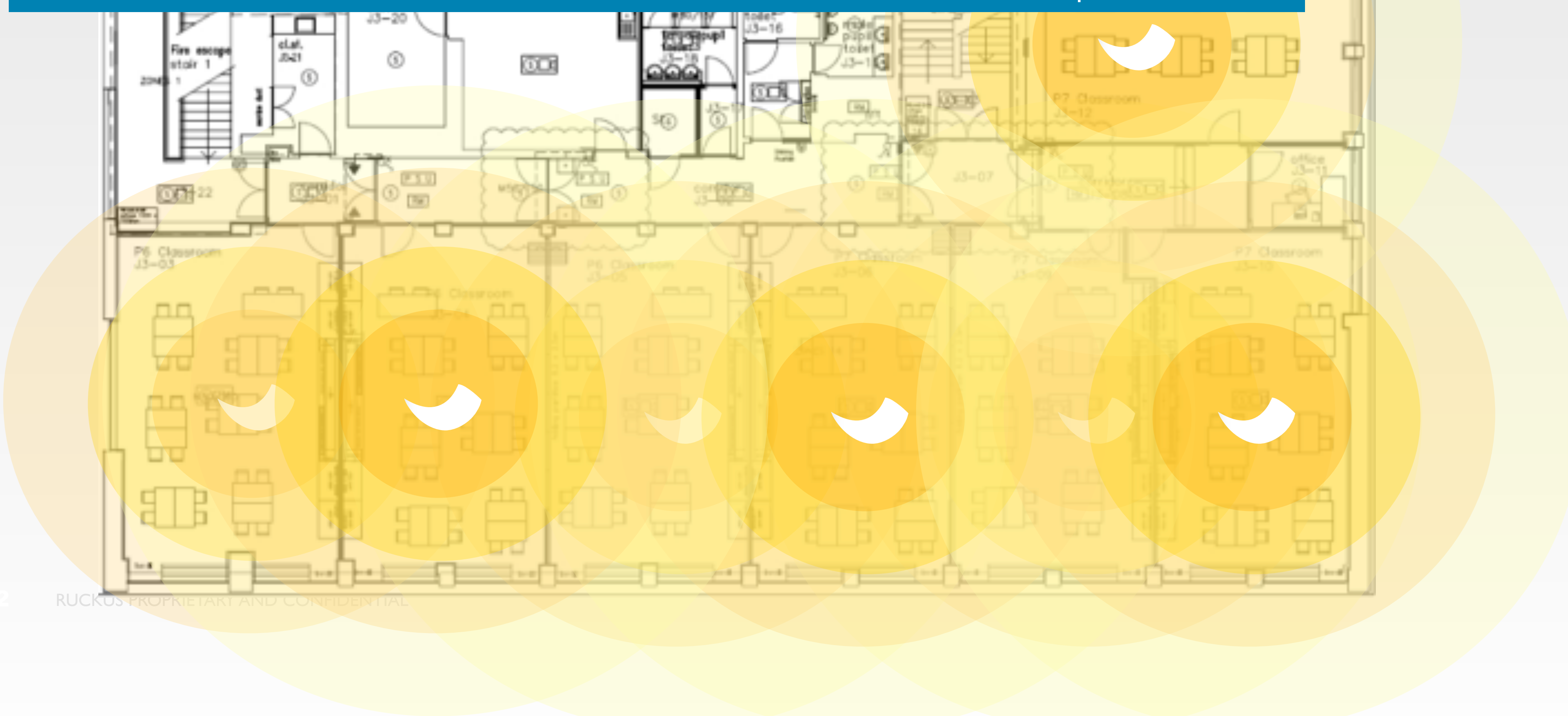
# High Density Math Example

- 7 classrooms with 30 students using 1x1:1 5 GHz tablets
  - Need low latency and about 1 Mbps each for streaming video
  - Simultaneous usage

Number of devices = 210
210 / 7 radios (5 GHz) = 30 clients/radio – no channel overlap
210 / 14 radios (dual) = 15 clients/radio – 4 channel overlap (2.4 GHz)



# High Density Strategies

- 5GHz
- Increase AP count to the extent possible
- Use attenuation (obstacles)
- Frequency re-use via structural separation
- Non-traditional 2.4GHz channel plans
- Use RF simulation tools to optimize design
- Configuration optimizations & adaptive algorithms

# Reducing Transmit Power

- Does not help signal to interference
- Guaranteed to reduce signal to external interference
  - Not good! Your clients should hear you better than someone else
- Lower power = lower transmit speed = clients take longer to get on/off the air
- Reduces capacity

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# More Strategies

- Layer 7 filtering
- Disable background scanning
- Limit # of SSIDs if possible

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# Troubleshooting

# Identify the Problem

**"Email is down" is not useful!**

- Can the client connect?
- Can it authenticate?
- Low performance?
- Roaming?
- Are certain types of clients affected or all?

# Client Can’t Connect

- RF interference may prevent this
- Client is not configured correctly
- Client doesn’t support 5Ghz
- Distance from AP

# Classic Symptoms of RF Interference

- Classic symptoms:
  - Clients drop off network randomly or have difficulty connecting
  - High latency or data loss
  - Huge number of PHY errors (>2500 per second)
- Can be difficult to detect without an RF analyzer

# RF Interference Mitigation

- Things you can do:
  - Eliminate source of interference
  - Change channel assignments (if clear ones exist)
  - Lower transmit power
  - Move clients to 5 GHz – possibly new machines or change WLAN adapter

# Client Can't Authenticate

- Misconfigured authentication
- User name/password incorrect
- Client blacklisted
  - WIPS/WIDS
- Trying to connect to the wrong SSID

# Low Performance

- No strong signal available (no nearby AP)
- High interference
- Low connection rate (MCS)
- Client stickiness
  - Roaming
- **Too many clients per AP radio**
- High latency
- The client just ain't that fast

# Performance Fixes

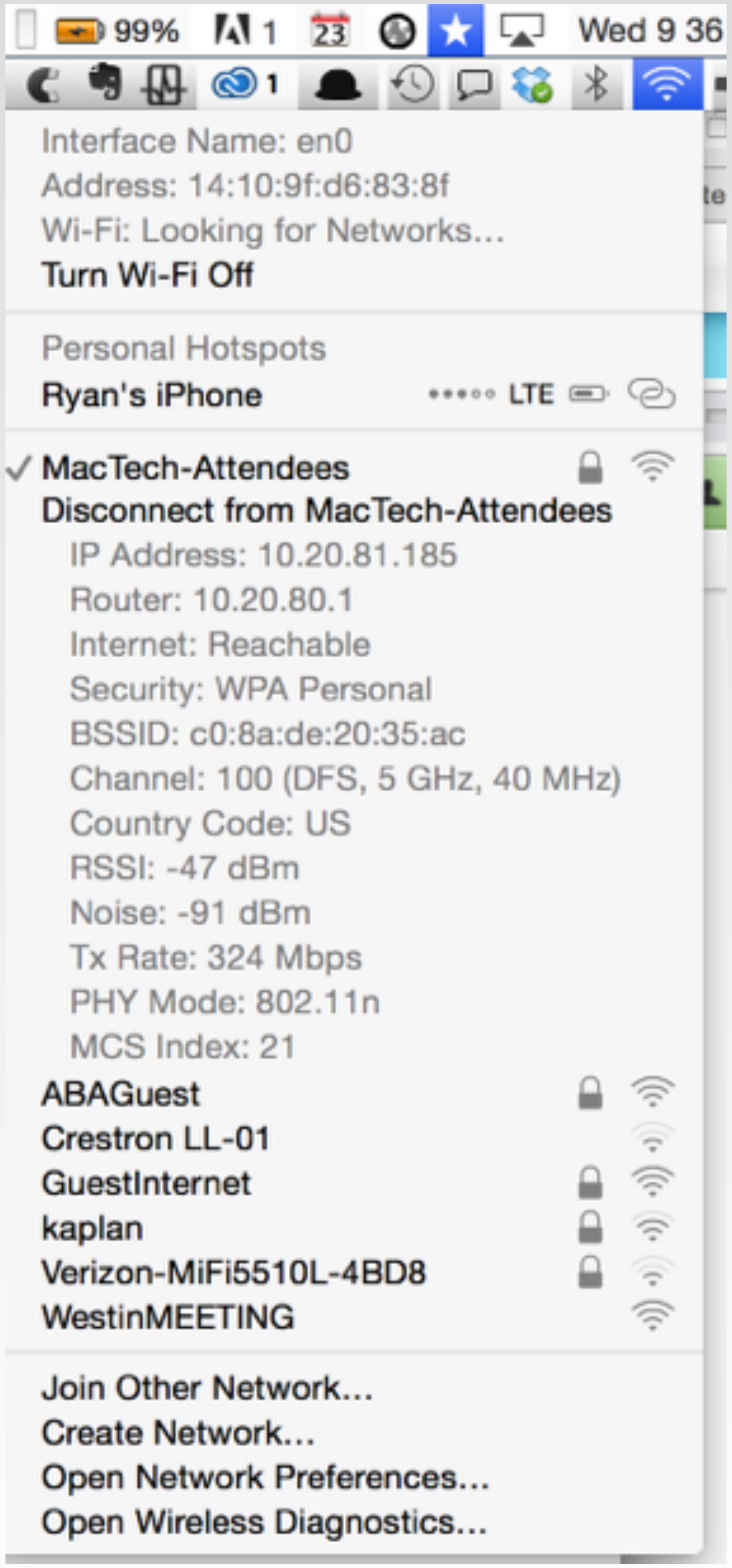
- Add more APs if coverage is too sparse, i.e. clients can get too far away=lower connection rate
- Reduce interference
- More channels
- Increase capacity in areas with excessive number of clients per AP
- Airtime fairness – allows differently capable clients to share medium in a managed fashion

# Essential Troubleshooting Tools

- Different types of clients
  - Isolate driver-specific issues
- Performance test tools
  - iPerf
  - MetaGeek inSSIDer
  - Vendor tools like:
    - Ruckus SWAT, SpeedFlex, Zapper
- RF analyzer (MetaGeek, AirMagnet, etc.)

# Apple-specific Tools

- Check Wi-Fi connection on Mac
  - Hold down Option key and click airport icon in top menu bar
- Learn and use the command line airport tool
- http://osxdaily.com/2007/01/18/airport-the-little-known-command-line-wireless-utility/

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# Do-It-Yourself Performance Testing


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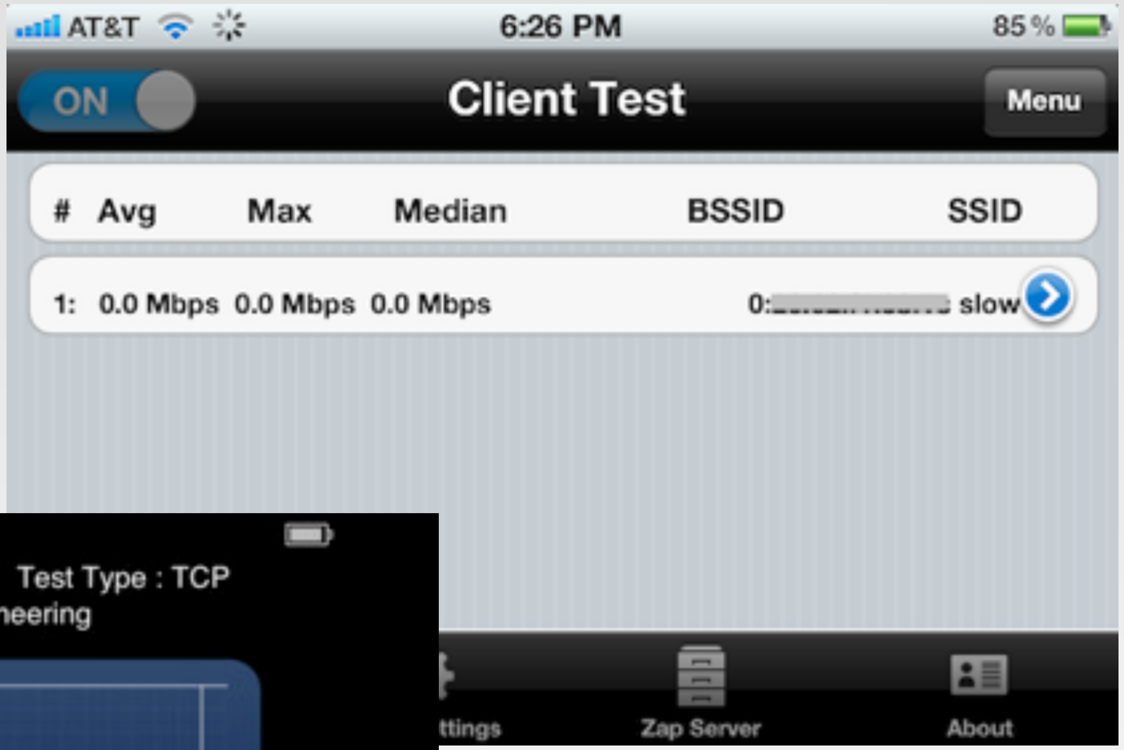
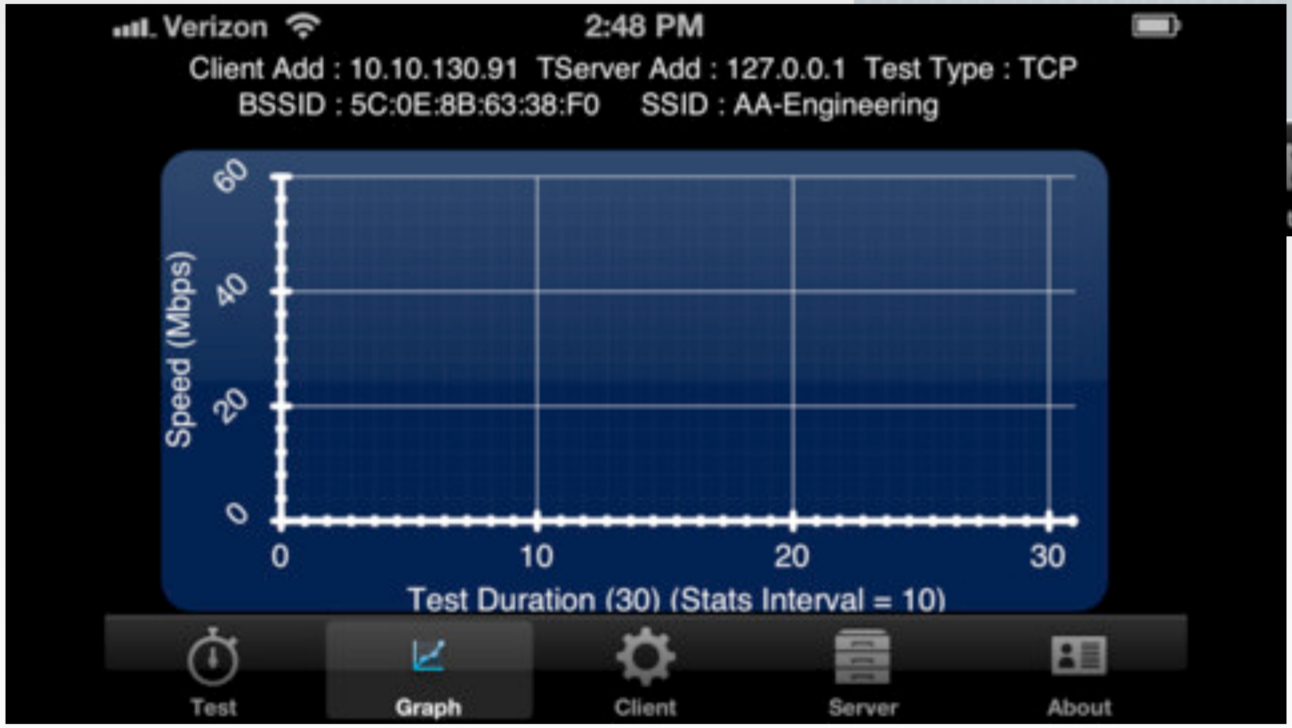
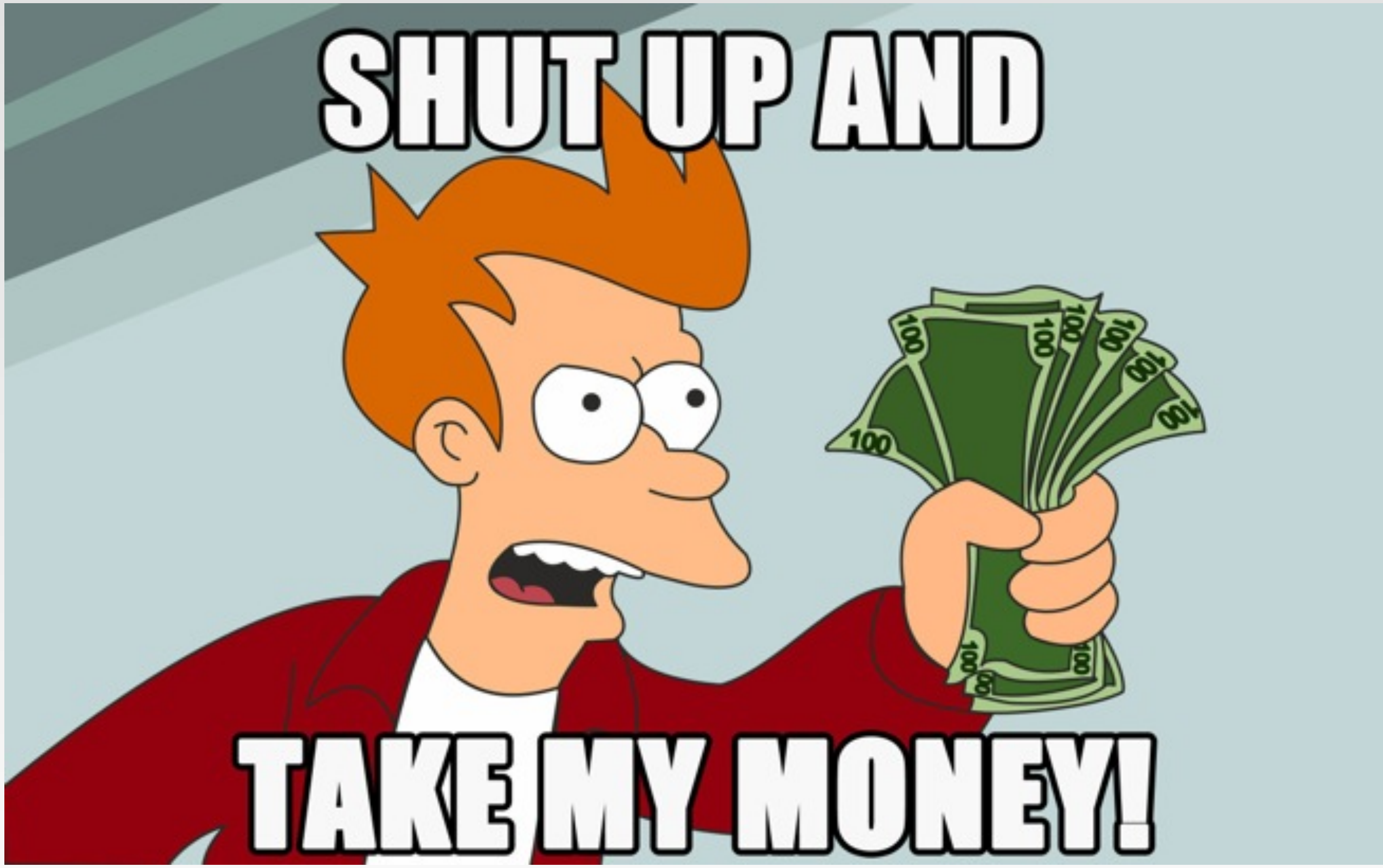
# ZapPerf and iPerf2 (Access Agility)

- Based on zap/iperf
- Available for iOS



# Ok…now what should I buy?

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# Good, Better, Best 802.11ac

- Apple - Small office, small home setting. Limited Management, Limited configurations. $179
- Ubiquiti - Larger Office/Home where more than one AP would be needed. Medium level of management and reporting. $300
- Meraki/Aerohive - Very dense environments such as schools, corporations. High level of management and reporting. $1100-$1500.

# Questions?

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