NEXT GEN WIFI: EVOLUTION BEYOND 11AC

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WI-FI DOMINATES THE HOME
CONSUMERS CRAVE IT

60%

Of respondents can’t last a day without Wi-Fi before missing it.
39% of respondents would give up coffee for one month in exchange for Wi-Fi.
50%

Of respondents would give up Facebook for one month in exchange for Wi-Fi
NEW WIFI USE CASES

- Tethering
- Cellular offload (indoor/outdoor)
- Mirroring: “Project” from mobile devices to large screen
- In-home multiple HD video streaming
- Fast syncing for mobile devices
- Sensors/M2M
- Wearable devices
In the first part we review of WiFi PHY standards evolution up to 11ac
- .11 → .11b → 11a → 11n → 11ac

In the second part we review standardization beyond 11ac
- WiFi is evolving beyond the traditional bands @2.4 and @5GHz.
- WiFi is improving functionality for new use cases
- WiFi is targeting improvements for future dense networks @2.4,5GHz

11ad - 60GHz evolution
11af - Sub 1GHz TVWS spectrum
11ah - Sub 1GHz in unlicensed spectrum
11ai - Fast initial link set-up
11ak - Improved bridging between WiFi and wireline Ethernet
HEW study group - (high efficiency WLAN, no alphabet yet)
The evolution of WiFi to date: 802.11 → 802.11b → 802.11a → 802.11n → 802.11ac
5G WIFI

802.11 2 Mbps
DSSS

802.11b 11 Mbps
DSSS

802.11g/a 54 Mbps
OFDM

802.11n 600 Mbps
MIMO

1st Generation
1997-1998

2nd Generation
1999-2001

3rd Generation
2002-2006

4th Generation
2007-2011

Today!
EVOLUTION OF 802.11 PHY STANDARDS

- **802.11**: 2.4 GHz, 1,2 Mbps
- **802.11b**: 2.4 GHz, 20 MHz channels, DSSS, up to 11 Mbps
- **802.11a/g**: 2.4 & 5 GHz, 20 MHz channels, OFDM, up to 54 Mbps
- **802.11n**: 2.4 & 5 GHz, 20/40 MHz channels, OFDM, MIMO (up to 4 streams)
- **802.11ac** (new features relative to 11n shown in red)
  - 5 GHz
  - OFDM, MIMO (up to 8 streams)
  - 20/40/80/160/80+80 MHz channels
  - 2/4/16/64/256 QAM
  - LDPC
  - MU-MIMO
  - Explicit channel feedback + Beamforming
  - Some features optional
    - LDPC, 160 MHz, 256 QAM, Beamforming, MU-MIMO
Going from 11a to 11ac, both BW and the number of antennas in the spec grew by a factor of 8 leading to a theoretically 64-fold increase in peak throughput. The highest MCS grew by 50% leading to a combined close to 100-fold increase in peak throughput.

The preamble length grew by a factor of 2 reducing efficiency for short packets.

MAC efficiency increased in 11n for short duration packets with the introduction of aggregation.

Finally, MU-MIMO is a DL technique that enables increasing throughput proportionally to the number of antennas at the AP even if the clients have one antenna.
Doubling bandwidth or number of spatial streams approximately doubles rate

Spectrum availability
- 2.4 GHz ISM band: 3 non-overlapping 20 MHz channels, 30 dBm power limit in the US
- 5 GHz ISM band: 25/12/6/2 non-overlapping 20/40/80/160 MHz channels currently in US
  - Some channels have radar detection requirement
  - Power limits: 17, 24, 30 dBm in different bands
  - The FCC is currently considering adding more 5GHz spectrum
For all bandwidths

- OFDM symbol length is 3.2 usec
- Normal cyclic prefix (CP) is 0.8 usec (1/4 of symbol), short CP is 0.4 usec
- Subcarrier spacing is 312.5 kHz

<table>
<thead>
<tr>
<th>BW</th>
<th>NFFT</th>
<th># Data Tones</th>
<th># Pilot Tones</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 MHz</td>
<td>64</td>
<td>52</td>
<td>4</td>
</tr>
<tr>
<td>40 MHz</td>
<td>128</td>
<td>108</td>
<td>6</td>
</tr>
<tr>
<td>80 MHz</td>
<td>256</td>
<td>234</td>
<td>8</td>
</tr>
<tr>
<td>160 MHz</td>
<td>512</td>
<td>468</td>
<td>16</td>
</tr>
</tbody>
</table>

8 pilot tones

11 non-modulated edge tones

3 non-modulated DC tones
### Modulation
- BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM

### Coding
- Binary convolutional coding (64-state): R=1/2 (mother code), 2/3, 3/4, 5/6
- LDPC: same rates, 3 different blocklengths (largest: 1944 coded bits)
- Decoding time limited because the receiver must ACK 16 usec after reception

### Single spatial stream, 80 MHz data rates

<table>
<thead>
<tr>
<th>MCS Index</th>
<th>Modulation</th>
<th>Code Rate</th>
<th>Spectral Efficiency (bps/Hz)</th>
<th>Required SNR for BCC (dB)</th>
<th>Data Rate (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>BPSK</td>
<td>1/2</td>
<td>1/2</td>
<td>0.6</td>
<td>29.3</td>
</tr>
<tr>
<td>1</td>
<td>QPSK</td>
<td>1/2</td>
<td>1</td>
<td>3.6</td>
<td>58.5</td>
</tr>
<tr>
<td>2</td>
<td>QPSK</td>
<td>3/4</td>
<td>1 1/2</td>
<td>6.1</td>
<td>87.8</td>
</tr>
<tr>
<td>3</td>
<td>16-QAM</td>
<td>1/2</td>
<td>2</td>
<td>9.2</td>
<td>117</td>
</tr>
<tr>
<td>4</td>
<td>16-QAM</td>
<td>3/4</td>
<td>3</td>
<td>12.4</td>
<td>175.5</td>
</tr>
<tr>
<td>5</td>
<td>64-QAM</td>
<td>2/3</td>
<td>4</td>
<td>16.4</td>
<td>234</td>
</tr>
<tr>
<td>6</td>
<td>64-QAM</td>
<td>3/4</td>
<td>4 1/2</td>
<td>18.1</td>
<td>263.3</td>
</tr>
<tr>
<td>7</td>
<td>64-QAM</td>
<td>5/6</td>
<td>5</td>
<td>19.3</td>
<td>292.5</td>
</tr>
<tr>
<td>8</td>
<td>256-QAM</td>
<td>3/4</td>
<td>6</td>
<td>23.0</td>
<td>351</td>
</tr>
<tr>
<td>9</td>
<td>256-QAM</td>
<td>5/6</td>
<td>6 2/3</td>
<td>24.7</td>
<td>390</td>
</tr>
</tbody>
</table>
MAC HIGHLIGHTS

▪ Frame aggregation & block ACK’s are extensively used to reduce MAC overhead

▪ CSMA is the basic contention mechanism, but 802.11 contains many improvements which improve its efficiency:
  ▪ A device can reserve the medium for an extended period of time
  ▪ All devices are constantly decoding over-the-air packets to determine if the medium is busy, and every packet contains length information
  ▪ RTS-CTS can be used to extend protection radius

▪ CSMA imposes a strict limit on spatial reuse: nodes within decoding distance of each other are not allowed to simultaneously transmit
  ▪ In dense networks leads to low interference levels but infrequent channel access
PART II

- Beyond 11ac – 11ad, 11af, 11ah, 11ai, 11ak, HEW
IEEE 802.11AD: 60 GHZ WIFI

- Utilizes high frequency spectrum, 7-9GHz available BW centered around 60GHz around the world, to offer very high data rates over shorter range than traditional WiFi
  - A related group, 802.11aj is in the process of defining additional channels specific to China (where only 5GHz is available around 60GHz but 3.5GHz are also available around 45GHz)

- 2 PHY modes: single-carrier (up to 16-QAM, 4.6 Gbps) and OFDM (up to 64-QAM, 7 Gbps)

- Beamforming (TX and RX) is a critical component of 11ad and support is embedded into the standard
  - Beamforming is used to increase the range of the lowest data rate – but beamforming is a closed loop mode and only works after initial link setup -> a separate control PHY is built into the standard to allow for low SNR operation prior to beamforming
  - Beamforming brings about numerous MAC level challenges, e.g., beams are spatially very narrow so beamformed transmissions are likely to not be heard by all devices, which requires a rethink of CSMA
MOBILE-CENTRIC 60G MARKET USE CASES

- **Mobile-to-mobile sync-and-go application**
  - Transferring gigabits of data in seconds
  - Phone/Tablet to Sync&Go/Kiosk application – Download DVD, digital contents in matter of seconds for later enjoyment.

- **Mobile wireless docking and HomeSync application**
  - The docking-end 60G station contains a complex antenna array to maintain a robust link even with much simplified mobile-end 60G
  - Wireless charging is a perfect complementary technology: The connector-less design makes 60G mobile wireless docking a necessity.
  - Access, upload, download handsets content to home media hub.

- **Mobile to UHD/HDTV/Media Link, display, laptop/storage**
  - Screen casting, 3D gaming, video streaming application
  - When the 60G-enabled devices become ubiquitous.
IEEE 802.11AF: WIFI FOR TV WHITESPACES

- Spectrum available between unused VHF/UHF TV channels in a given area
- FCC allowed unlicensed operation in this spectrum, called TV Whitespaces (TVWS), in 2008 with subsequent revisions in 2010 and 2012.
- IEEE is defining 802.11af, the Wireless LAN standard for TVWS
- PHY design: 40 MHz 802.11ac downclocked by 7.5x to give a 5.33 MHz waveform for 6MHz channels (Americas and parts of Asia) and by 5.625 to give 7.11MHz waveform for 8MHz channels (Europe and parts of Asia)
  - Devices may use up to 4 channels for higher throughput
- Initially it was assumed that spectrum sensing would be used to determine free channels using cognitive approaches
  - Sensing requirement <= -114 dBm power levels
- However, the FCC later concluded that sensing alone was not yet a proven technology and geo-location (with database access) was added to the rules. A device needs to know its location up to 50m and then can access a database via the internet and be told which channels are available
- Currently three database providers are approved by the FCC with more coming in the near future.
- Database access spectrum is pioneered in TVWS but may also be used in the future in other spectrum bands to enable sharing of primary (licensed) and secondary (unlicensed) devices
In densely populated areas very few channels are available

Some of this spectrum will be auctioned in 2014 to cellular providers
TVWS POTENTIAL COVERAGE

- **Range:**
  - Roughly 2.9 times radius at 600 MHz carrier frequency when compared to 2.4 GHz carrier frequency (assuming path loss exponent of 3.5)
  - Roughly 2.5 times radius at 600 MHz carrier frequency when compared to 2.4 GHz carrier frequency (assuming path loss exponent of 4)

  - **Range also depends on transmit power** – the FCC defines three categories 4W, 100mW and 40mW EIRP. Portable devices are allowed to be in the 40/100mW categories.
IEEE 802.11AH: SUB 1 GHZ WIFI

- Targeted for longer range lower throughput communication in unlicensed spectrum < 1 GHz, excluding TV white space

- Bands of operation:
  - 902-928 MHz (USA)
  - 863-868.6 MHz (Europe), 915-921 MHz possible in the future
  - 916.5-927.5 MHz (Japan)
  - 755-787 MHz (China)
  - 917–923.5 MHz (Korea)

- Use Cases: sensor networks (especially battery operated devices), smart grid, extended range WiFi

- PHY design: 802.11ac downclocked by 10x (20/40/80/160 MHz channels -> 2/4/8/16 MHz channels)
  - Also added 1 MHz mode (using 32FFT new PHY design) with repetition coding for additional range → lowest throughput 150kbps
  - Many MAC changes to handle large number of devices per AP and for power-savings in sensor-type devices
APPLICATION OF 802.11AH

**Sensors and Meters**
- Smart Grid - Meter to Pole
- Environmental/Agricultural Monitoring
- Industrial process sensors
- Home/Building Automation
- Educational Institutions

**Backhaul Sensor and meter data**
- Backhaul aggregation of sensors
- Simplified network topology

**Machine to Machine Communication**
- Factory Automation
- Medical Devices
- Home Appliances
- Traffic Control
- Smart Cities

**Extended Range Wi-Fi**
- Outdoor extended range hotspot
- Extended range for Home and Building Connectivity
WIRELESS SENSORS NETWORKS: SEGMENTATION

- Highest Growth in Volumes
  - AMI (Advanced Metering Infrastructure)
  - CAGR (74.3%)

- Highest Growth in CAGR
  - Medical  CAGR (223.9%)

- Growth in other segments
  - Home Entertainment
  - Home Automation
  - Building Automation
  - Industrial Automation

Source: ABI Research
TGai aims at providing a fast initial link set-up in less than 100ms under most circumstances
- For busy areas such as the Tokyo Metro station where large numbers of commuters with one or more mobile 802.11 devices arrive at once
- The devices may associate to multiple APs as the commuter traverses the station and associated commercial areas

The initial link setup includes all operations required for IP data exchange:
- Discovery of the network and the BSS
- Authentication and association signaling for security
- IP address configuration

Signaling overhead is reduced during link setup
- Improves link setup performance and reliability
- Reduces power consumption
Many new products have both IEEE 802.11 very high throughput wireless (11ac/11ad) and IEEE 802.3 Ethernet capability

- Home entertainment systems
- Industrial control equipment

Such devices could benefit from being able to bridge between the two media

- 802.11 can then be internal to an 802.1Q bridged network and not just offer access to that network

802.11ak aims to support standard 802.1Q bridging services by creating, together with 802.1Qbz, bridgeable 802.11 links between 11ak access points and 11ak devices/bridges

- Bridging services include Virtual LANs, audio visual stream support, time synchronization for audio visual streams etc
HEW (HIGH EFFICIENCY WLAN) STUDY GROUP

- Formed in March 2013 with the goal of enhancing WiFi in 2.4GHz and 5GHz → successor to 11ac
- Transition to a task group planned for mid 2014
- The group saw very high interest so far. For a list of contributions see https://mentor.ieee.org/802.11/documents?is_dcn=DCN%2C%20Title%2C%20Author%20or%20Affiliation&is_group=0hew

- The dimensions of improvement envisioned are conceptually different from those on slide 10. Focus shifts away from peak per-link point to point throughput enhancements to:
  - Goal 1: Improving spectrum efficiency and area throughput
  - Goal 2: Improving real world performance in indoor and outdoor deployments
    - in the presence of interfering sources, dense heterogeneous networks
    - in moderate to heavy user loaded APs
HEW MAIN DRIVERS

- Increased usage of mobile devices

Most environments will become dominated by a high density of devices and/or APs

- User demand for Wi-Fi anytime and everywhere pushes its usage into many environments characterized by a high density of devices and APs
  - hotspots in airport/train stations, shopping centers, stadiums, parks, streets, campuses

- Increased usage of Wi-Fi leads to an increased density in “traditional” Wi-Fi environments as well
  - home (dense apartments buildings), enterprise

- 2.4GHz already congested in some areas, and likely 5GHz will become congested several years out;

**Growing use of Wi-Fi outdoors**

- Parks, campuses, street deployments
- Coverage of special outdoor events
HEW MAIN DRIVERS(2)

- **Evolution of Wi-Fi applications**
  - Per user average real-world throughput follows a regular year by year increase (pushed by higher resolution video for example)
  - Cloud services and social networks generating more Uplink traffic
  - Increased peer-to-peer applications

- **HEW aims to achieve a very substantial increase in the real-world throughput achieved by each user in such scenarios**
  - Creating an improvement in Quality of Experience for the main use cases and generating spatial capacity increase (area throughput)
SUMMARY

- **WiFi is ubiquitous, but continues to rapidly evolve:**
  - Increased efficiency in current spectrum (2.4GHz & 5 GHz)
  - Moving to new bands (TV whitespace, 900 MHz, 60 GHz)
  - More and more diverse use cases

- **WiFi presents a myriad of technical challenges:**
  - Advanced PHY techniques
  - Low-cost & low-power system-on-chip implementation
  - Improved performance in dense networks and outdoor deployments
Thank you