Evolution and Prospect of Wi-Fi Technology

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Agenda

• Wi-Fi Evolution
  • Throughput Enhancements
  • Long-Range Extensions
  • Greater Ease of Use

• Forward Looking
  • Needs for more spectrum
  • Envisioning Future of Wi-Fi

• Conclusion
Wi-Fi Evolution: Up to Now (1)

- IEEE 802.11 standards and amendments
  - Defines only MAC and PHY
  - Use 2.4 GHz and 5 GHz unlicensed bands

802.11-1997: DSSS, FHSS @2.4 GHz (’97)

802.11-1997 MAC (’97)

.11a: OFDM @5 GHz (’99)

.11b: CCK @2.4 GHz (’99)

.11g: OFDM @2.4 GHz (’03)

.11e: QoS (’05)

.11n: HT @5/2.4 GHz (’09)
Evolution of Wi-Fi

• Throughput Enhancements
• Long-Range Extensions
• Greater Ease of Use

* Comic by Manu Cornet (www.bonkersworld.net)
Wi-Fi Evolution: From Now On

IEEE 802.11 Working Group

- 802.11ac (`13)
- 802.11af (`13)
- 802.11ah
- 802.11ax
  - Throughput enhancement
- 802.11ad (`12)
- 802.11ah
- 802.11aq
- 802.11ai
  - Wi-Fi Direct (Wi-Fi P2P)
- 802.11ai
  - Miracast (Wi-Fi Display)
- 802.11aq
  - Passpoint (802.11u)

Wi-Fi Alliance

- Greater ease of use
Throughput Enhancements

- IEEE 802.11ac
- IEEE 802.11ad
- IEEE 802.11ax
IEEE 802.11ac: Very High Throughput

- Wider channel bandwidth
  - 5 GHz-only successor to 802.11n
  - 20/40/80/160/80+80 MHz channels

- **Downlink Multi-User MIMO (MU-MIMO)**
  - Transmit multiple independent spatial streams to multiple users with few antennas simultaneously

- Higher order modulation
  - 256-Quadrature Amplitude Modulation (256-QAM)
IEEE 802.11ad: Very High Throughput

- **60 GHz Wi-Fi (or WiGig)**
  - Broader channel bandwidth (2.16 GHz)
  - Severe propagation loss and signal attenuation (~10 m)
  - Short wavelength
    - Highly-directional beams enabled by large # embedded antennas

- **MAC feature**
  - Time Division Multiple Access (TDMA) above CSMA/CA for Quality of Service (QoS) provisioning

- **PHY feature**
  - Single Carrier (SC) PHY
    - Short range & low power
  - OFDM PHY
    - Longer range and high power

(source: Panasonic)
IEEE 802.11ax: High Efficiency WLAN (HEW)

- So far, focus on theoretical peak throughput (802.11n/ac/ad)
- Start to consider "real-world" performance
  - Dense deployment followed by inter-WLAN interference
- Enhance 802.11 PHY and MAC in 2.4 GHz and 5 GHz
  - For improving spectrum efficiency and areal throughput in real world densely deployed (indoor & outdoor) environment

Source: wigle.net (2014)
Long-Range Extensions

• IEEE 802.11af
• IEEE 802.11ah
IEEE 802.11af: TV White Space (TVWS)

• Motivation
  • Superior propagation characteristic of low frequency band
  • Legacy spectrum bands are under-utilized

• Super WiFi (or 802.11af) defines TVWS spectrum sharing
  • Among unlicensed devices 802.11af devices and licensed services (TV broadcast, wireless microphone)

• PHY
  • Based on 802.11ac PHY

• MAC
  • Geo-location Database (GDB)-based channel access
IEEE 802.11ah: Sub 1 GHz

• Motivation
  • Superior propagation characteristic of low frequency band
  • 802.11af’s drawback of regulation constraints

• Operation at sub 1 GHz excluding TVWS

• Large-scale low-rate application (e.g., smart grid)
  • Support of more stations (~8,191 stations)
  • Deep power saving

• Scarcity of available bandwidth
  • 10 times down-clocking

802.11ac’s PHY
Greater Ease of Use

• IEEE 802.11ai
• IEEE 802.11aq
• Wi-Fi Direct & Wi-Fi Display
• Passpoint
IEEE 802.11ai: Fast Initial Link Setup

• Motivation
  • Initial link setup is slow and burdensome to users

• Aims at Fast Initial Link Setup (FILS) (< 100 ms)

• Approach
  • Optimizations in AP/network discovery, concurrent cross-layer configuration
  • Passive scanning
    • FILS Discovery frame delivers partial information of beacon more frequently
  • Active scanning
    • Adaptively omit or delay probe frames
IEEE 802.11aq: Pre-Association Discovery

• Motivation
  • Diversified service categories of Wi-Fi
    • Internet access, 3D printer, video streaming, free or not
  • Find “right” AP become more complex

• 802.11aq enables pre-association service discovery
  • By delivering more considerate information to users before association

• Consider how to utilize existing service discovery/description schemes
  • UPnP, Bonjour, ANQP
Wi-Fi Direct & Miracast

• Direct Wi-Fi (based on Wi-Fi P2P spec) communication without infrastructure (AP)

• Mimic former 802.11 WLAN BSS architecture
  • P2P Group Owner (GO): AP-like device
  • P2P Client: station-like device

• GO power saving
  • Opportunistic power saving
  • Notice of Absence (NoA)

• Wi-Fi Direct Services
  • Platform interface to encourage more Wi-Fi Direct applications

• Miracast (based on Wi-Fi Display spec) on top of Wi-Fi Direct
Passpoint

• Motivation

  • Network access in hotspot area is complicated
    • Search and choose a network
    • Request connection
    • (Re)enter authentication credentials

• Passpoint **automates entire network access process**

  • By enabling a seamless connection between hotspot networks and mobile devices
  • Implemented based on IEEE 802.11u and Hotspot 2.0 specs
Forward Looking

- Capacity vs. Coverage
- Needs for more spectrum
- Future of Wi-Fi
- Wi-Fi vs. LTE?
Evolution of Wi-Fi for Smartphones (1)

• More optional features are being added into new models

• Samsung Galaxy S family
  
  • 802.11n: 2.4 GHz band (S) → 5 GHz band (S2) → 40 MHz channel (S3)
  
  • 802.11ac: VHT80 (S4) → 2x2 MIMO (S5) & download booster → MU-MIMO(S6???)

<table>
<thead>
<tr>
<th>Models</th>
<th>S</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
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<td>May 2012</td>
<td>April 2013</td>
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<td>Standards</td>
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<td>Max. Rate</td>
<td>72(?)</td>
<td>72(?)</td>
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<td>433</td>
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<td>New features</td>
<td>802.11n 2.4 GHz</td>
<td>5 GHz support</td>
<td>40 MHz channel bonding</td>
<td>802.11ac VHT80</td>
<td>MIMO (2x2) Download Booster</td>
<td>MU-MIMO?</td>
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</table>
Evolution of Wi-Fi for Smartphones (2)

- LG Optimus family
  - 802.11n: 2.4 GHz band (Optimus 2x) → 5 GHz band & 40 MHz channel (Optimus LTE)
  - 802.11ac: VHT80 (G pro/G2/G3) → 2x2 MIMO & MU-MIMO (G4???)

<table>
<thead>
<tr>
<th>Models</th>
<th>Optimus</th>
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<th>LTE</th>
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<tr>
<td>Max. Rate</td>
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<td>802.11ac VHT80</td>
<td>MIMO? MU-MIMO?</td>
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Evolution of Wi-Fi for Smartphones (3)

- Apple iPhone family
  - 802.11n: 2.4 GHz band (4/4s) → 5 GHz band & 40 MHz channel (5/5c/5s)
  - 802.11ac: VHT80, MIMO, and MU-MIMO(6???)

<table>
<thead>
<tr>
<th>Models</th>
<th>iPhone</th>
<th>3G/3GS</th>
<th>4/4S</th>
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<td>802.11ac? MIMO?</td>
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Capacity vs. Coverage

- Various rates and coverage due to different spectrum
  - Low frequency spectrum → long range
  - High frequency spectrum → high rate
Augmented Spectrum Heterogeneity

- Region-dependent spectrum availability

IEEE 802.11ac @5 GHz

IEEE 802.11af @TVWS

IEEE 802.11ad @60 GHz

IEEE 802.11ah @Sub 1 GHz
Wi-Fi Forward

• Motivation
  • Ever-increasing demand for data and overloaded spectrum

• Wi-Fi Forward
  • A group of companies, organizations and public sector institutions
  • For protecting existing unlicensed spectrum designations
  • For freeing up new unlicensed spectrum, including low, medium, and high frequency bands
  • For establishing (investment) friendly, transparent and predictable rules that encourage growth and deployment
Envisioning Future of Wi-Fi

• Will all Wi-Fi ecosystem be possible in the future?!?
Wi-Fi vs. LTE-A

• Competitive or complementary?

• Competition with LTE-U
  • Carrier aggregation of LTE-A aggregating licensed spectrum and unlicensed spectrum @5 GHz

• Interworking between Wi-Fi and LTE
  • e.g., Samsung Galaxy S5’s download booster using LTE-A and Wi-Fi simultaneously

(source: Qualcomm)
Conclusion

• Wi-Fi continues evolving to keep pace with
  • Spectrum availability
  • Technological development

• Three main direction of evolution
  • Throughput enhancements
  • Long-range extensions
  • Greater ease of user

• Future vision
  • More diversified services with spectrum heterogeneity and greater ease of user
  • Close interworking with cellular technology as part of 5G wireless
Reference


