Wi-Fi Could Be Much More

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Weiping Sun, Okhwan Lee, Yeonchul Shin, Seongwon Kim, Changmok Yang, Hyoil Kim, and Sunghyun Choi, "Wi-Fi Could Be Much More," to appear in IEEE Communications Magazine, Special Issue on The Future of Wi-Fi, Nov. 2014.

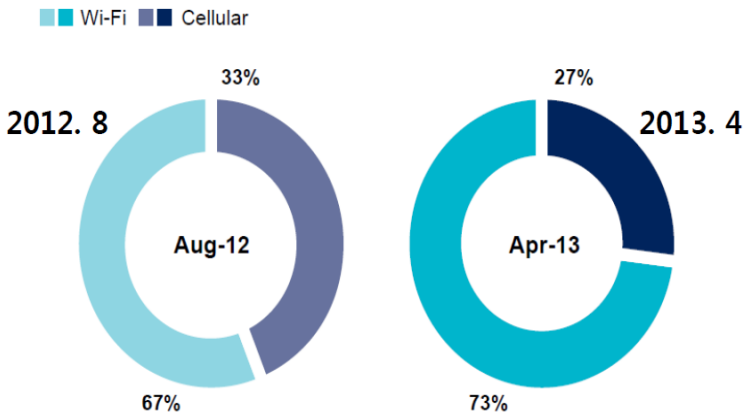
Agenda

- Introduction
- 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 Market

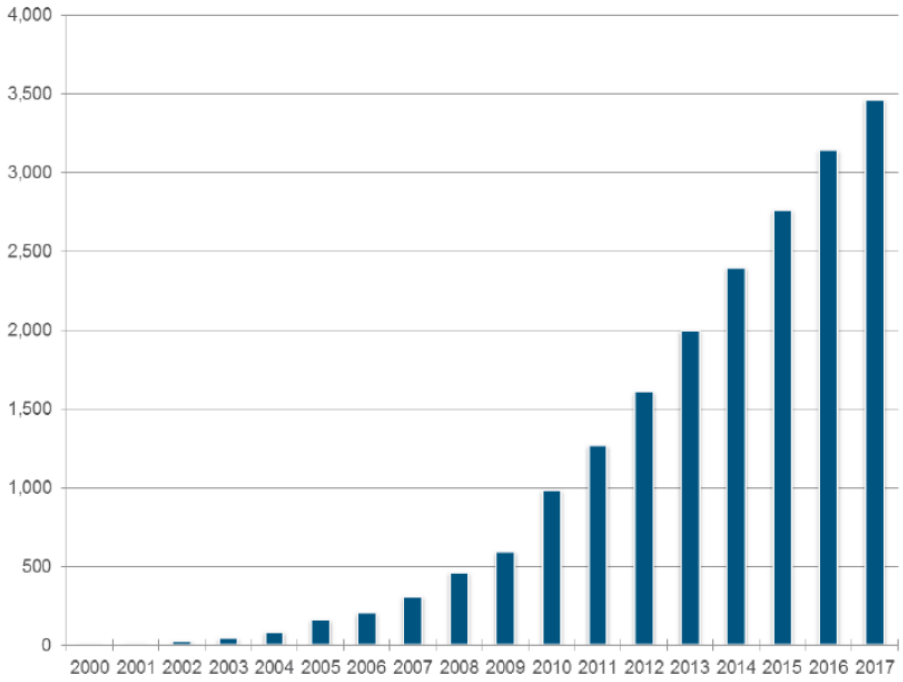
- **Wi-Fi data traffic in smartphone is more than 2X of cellular**

Android smartphone data traffic (Canada, Germany, Japan, South Korea, UK, US)



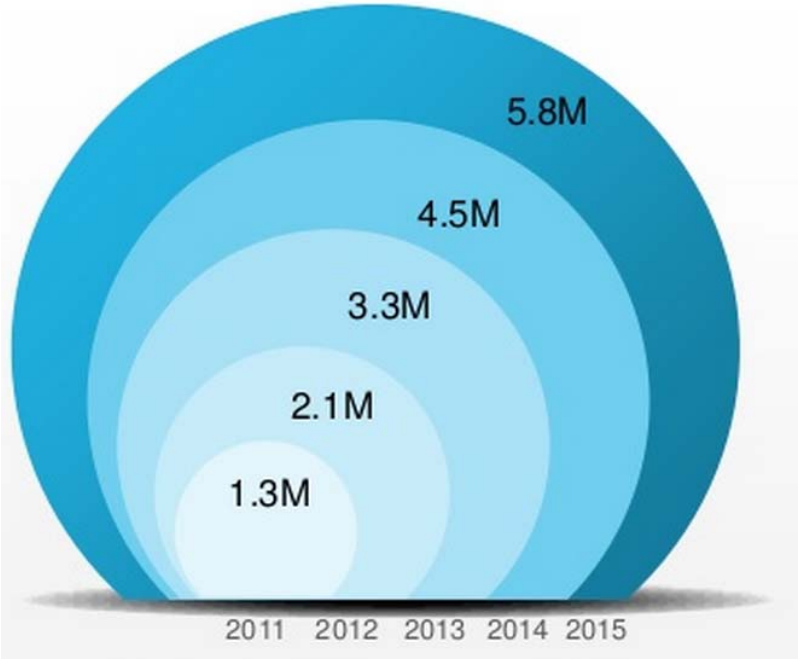
Source: Mobidia'13

Wi-Fi chipset shipments (millions of units)



Wi-Fi Is Becoming Ubiquitous

Growing global deployments



Number of public hotspots worldwide

Source: Wireless Broadband Alliance (WBA) and Informa Telecoms & Media

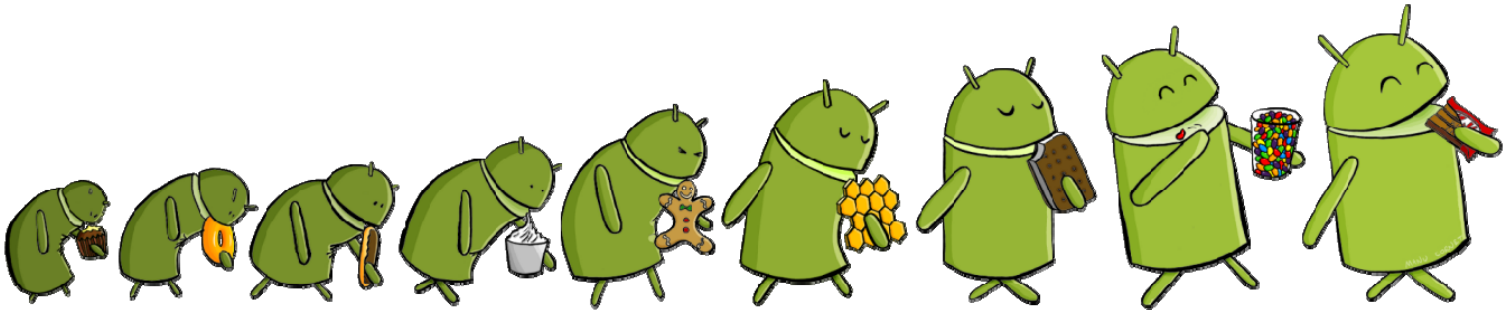
Expanding device support

Wi-Fi Enabled Devices Shipped	2012 MU	2015 MU
Phones/Accessories	685	1,459
Tablets, E-Readers, Media Players, etc	199	360
Laptops, Desktops, Peripherals, etc.	392	717
Connected Home	107	287
Others	39	338
TOTAL	1,422	3,161

Source: ABI Research Forecast 2012

Wi-Fi Connects More Than the Internet

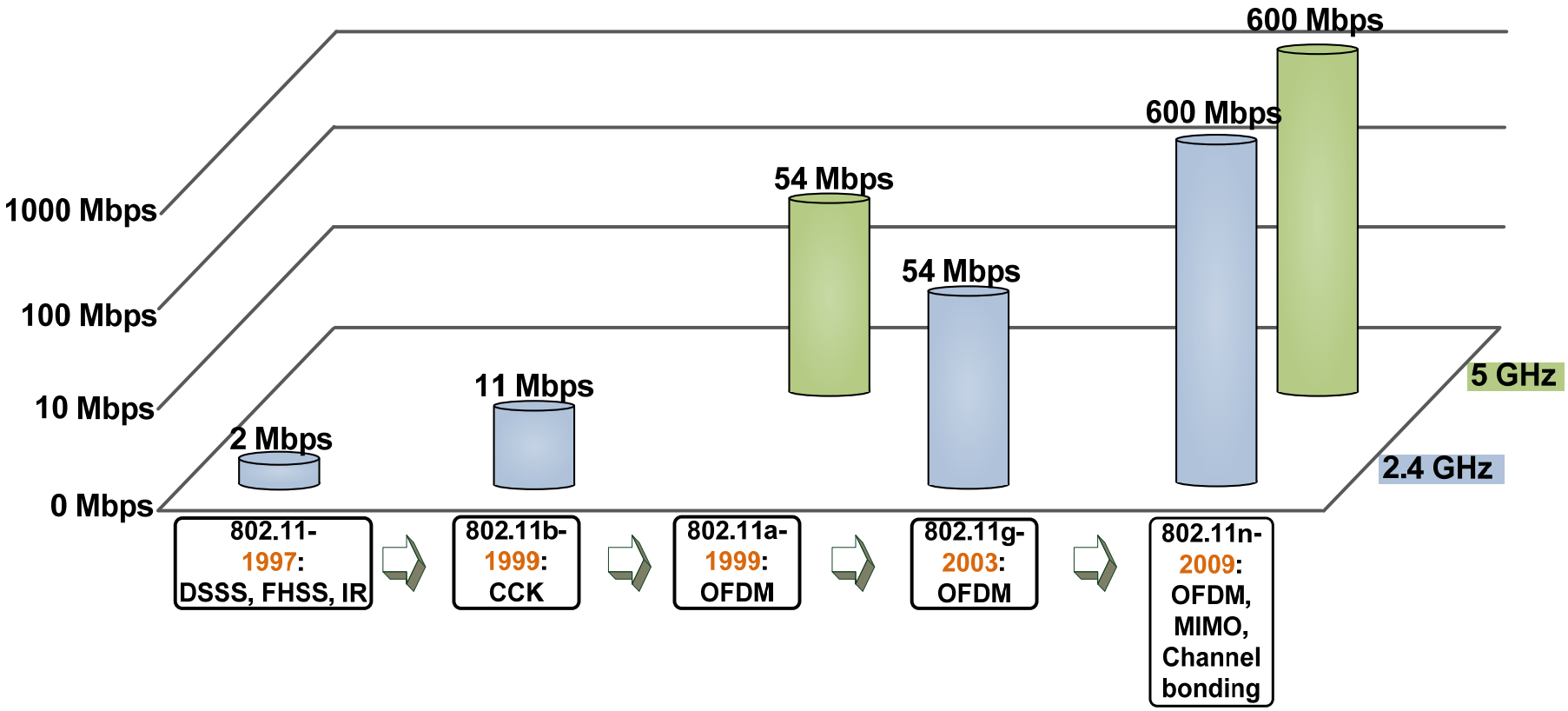
- Wi-Fi has connected ever-expanding range of user-centric devices last 10 years
- By 2013, Wi-Fi was installed in more than 4 billion devices [ABI Research, Nov. 2013]
- By 2015, more than 725 million households around the world will have Wi-Fi connection [HIS iSuppli, May 2013]



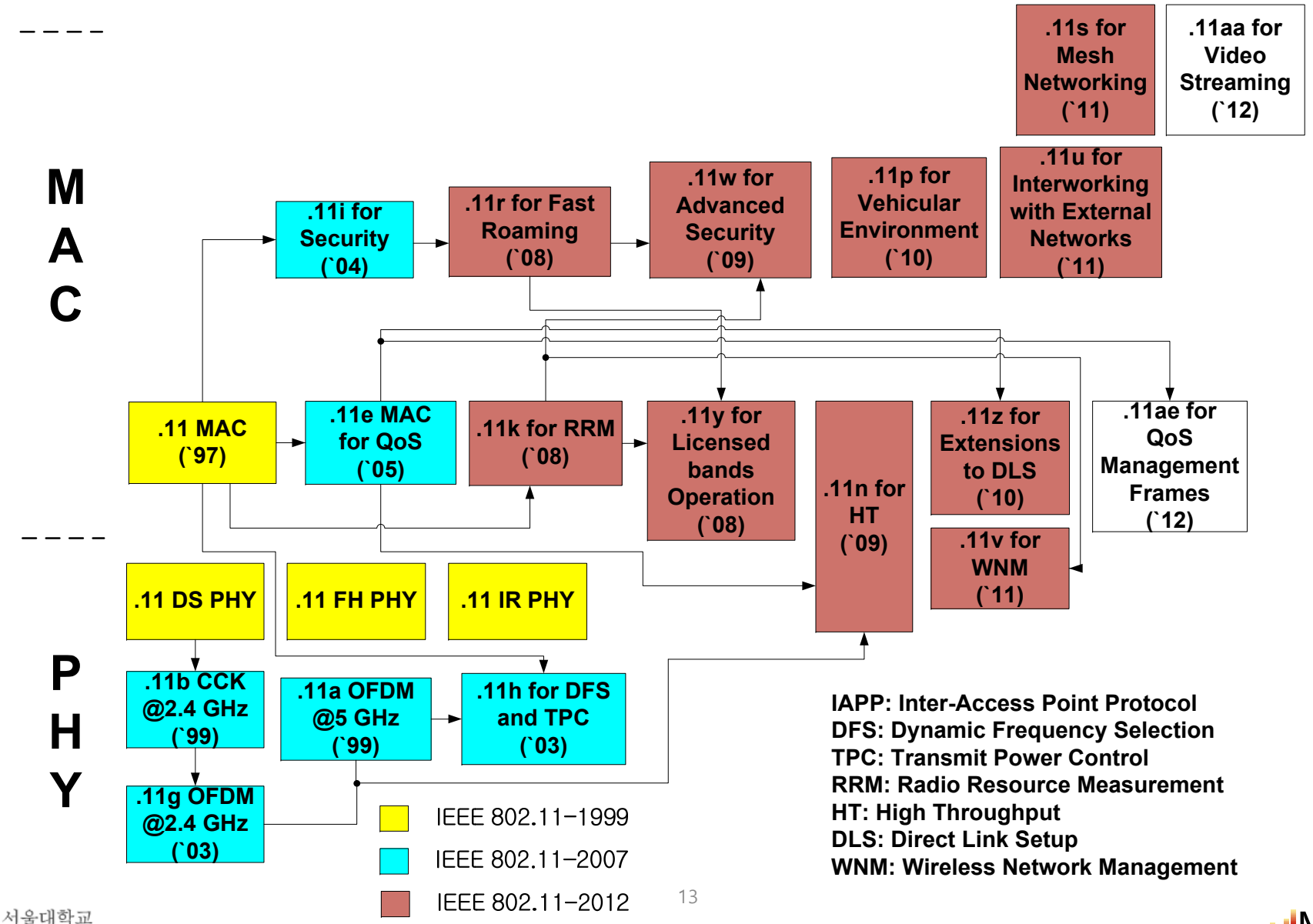
Evolution of Wi-Fi

Wi-Fi Evolution: Up to Now (1)

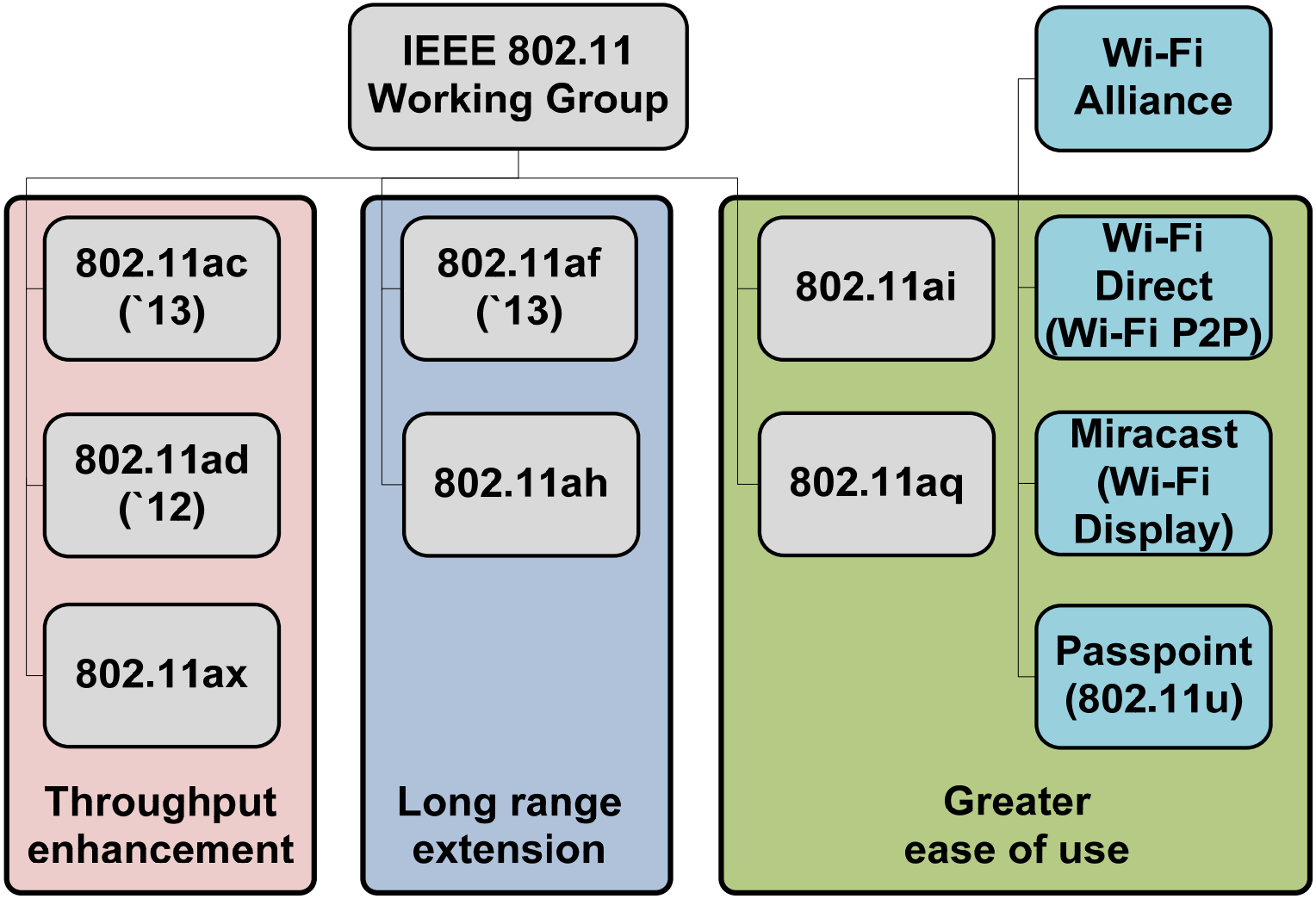
- IEEE 802.11 a/b/g/n
  - Defining PHY/MAC at 2.4 & 5 GHz ISM bands



Wi-Fi Evolution: Up to Now (2)



Wi-Fi Evolution: From Now On

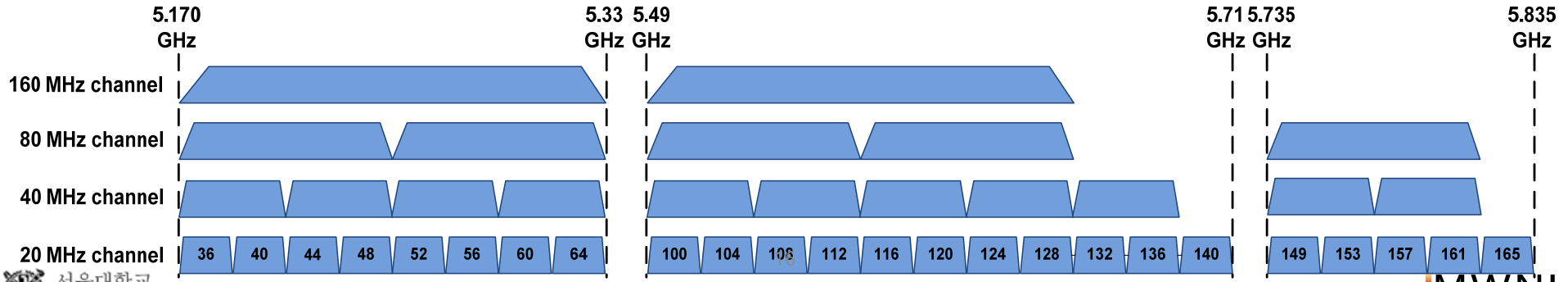


Throughput Enhancements

- IEEE 802.11ac-2013
- IEEE 802.11ad-2012
- 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 802.11ac Modulation and Coding Schemes (MCSs)

MCS index	Modulation	Code rate	Data rate (Mbps)	
			20 MHz N_{ss}=1	160 MHz N_{ss}=8
0	BPSK	1/2	7.2	520
1	QPSK	1/2	14.4	1040
2	QPSK	3/4	21.7	1560
3	16-QAM	1/2	28.9	2080
4	16-QAM	3/4	43.3	3120
5	64-QAM	2/3	57.8	4160
6	64-QAM	3/4	65	4680
7	64-QAM	5/6	72.2	5200
8	256-QAM	3/4	86.7	6240
9	256-QAM	5/6	N/A	6933.3

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?)

Models	S	S2	S3	S4	S5	S6
Release date	June 2010	May 2011	May 2012	April 2013	April 2014	April 2015?
Standards	802.11b/g/n SISO	802.11a/b/g /n, HT20 SISO	802.11a/b/g /n, HT40 SISO	802.11a/b/g /n/ac, VHT80 SISO	802.11a/b/g /n/ac, VHT80 MIMO (2x2)	?
Max. Rate	72(?)	72(?)	150	433	867	?
New features	802.11n 2.4 GHz	5 GHz support	40 MHz channel bonding	802.11ac VHT80	MIMO (2x2) Download Booster	MU-MIMO?

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?)**

Models	Optimus	2x	LTE	G Pro/G2/G3	G4
Release date	Jan. 2010	Dec. 2010	Oct. 2011	Feb. 2013 Aug. 2013 May 2014	Aug. 2015?
Standards	802.11b/g SISO	802.11b/g/n SISO	802.11a/b/g/n, HT40 SISO	802.11a/b/g/n/ ac, VHT80 SISO	?
Max. Rate	54	72(?)	150	433	?
New features	2.4 GHz	802.11n 2.4 GHz	5 GHz Support Channel bonding	802.11ac VHT80	MIMO? MU-MIMO?

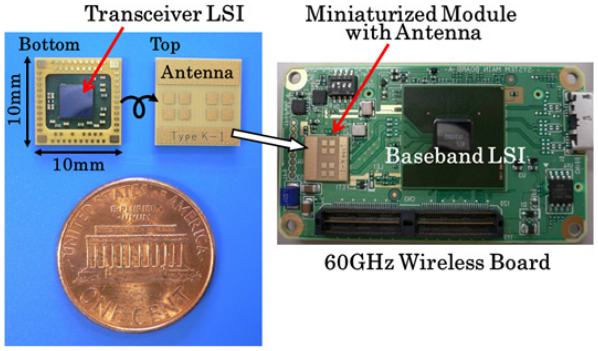
Evolution of Wi-Fi for Smartphones (3)

- **Apple iPhone family**
  - **802.11n: 2.4 GHz band (4/4s) → 5 GHz band & 40 MHz channel (5/5c/5s)**
  - **802.11ac: VHT80 (6) → MIMO and MU-MIMO (7?)**

Models	iPhone	3G/3GS	4/4S	5/5c/5s	6
Release date	June. 2007	Jul. 2008, Jul.2009	Jun. 2010, Oct. 2011	Sep. 2012 Sep. 2013	Sept. 2014
Standards	802.11b/g SISO	802.11b/g SISO	802.11b/g/n SISO	802.11a/b/g/n, HT40 SISO	802.11a/b/g/n/ ac, VHT80 SISO
Max. Rate	54	54	72(?)	150	433
New features	802.11b/g 2.4 GHz		802.11n 2.4 GHz	5 GHz support Channel bonding	802.11ac VHT80 Wi-Fi Calling

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
    - Low power consumption
  - OFDM PHY
    - Long range with large delay spread



Large # of **on-chip antennas**

(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

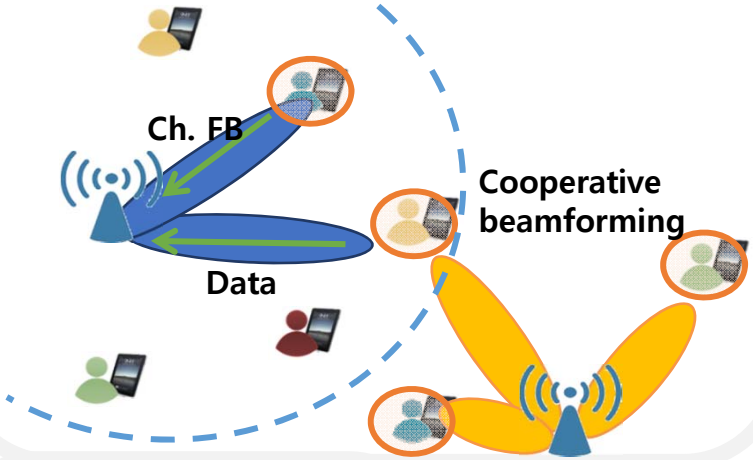
Source: wigle.net (2014)

IEEE 802.11ax Scope

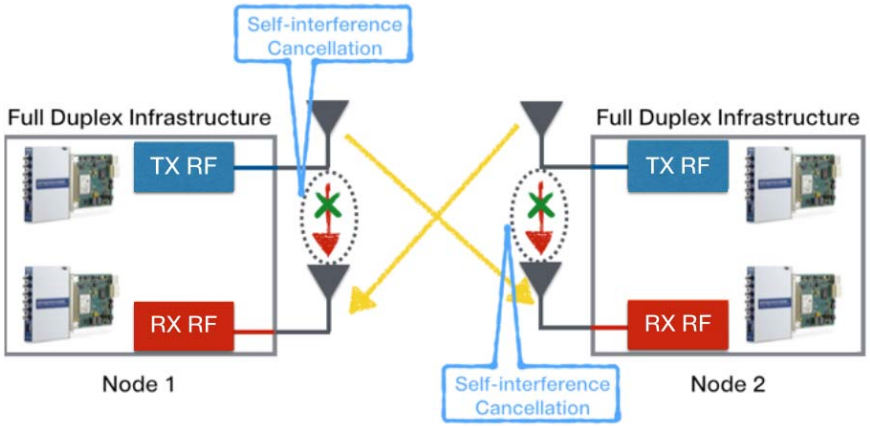
- Scope defined in Project Authorization Request (PAR)
  - At least 4X improvements in the average throughput per STA
    - Throughput is measured at MAC data service access point
    - 5-10X improvements are expected depending on technology and scenario
  - Improving power efficiency per STA
  - Indoor and outdoor operations in frequency bands between 1 GHz and 6 GHz
  - Enabling backward compatibility and coexistence with legacy IEEE 802.11 devices operating at same band

IEEE 802.11ax Candidate Approaches

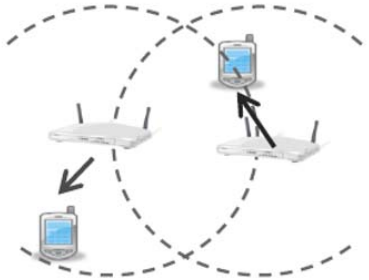
Uplink MU-MIMO & OBSS cooperation



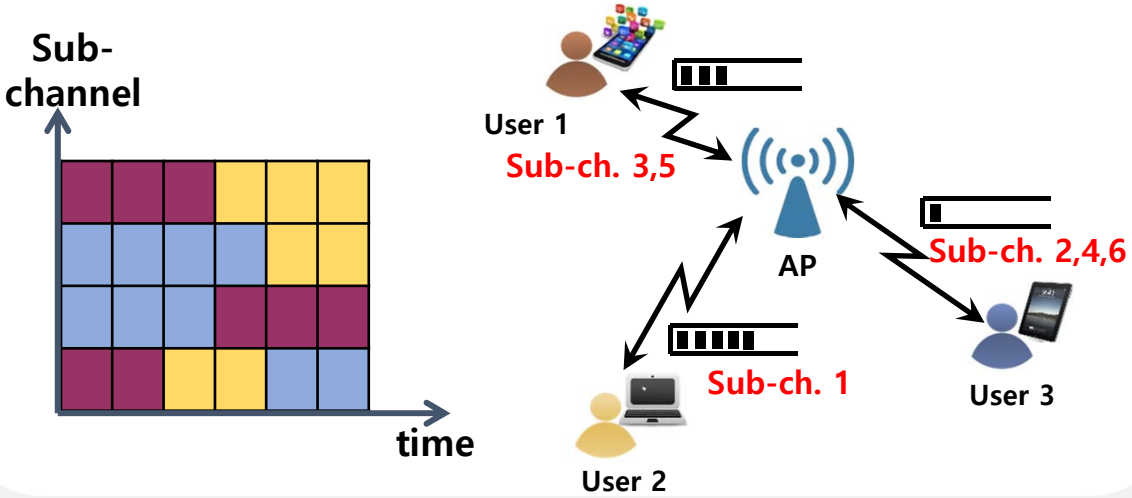
Simultaneous Transmit and Receive (STR)



Dynamic Sensitivity Control (DSC)



Orthogonal Frequency Division Multiple Access (OFDMA)



Long-Range Extensions

- IEEE 802.11af-2013
- IEEE 802.11ah

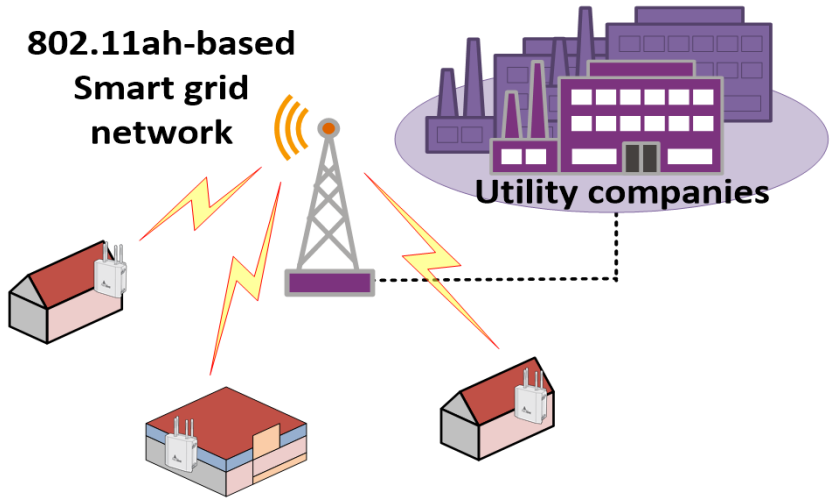
IEEE 802.11af: TV White Space (TVWS)

- 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 Alliance Certification Programs

- Connectivity
  - Interoperable connectivity: Wi-Fi CERTIFIED a/b/g/n/ac
  - Wi-Fi Direct: Connect Wi-Fi devices without AP
- Security
  - WPA2 (government-grade security mechanism), EAP (for enterprise)
- Access
  - Passpoint
  - Wi-Fi Protected Setup (PIN, pushbutton, etc.)
- Applications and Services
  - Miracast
  - Voice-Enterprise, Voice-Personal
- Optimization
  - TDLS
  - WMM

Wi-Fi Direct & Miracast

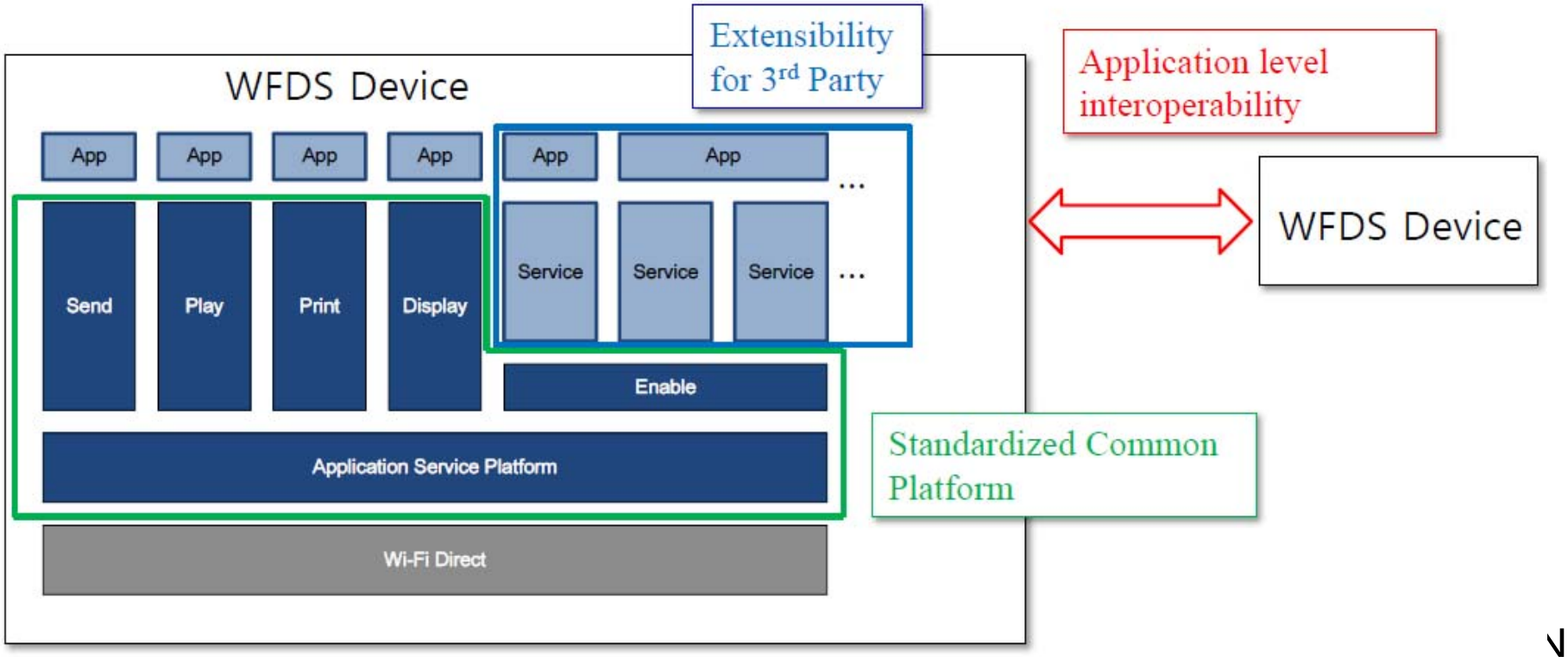
- Direct Wi-Fi (based on Wi-Fi P2P spec) communication without infrastructure (AP)
- Mimic former 802.11 WLAN BSS architecture
  - P2P Group Owner (GO): AP-like device
  - P2P Client: station-like device
- GO power saving
  - Opportunistic power saving
  - Notice of Absence (NoA)
- Wi-Fi Direct Services
  - Platform interface to encourage more Wi-Fi Direct applications
- Miracast (based on Wi-Fi Display spec) on top of Wi-Fi Direct

Galaxy's S-Beam

Galaxy's Screen Mirroring (or All Share Cast)

Wi-Fi Direct Services (WFDS)

- Define architecture, protocol and functionality for interoperability of Wi-Fi Direct Services
- Address solution requirement areas
  - Send, play, print, display, enable, application service platform



Passpoint

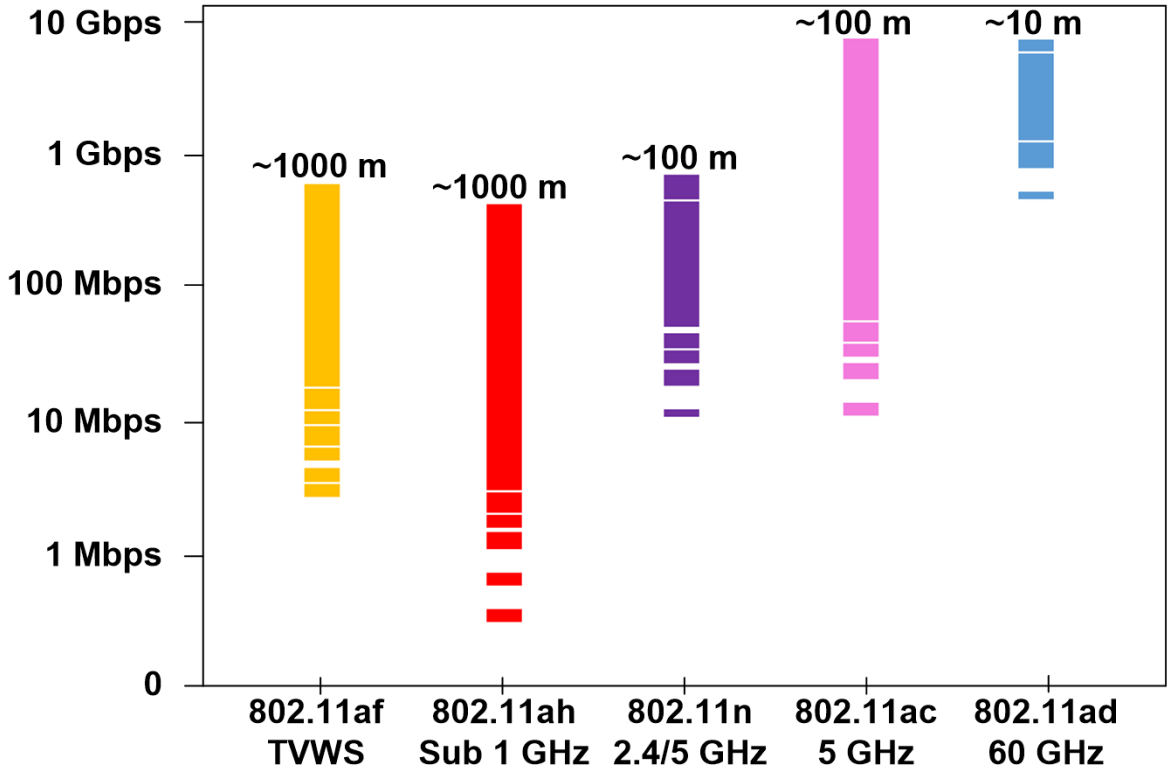
- Motivation
  - Network access in hotspot area is complicated
    - Search and choose a network
    - Request connection
    - (Re)enter authentication credentials
- Passpoint automates entire network access process
  - By enabling a seamless connection between hotspot networks and mobile devices
  - 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?

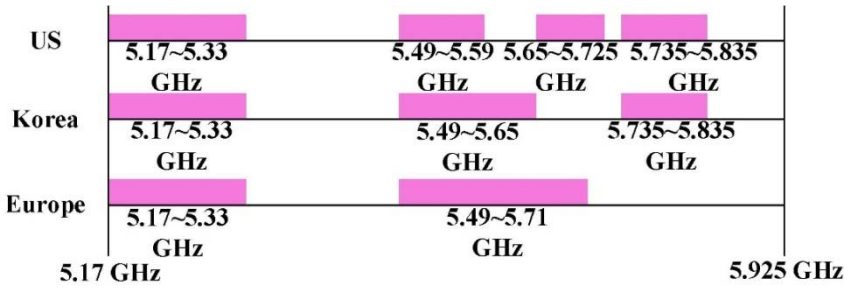
Capacity vs. Coverage

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

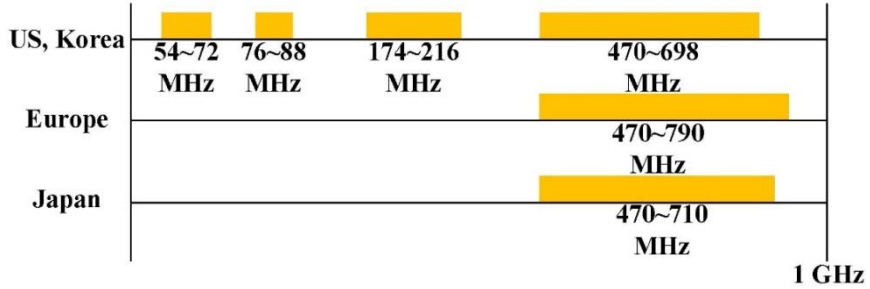


Augmented Spectrum Heterogeneity

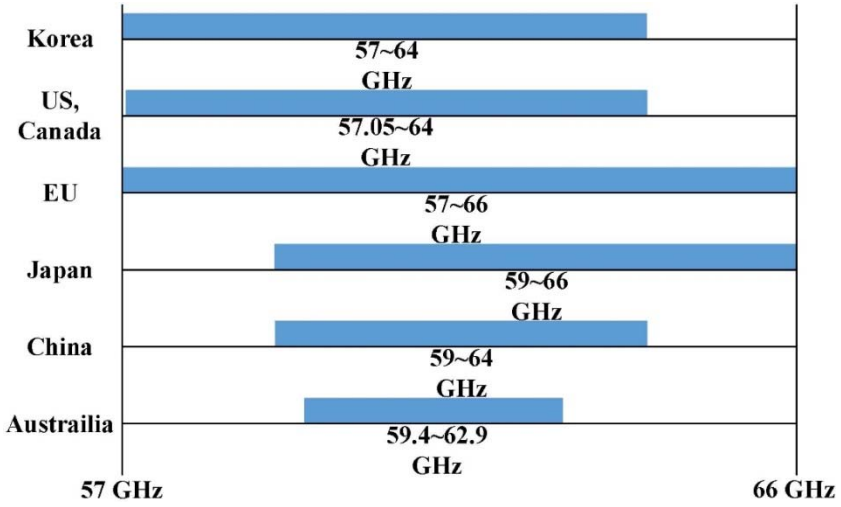
- **Region-dependent** spectrum availability



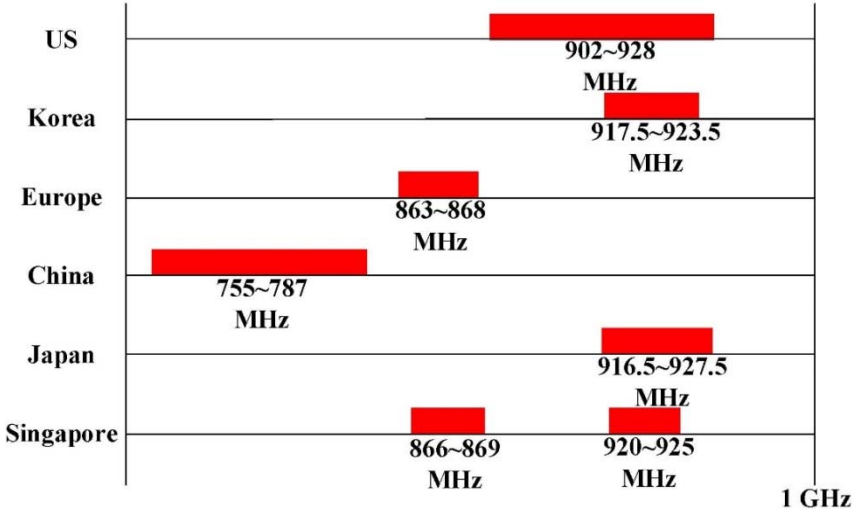
IEEE 802.11ac @5 GHz



IEEE 802.11af @TVWS



IEEE 802.11ad @60 GHz



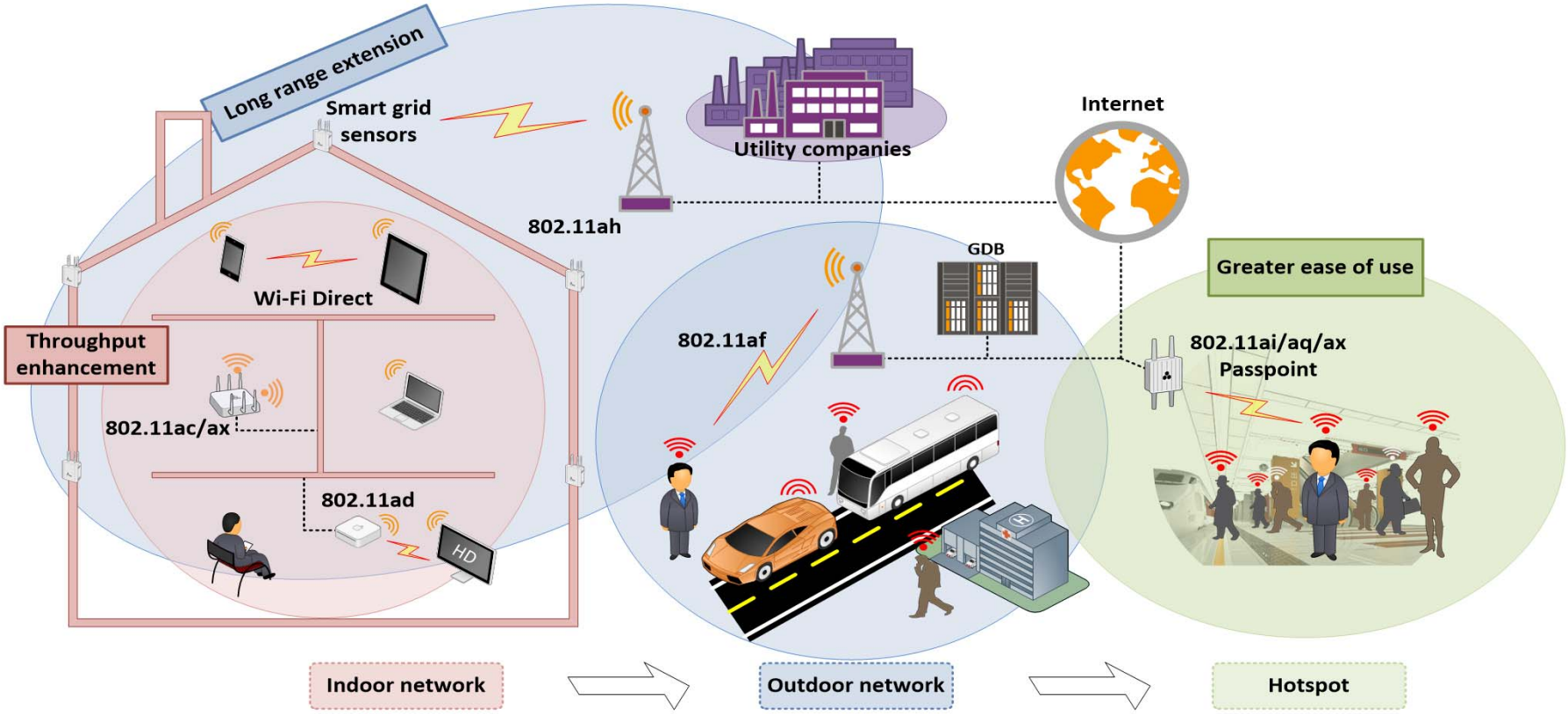
IEEE 802.11ah @Sub 1 GHz

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

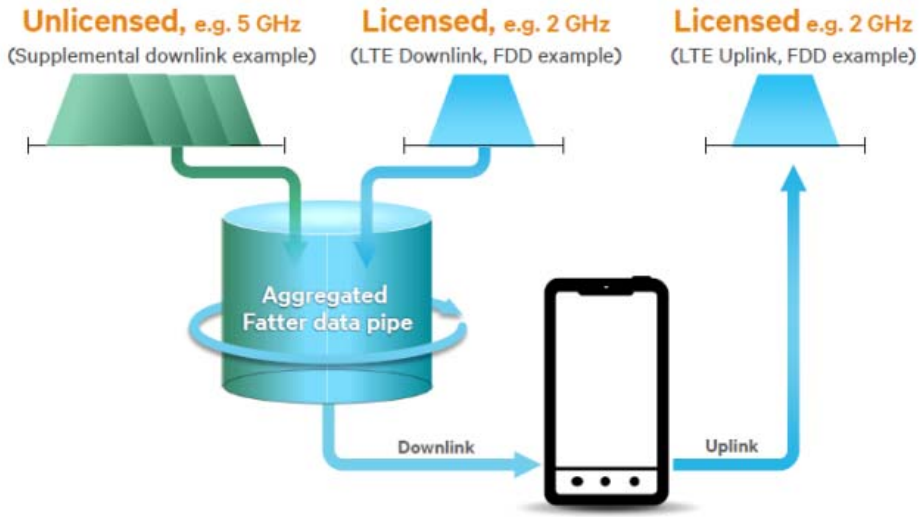
Envisioning Future of Wi-Fi

- **Will all Wi-Fi ecosystem be possible in the future?!?**

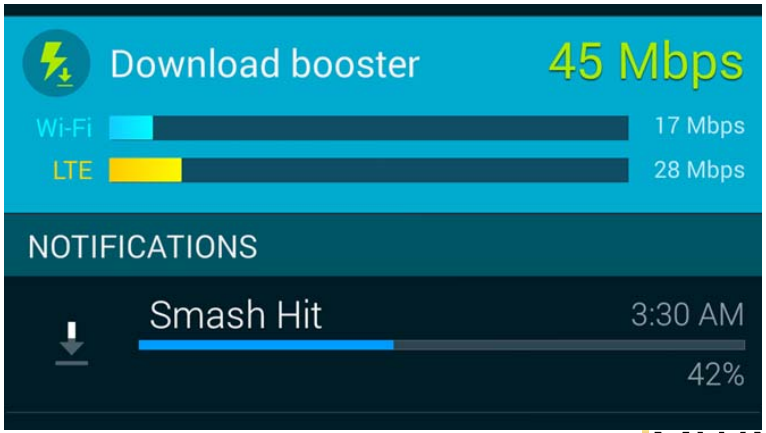


Wi-Fi vs. LTE-A

- 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., Galaxy S5's download booster using Wi-Fi and LTE-A simultaneously



(source: Qualcomm)



Conclusion

- Wi-Fi is still evolving today!
- Three main directions of evolution
  - Throughput enhancements
  - Long-range extensions
  - Greater ease of user
- Future vision
  - More diversified services with spectrum heterogeneity and greater ease of user
  - Performance enhancement in dense environment will be key challenge
  - Close interworking with cellular and coexistence/interworking with other unlicensed band-based connectivity technologies

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