Wi-Fi as a Commercial Service: New Technology and Policy Implications

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Abstract

While Wi-Fi has enjoyed explosive growth and deployment for use in residential homes, the rollout of commercial Wi-Fi service has been more limited. Part of the holdback on large-scale commercial deployment has been the strategic concern that the commons model to spectrum management lacks the incentives for service providers to invest due to the limited ability to manage interference in the unlicensed band. Today, however, this situation appears to have changed. To explain the new confidence by service providers in commercial Wi-Fi, we analyze the activities of the Wi-Fi Alliance and IEEE 802.11 standards body to show how these groups essentially replicate many, but not all, of the functions traditionally employed by an effective band manager that is optimizing efficiency on a licensed spectrum block more typically associated with the deployment of commercial services. Consequently, with the Wi-Fi ecosystem functioning as an effective spectrum manager, we conclude that the service provider investment in Public Wi-Fi networks is rational and the risk posed by saturation or overuse has been reduced to an acceptable level. We then examine the strategic implications of this finding on the Wi-Fi platform. We discuss how the requirements from service providers are already significantly influencing the evolution of the Wi-Fi standard, and attempt to address the risks and liabilities associated with the unlicensed spectrum management model. Thus, service providers increasingly need functionality in Wi-Fi technology to manage interference, and monitor and improve network performance. We discuss the current ideas under discussion for the next version of Wi-Fi to support both commercial Wi-Fi requirements, which address the interference concerns, but only up to a point as the unlicensed model intrinsically leaves some risk to participants of spectrum saturation through overuse.

Section I: Introduction

While Wi-Fi has enjoyed explosive growth and deployment for use in residential homes, the rollout of commercial of public Wi-Fi has been more limited. Part of the holdback on large-scale commercial deployment has been the strategic concern that the commons model to spectrum management lacks the incentives for service providers to invest due to the limited ability to manage interference in the unlicensed band.

Today, however, this situation is changing. While some mobile operators already have built significant public Wi-Fi deployments (China Mobile, for example, as deployed 2.83M hotspots as of June 2012), the interest among service providers in large networks for public Wi-Fi is growing.[3] Large cable operators will reportedly spend around $350-million by mid 2014 to deploy 250,000 hotspots throughout the United States.[4] Two reasons most often provided for the growing interest of service providers in the offering of a commercial Wi-Fi service to customers are: 1) increased popularity and availability of Wi-Fi devices, and 2) the need of wireless operators for "data offload" to help manage congestion on their mobile broadband networks.[5]

This paper will address two strategic questions raised by the growing interest in Wi-Fi as a commercial service:

1. Why is there growing confidence in Wi-Fi as a commercial wireless platform despite its unlicensed status and the associated strategic concern and risk?
2. How might a growing constituency of service providers relying upon Wi-Fi technology influence the direction of the technical specifications and spectrum policy issues associated with Wi-Fi?

To answer the first question, we will argue that service providers having growing confidence in Wi-Fi as a commercial platform due to the activities of the Wi-Fi Alliance and the IEEE 802.11 standards group.[6] Through the efforts of these groups,

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[3] As a comparison, AT&T has deployed 32,000 hotspots, and Boingo operates an aggregated network of 500,000 hotspots across the globe. See Informa Telecoms and Media, *White Paper: Understanding the Role of Managed Public Wi-Fi in Today's Smartphone User Experience* (February 2013). While AT&T has been pursuing a data offload strategy to Wi-Fi for several years, Verizon started it data offload strategy in 2011. See Caroline Gabriel, *Verizon follows AT&T into Wi-Fi offload and tiers: But claims Wi-Fi is not key part of network capacity, and prefers to invest in LTE, going beyond current 3G footprint*, :Rethink Wireless, (May 12, 2011) at http://www.rethink-wireless.com/.

[4] See Sue Marek, *Cable companies will deploy 250,000 Wi-Fi hotspots by mid-2014*, FierceWireless, 7/8/2013, at http://www.fiercewireless.com/

[5] See, for example, GSMA, *Recommendations for Minimal Wi-Fi Capabilities of Terminals*, Version 1.0, 7/12/2012, p. 28, at http://www.gsma.com/newsroom/wp-content/uploads/2012/06/TSG_PRD_TS.22_v1.0_Recommendations_for_Minimal_Wi-Fi_Capabilities_of_Terminals.pdf

[6] We also could have included the activities and efforts of the Wireless Broadband Alliance (WBA) in the list of organizations influencing the evolution of public Wi-Fi. WBA is an organization formed in 2003 by service providers to "secure an outstanding user experience through the global deployment of next generation Wi-Fi" (see http://www.wballiance.com). To date, the WBA initiatives have focused on defining carrier roaming and hotspot requirements. While we will note the WBA later in the strategic implications discussion, we do not choose to include them in

the Wi-Fi technology platform is evolving to support higher data rates over longer distances. Our analysis will show that the activities of these groups essentially replicate many, but not all, of the functions traditionally employed by an effective band manager that is optimizing efficiency on a licensed spectrum block more typically associated with the deployment of commercial services.

To answer the second question above, we will show that requirements from service providers are already significantly influencing the evolution of the Wi-Fi standard. Many of these requirements attempt to address the risks and liabilities associated with the unlicensed spectrum management model. Thus, amongst the hotspots affiliated with its service, service providers increasingly need functionality in Wi-Fi technology to manage interference, and monitor and improve network performance. We discuss the current ideas under discussion for the next version of Wi-Fi to support both personal and commercial Wi-Fi requirements, which address the interference concerns, but only up to point as the unlicensed model intrinsically leaves some risk to participants of spectrum saturation through overuse.

The outline of the paper follows the basic elements of this analysis. Section II provides a brief description of market trends and the critical roles of a spectrum band manager pertinent to our study. Section III describes recent activities of the Wi-Fi Alliance and the IEEE 802.11 standards group, particularly those reflecting the requirements for commercial services, and compares the actions of these Wi-Fi groups against that of a traditional spectrum manager. Section IV concludes with a discussion of the strategic implications on the evolution of Wi-Fi technology and policy given our analysis.

Section II: Roles of Traditional Spectrum Manager

The section briefly reviews the roles of manager that can optimize the efficient use of a band of spectrum, beginning with the market trends and developments that are driving service provider interest in Wi-Fi.

Trends to Public Wi-Fi

With the emergence of the unlicensed model of spectrum management over the past three decades, a commonly held strategic tenet has been that commercial providers of wireless services would generally favor the use of licensed over unlicensed spectrum. The rationale for this strategic advice has been grounded in three straightforward facts: 1) unlicensed technology is optimized for shorter distances and transmission rates not suited for large networks, 2) use of licensed spectrum allows the service provider to proactively manage the interference environment while the unlicensed band provides a service provider very little ability to manage interference, and 3) the flexibility typically associated with spectrum licenses today

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the list of key organizations helping to serve as proxy spectrum manager at this time as their efforts are more tangential to this focused function.

allow service providers the ability to rapidly change the mobile services offered in typically highly competitive markets. Regarding the latter, the concern is that uncertainty posed by the lack of control over interference poses an unacceptable risk to the capital investment required to deploy a wireless network operating over unlicensed bands. In short, service providers are not immune to the "tragedy of commons" risk to the unlicensed band spectrum any more than another user of the spectrum, though the consequences of potentially lower quality wireless connections are much higher for the commercial service provider than the individual user.

Given these limitations, the strategic advice for service providers has long been to acquire costly licensed spectrum to lower the risk posed by interference, and leave the unlicensed bands to equipment vendors building devices for individual users. Yet the strategic landscape now appears to be changing. Service providers are building and launching the largest Wi-Fi networks to be found. What has occurred to propel this change in philosophy by the service providers?

Two ongoing market developments are most often given credit for driving service providers beyond the tipping point in the deployment of Public Wi-Fi. The first is the incredible growth of devices using Wi-Fi. It has been widely reported that the number of Wi-Fi devices shipped in a calendar year went over a billion in 2011, reaching 1.5 billion in 2012.[7] With the proliferation of Wi-Fi enabled devices, services providers are scrambling to satisfy consumer demand for Internet access over their Wi-Fi devices.

The second trend is the recognition by mobile operators that Wi-Fi can be used to offload data traffic from their expensive mobile broadband networks to lower-cost Wi-Fi access points connected to wireline broadband networks. The popularity of streaming applications in particular drives the urgency of service providers to implement data offload strategies for these bandwidth-intensive applications. Recent forecasts from Cisco have pegged the amount of mobile data traffic offloaded to small cells, primarily Wi-Fi, to grow from 33% in 2012 to almost half, or 46%, by 2017.[8]

Beyond the above, there are other technical and business reasons that might be driving service providers to embrace Public Wi-Fi as well:

1. *Technical improvements supporting larger networks*. As we will discuss in the next section, the Wi-Fi Alliance and IEEE 802.11 standards group is evolving Wi-Fi technology to support communications over longer distances with

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[7] See Wi-Fi Alliance, *Wi-Fi Innovation and Adoption Still Going Strong*, CES 2012, at www.virtualpressoffice.com.

[8] See Cisco Mobile VNI 2013 Report, http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.html.

higher transmission rates that are necessary for the viable implementation of the larger outdoor geographic networks required for Public Wi-Fi.[9]

2. *The cost of spectrum to the service provider is free.* For mobile providers, the "data offload" strategy effectively moves traffic off of their private, licensed network, for which they most likely have paid a price through auction to obtain, onto the public, unlicensed band for which there is no cost of use. For other service providers like cable operators, the unlicensed band eliminates a substantial cost element from their cost function while still providing them an outlet to deliver wireless services.
3. *Wi-Fi devices support new service strategy*. Many service providers are incorporating Wi-Fi into the devices that they provide to their customers to receive their existing or new services. As more of their customers have these devices in their homes, service providers such as cable operators are recognizing that Wi-Fi technology can enable the establishment of a Public Wi-Fi network utilizing all these hotspots in consumer households, as well as serve as a source for revenues through the provision of home networking and home security services featuring wireless gateways for residential customers.[10]
4. *Need for wireless in the service bundle*. Public Wi-Fi can serve as the wireless component in an increasingly competitive bundle of broadband services to the home. Service providers, and cable operators such as Cablevision in particular, deploy Public Wi-Fi as a complement to its wireline broadband service to support Internet connectivity to IP devices outside the home, with the result of reducing broadband service churn of customers.[11]

For increasing numbers of service providers, these primary benefits have tipped the scale in favor of deploying public Wi-Fi networks despite the limitations posed by

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[9] See Mari Silbey, *Comcast Turns Homes Into Hotspots*, Light Reading, 6/11/13 (reporting statement from Comcast Senior Vice President Tom Nagel: "Wi-Fi is at the center of our strategy to offer our customers the best online experience, whether it's the fastest Wi-Fi experience in the home, or a fast and reliable Wi-Fi environment outside the home") at http://www.lightreading.com.

[10] *Ibid.* (describing plans of Comcast to provide Wi-Fi residential gateway devices to deliver Community Wi-Fi, home automation and security services). See also http://ww2.cox.com/residential/connecticut/internet/home-network-equipment-and-support/features.cox (Cox Communications offers its broadband customers wireless gateways for $6.99 per month and tech support services in the home for $9.99 per month) and Jeff Baumgartner, *Intel's DOCSIS 3.0 Chips also do Wi-Fi Sharing*, Light Reading, 9/13/2013 (describing availability of Wi-Fi sharing or Community Wi-Fi capability in DOCSIS 3.0 chipsets) at http://www.lightreading.com.

[11] See Craig Leddy, *Is Wi-Fi the Way Forward for Cable?* Light Reading, 5/31/13 (noting cable insiders saying there already is evidence that Wi-Fi is helping to retain cable customers, thus driving down churn rates) at http://www.lightreading.com.

the unlicensed band and the ability to control interference and overall network performance.

Spectrum Manager Functions

The basic elements of spectrum management are recognized generally to be allocation, establishment of service rules, assignment, and enforcement.[12] Within the context of our analysis, we are most interested in the question of whether the Wi-Fi Alliance and IEEE 802.11 standards group has served as a proxy band manager to provide some of these functions to the benefit of the Wi-Fi ecosystem.

Wi-Fi Spectrum Rules in the United States

Most Public Wi-Fi today operates in the 2.4 GHz industrial, scientific and medical (ISM) radio bands. As the name implies, this radio band is reserved for industrial, scientific and medical purposes. Wi-Fi devices operating in this band, along with other unlicensed band devices such as cordless phones and Bluetooth devices, must tolerate interference generated by ISM equipment (e.g., microwave ovens) without any regulatory protection from, or causing problems for, ISM device operation.[13]

Wi-Fi in the 5 GHz bands is growing rapidly in importance as the 2.4 GHz band has become saturated. The regulations for 5 GHz are more complicated. While there is an ISM band at 5 GHz, very few Wi-Fi devices use the ISM band rules; they almost all are certified under the Unlicensed National Information Infrastructure (U-NII) rules. The U-NII bands are subdivided into four sub-bands: UNII-1 (5.15-5.25 GHz), UNII-2 (5.25-5.35 GHz), UNII-2e (5.47-5.725 GHz) and UNII-3 (5.725-5.825 GHz). These bands are still Part 15, but with slight variations in the rules from ISM.

Thus, Wi-Fi users operate equipment that complies with maximum power level restrictions as set forth in the Part 15 rules as specified and enforced through a certification regime established by the FCC. The Part 15 rules mandate that any unlicensed device cease operating if it causes interference to its licensed counterparts. This straightforward Part 15 regulatory regime of assigning liability to manufacturers for failing to follow the applicable certification requirements has been the springboard to launch the successful Wi-Fi platform. The simplicity of the approach has been rightfully lauded as a "paradigm of regulatory minimalism".[14]

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[12]See Jonathan E. Nuechterlein & Philip J. Weiser, *Digital Crossroads: American Telecommunications Policy in the Internet Age* pp. 231-39 (2005).

[13] Part 15.5 in Title 47 of the Unites States Code of Federal Regulations (CFR) states that low power communication devices must accept interference from licensed users of that frequency band. A Part 15 device must cease operating if it causes interference to its licensed counterparts.

[14] See Phi Weiser and Dale Hatfield, *Policing the Spectrum Commons*. Fordham Law Review, Vol. 74. Available at SSRN: http://ssrn.com/abstract=704741.

Spectrum Manager Roles

Under Part 15, the rules of spectrum for Wi-Fi bands while straightforward, still leave the much-discussed limitation of an unlicensed spectrum model – namely the lack of control of interference beyond maximum power transmission levels. Thus, the FCC through its spectrum allocations and unlicensed rules has provided some of the basic spectrum manager roles for the Wi-Fi bands; it specified the spectrum allocations, provided a set of technical standards and permitted services, and established enforcement through ongoing equipment certification.

As noted earlier and in contrast to licensed spectrum, the inability to manage interference within the unlicensed bands has been viewed as a key strategic drawback for the deployment of commercial networks based on this spectrum. Given this absence of ability to control interference, technical standards groups have stepped in to provide technical standards to help manage and reduce the impact of unwanted interference. To the extent these standards group succeed in this endeavor, the market for devices based on these standards will grow and be adopted by service providers seeking to deploy commercial systems based on the technology.

Unlicensed band technology that is attractive to service providers for commercial service, therefore, first needs to provide some assurance of robustness against interference of other users in the commons. In other words, the technology needs to demonstrate some ability to manage interference, similar to the role performed by a band manager in licensed spectrum. Beyond this, service providers also will consider the following platform attributes of the unlicensed band technology:

- *Spectrum Allocation*. Is there sufficient spectrum to support the services offered by the service provider both now and in the future?
- *Service Flexibility*. Are the service rules of the spectrum, and the process of the relevant standards group, sufficiently flexible to support new services?
- *Technical Evolution*. Does the platform have a well-defined process of network evolution to support changes over time? Is there substantial investment in research and development for the platform?
- *Platform Ecosystem*. Is the platform ecosystem sufficient to provide competitive options of supply for equipment and operations systems to service providers and consumers?

Service providers will evaluate this list of platform attributes and assess whether the answers to these questions sufficiently reduce the risk of investment in an unlicensed band technology platform enough to justify investment in the development and deployment of the platform.

We now turn to assess how well the efforts of the Wi-Fi Alliance and IEEE 802.11 standards body have done to address and allay the strategic concerns of service providers.

Section III: Activities of Wi-Fi Alliance and IEEE 802.11

This section reviews some of the requirements being established by service providers for the Wi-Fi platform, and the technology development efforts of IEEE 802.11 to meet these (and other) requirements to manage the use of the unlicensed band spectrum in an effective manner.

Requirements

Probably the signature contribution by service providers for the Wi-Fi platform has been the Hotspot 2.0 specification by the Wi-Fi Alliance. This specification established a set of new network access requirements for public Wi-Fi from the point of view of the service provider. The goal is to create a user experience over Wi-Fi more akin to mobile services with regard to ease of connection to the network, and to support mobile operator goals of leveraging Wi-Fi technology for data offload.

The Hotspot 2.0 program – now labeled with the brand name Passpoint – established an equipment certification program that would ensure the manufacture of Wi-Fi devices that support an end-user experience similar and equivalent to cellular with an automatic connection process to Public Wi-Fi. It was necessary since no *certification* specification for end-user experience existed to address network discovery, selection, roaming and authentication for Wi-Fi hotspots. Hotspot 2.0 is based on the IEEE 802.11u standard that enables cellular-like roaming. If the device supports 802.11u and is subscribed to a Hotspot 2.0 service, it will automatically connect and roam. This is accomplished through a connection manager that follows a connection policy to connect automatically with hotspots based on the credentials of the user.[15]

New requirements for Wi-Fi are largely centered on improving the ability to connect to Wi-Fi networks both at home and when roaming. It follows that new versions of Wi-Fi should mirror these requirements for a better user experience and more seamless roaming.

Technology Development

The IEEE 802.11 Working Group has been in existence for over 20 years, having been created in 1990. During that time, activities of the working group have primarily focused on increasing the physical layer (PHY) speeds while adding additional features to the Medium Access Control (MAC) layer to prioritize traffic and improve throughput with faster PHY layers. We have seen a steady progression of technology generations as summarized in Table 1:

[15] See http://www.wefi.com/ for an example of a Wi-Fi Connection Manager available for purchase today by service providers.

IEEE 802.11 Specification (year)	PHY rates supported (Mbps)
802.11DS (1997)	1, 2
802.11b (1999)	1, 2, 5.5, 11
802.11g (2003)	6, 9, 12, 18, 24, 36, 48, 54
802.11n (2009)	7.2-150[16]
802.11ac (2013)	7.2-866.7[17]

Table 1: Selected IEEE 802.11 Technology Generations

With each new generation, the "dot eleven" Working Group has added additional technical features such as Orthogonal Frequency Division Multiplexing (OFDM), Multiple Input/Multiple Output (MIMO), beamforming, multi-user (MU) MIMO, Enhanced Distribution Channel Access (EDCA), and aggregated MAC protocol data unit (A-MPDU) and aggregated MAC service data unit (A-MSDU). However, these technologies have been primarily focused on improving the throughput of an individual device in a relatively pristine environment. As Wi-Fi has become more successful, the radio environment, especially in the unlicensed 2.4 GHz band, has become more congested – the so-called "tragedy of the commons." This has led to having multiple overlapping coverage of access points (called overlapping Basic Service Sets, or OBSS) and numerous access points operating in the adjacent channels; there are only three non-overlapping channels available in the 2.4 GHz ISM band (channels 1, 6, and 11), so it is difficult in many places to find a channel that does not have co- or adjacent channel interference.

OBSS has a particularly harmful effect on 802.11 technologies because the underlying MAC protocol is based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA), which is a variation on what is commonly called "listen before talk." If there are multiple BSS's within detection range of each other, then throughput in any one BSS can slow dramatically as large numbers of users contend for the medium. This problem is compounded because interfering BSS traffic can also cause collisions, forcing retransmissions, which further congest the medium. Hence the problem of getting acceptable data throughput in a congested environment isn't just a "tragedy of the commons" problem, but the problems are exacerbated by the behavior of the 802.11 protocol.

Many people hope that increasing use of the 5 GHz spectrum will alleviate much of the congestion; in fact, the FCC recently released a Notice of Proposed Rulemaking (Docket 13-49) that proposes even more spectrum availability for unlicensed

[16] Assuming short guard interval and single spatial stream. Includes both 20 and 40 MHz bandwidth modes.
[17] Assuming short guard interval and single spatial stream. Includes, 20, 40, 80, and 160 MHz bandwidth modes.

technologies like Wi-Fi. There are two reasons why increased 5 GHz usage may not provide much relief for WLAN congestion:

1) The 802.11ac specification, which is targeted for the 5 GHz bands, specifies much wider channels (80 and 160 MHz), which means at most five 80 MHz channels in the U.S. (and only two channels which do not require Dynamic Frequency Selection (DFS) for radar detection) and two 160 MHz channels (and none that do not require DFS).[18]
2) New uses for Wi-Fi: One new class of use cases for Wi-Fi involves peer-to-peer communications that require much higher throughput. For example, Miracast is a relatively new technology from the Wi-Fi Alliance that allows users to send video content between two devices using H.264 compression technology. Transmission of high definition video content using Miracast can require peak data rates at the MAC of up to 200Mbps,[19] which will consume most of the channel capacity of an 802.11ac 1x1 or 2x2 channel. Another class of use cases for Wi-Fi is what is described as "cellular offload" – moving internet and other non-real-time traffic on a mobile phone to Wi-Fi networks, because cellular networks are becoming overloaded with video, data, and voice traffic. Cellular carriers have become increasingly dependent on Wi-Fi to free up critical licensed spectral capacity, but are finding that the congestion in Wi-Fi networks provides a poor user experience.

In other words, new uses and new users are increasing so rapidly for Wi-Fi that the 5 GHz spectrum will quickly become just as congested as the 2.4 GHz spectrum.

Another relatively new portion of the frequency spectrum that is becoming available is unused TV channels in the UHF band (roughly 400-700MHz). These so called "TV White Spaces" are only available for use in locations where there are no TV broadcasts currently operating in those channels.[20] Hence, there is a great deal of spectrum available in remote locations, but relatively few channels in densely populated urban areas – and there may be no channels at all in parts of major cities like New York or Los Angeles.[21] Nevertheless, the IEEE has developed a version of 802.11 designed to use the TV White Spaces spectrum (which some in the press

[18] The requirement for DFS is significant because the WLAN device must continually monitor the channel for the presence of types of radar emissions; in addition to the processing overhead of this scanning, there is a significant probability of a false alarm, which would force the WLAN network to move to another channel.
[19] Assuming 1080p (1920 x 1080), 30 fps requires an average throughput of 20Mbps and a peak of 200Mbps.
[20] Note that the FCC plans to "repack" and put up much of the unused TV spectrum for auction as licensed spectrum; as a result, a limited number of unused TV channels will actually be available for unlicensed sharing under the TV White Spaces regulations.
[21] An interactive map showing TV White Space spectrum availability is at http://whitespaces.spectrumbridge.com/WhiteSpaceSearch/interactive-map.aspx

have dubbed "Super Wi-Fi"), which is called 802.11af. One of the key use cases for 802.11af is cellular offload, because the UHF band will offer excellent propagation characteristics ideal for outdoor deployment and will also do a credible job of reaching inside buildings.[22] While 802.11af is attractive because of its coverage area, a large coverage area does not equal high capacity – in fact, the opposite is true; small cells have the highest spatial capacity. Of course, all the issues cited previously with the CSMA/CA protocol in an OBSS environment apply equally to 802.11af. In addition, the places where the additional capacity that could come from unlicensed spectrum would be of most use – densely populated urban areas – are the places that have the least spectrum available. So while 802.11af will be of some use for cellular offload in less densely populated suburbs, it will also suffer from the tragedy of the commons problem in denser environments as well because of lack of spectrum and OBSS issues in large coverage areas.

So what is the industry doing to get out in front of this tidal wave? Over the past two years, there have been several presentations in the Wireless Next Generation (WNG) Standing Committee in IEEE 802.11 that outlined a new program that has come to be called "High Efficiency WLAN" (HEW).[23] In March of 2013, the IEEE 802.11 Working Group created an HEW Study Group whose purpose is to describe the scope of work for a new version of 802.11 that will be more robust in the presence of congestion.[24] In other words, the goal for HEW is to develop new techniques, that could be either in the PHY, MAC or both, or even higher layers,[25]which will improve the performance of the link for a given user in environments that have high densities of access points and stations. This will be a challenging undertaking, given the <u>billions</u> of existing Wi-Fi devices, but the IEEE 802.11 Working Group has realized the need to solve these pressing issues in the Wi-Fi ecosystem – that the "tragedy of the commons" problem will only get worse as upwards of 10 billion new Wi-Fi enabled devices flood the market over the next 5 years.

There are a number of techniques that have been informally discussed in the HEW study group as possible ways to manage interference and improve delivered "goodput" expressed as delivered bits/second/Hertz/square meter.[26] Interference

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[22] "Channel Model Considerations for P802.11af" at https://mentor.ieee.org/802.11/dcn/10/11-10-0154-01-00af-channel-model-considerations-for-p802-11af.ppt

[23] "Beyond 802.11ac – A Very High Capacity WLAN" at https://mentor.ieee.org/802.11/dcn/13/11-13-0287-03-0wng-beyond-802-11ac-a-very-high-capacity-wlan.pptx

[24] "High Efficiency WLAN" at https://mentor.ieee.org/802.11/dcn/13/11-13-0331-05-0wng-high-efficiency-wlan.ppt

[25] Techniques above the MAC are outside of the scope of IEEE 802.11, but the Wi-Fi Alliance can specify techniques and certification above the MAC.

[26] Failed packets do not contribute to goodput, so minimizing packet failures and the inefficiency of multiple retries is a significant goal of the HEW effort.

can be managed through control of time, frequency, code, space, and power. For example, the 802.11 MAC is designed with an ability to manage the timing of transmission through several mechanisms: Point Coordination Function (PCF), Hybrid Coordination Function (HCF), and Request to Send/Clear to Send (RTS/CTS).[27] Of these, only RTS/CTS has been widely implemented.[28] RTS/CTS works by having a device that wants to initiate a data transfer send an RTS command to the intended recipient, which responds with a CTS. All devices that can receive either the RTS or CTS packet must get off the air for a period of time determined by a parameter in the RTS/CTS data exchange called the Network Allocation Vector (NAV). RTS/CTS is very effective in silencing all devices except the two who are in communication, but it dramatically reduces the spatial capacity of the overall network.[29] Other techniques that can be used to improve coexistence are beamforming and beam nulling, transmit power control, and interference cancellation. While presentations in HEW have mentioned the PHY and MAC tools that could be used to improve goodput,[30] it is much too early in the standardization effort to know which techniques will end up in this new 802.11 standard, which will ultimately be a next generation Wi-Fi technology, noting of course that the Wi-Fi Alliance may have to add additional features above the MAC in a certification program such as Passpoint. What can be said is that what is needed is a global view of network optimization in a heterogeneous mixture of access points and stations,[31] and the 802.11 HEW Task Group and its Wi-Fi Alliance counterparts will examine PHY, MAC and upper layer techniques to tackle these challenging issues.

Table 2 below categorizes some of these technology development efforts against the spectrum manager roles discussed in the previous section. The fact that the Wi-Fi Alliance and IEEE 802.11 efforts can be classified in this fashion supports our argument that these organizations are fulfilling some of the spectrum manager roles more traditionally associated with licensed bands.

Platform Attribute	Wi-Fi Approach
Interference Management	1. RTS/CTS to silence hidden nodes 2. Beamforming and beam nulling to direct energy in

[27] "IEEE 802.11 Tutorial" http://wow.eecs.berkeley.edu/ergen/docs/ieee.pdf
[28] For Wi-Fi certification, it is required to implement RTS/CTS, but products are not required to use it in operation.
[29] "Evaluating the Performance of IEEE 802.11 Network using RTS/CTS Mechanism", Hetal Jasani, Nasser Alaraje, 2007 IEEE International Conference on Electro/Information Technology, vol., no., pp.616,621, 17-20 May 2007.
[30] "Enabling Real World Improvement By Exposing Internal MAC State" https://mentor.ieee.org/802.11/dcn/13/11-13-0849-01-0hew-enabling-real-world-improvement-by-exposing-internal-mac-state.pptx
[31] "Coexistence and Optimization of WLAN: Time-frequency-space-power-load" https://mentor.ieee.org/802.11/dcn/13/11-13-0558-01-0hew-coex-and-optimization-of-wlan-time-frequency-space-power-load.pptx

	space 3. Future HEW techniques may allow coordination of transmit power control, frequency channel reuse, and beam steering across heterogeneous BSS deployments[32]
Spectrum Allocation	Wi-Fi channels can be units of 20 or 40 MHz (802.11n) or substantially more – 80 and 160 MHz (802.11ac). 802.11af uses smaller channels (6MHz, 12MHz, 24MHz, 48MHz in the US) to match television channel allocations.
Service Flexibility	The Wi-Fi platform supports the wide variety of applications available on the Internet using the Internet protocol. The 802.11 family of protocols allows substantially flexibility regarding type of service, spectrum band utilized, and platform functionality.
Technical Evolution	Current 802.11ac access points can control transmission scheduling (RTS/CTS, EDCA), channel frequency (including channel change to move an entire BSS), beamforming, and transmit power control. Future enhancements in HEW may add standards-based methods to coordinate time, frequency, beam shape and transmit power across access points in a heterogeneous "sea of access points." These PHY and MAC techniques along with evolution of the Wi-Fi Alliance Passpoint program will be used to give an improved quality of user experience in congested environments. It is certainly a possibility that future Passpoint standards could facilitate cloud-coordinated access points that could be used to manage interference, load and fairness in heterogeneous environments.
Platform Ecosystem	Historically, the Wi-Fi Alliance has been very successful in building the Wi-Fi ecosystem, beginning with the chip vendors, working with end product developers and module/subsystem manufacturers. Given the market power of service providers who

[32] If an environment like an office building has WLAN equipment from a single vendor with similar technology (homogeneous network), there are proprietary techniques available from most equipment vendors to manage the BSS, which generally manage channel usage, transmit power, and perform load balancing. Beamforming is not commonly used as an interference management technique today, although it is likely to be used increasingly in emerging deployments of 802.11ac, which has much-improved beamforming compared to 802.11n.

	want to deploy millions of access points and stations, there will be a strong economic incentive for the silicon providers and equipment manufacturers to implement new technologies that improve the quality of the user experience.

Table 2: Mapping Wi-Fi Technology Development Against Spectrum Manager Roles

Section IV: Strategic Implications

This section examines the strategic implications of our previous analysis. To do so, we return to address the strategic questions that we posed in the Introduction. Namely,

1. Why is there growing confidence in Wi-Fi as a commercial wireless platform despite its unlicensed status and the associated strategic concern and risk?
2. How might a growing constituency of service providers relying upon Wi-Fi technology influence the direction of the technical specifications and spectrum policy issues associated with Wi-Fi?

Emergence of Wi-Fi as a Platform for Commercial Services

The growing deployment and use of the Wi-Fi platform by commercial service providers speaks to their confidence that any concerns from the unlicensed band can be adequately managed in the future to justify their investment. Our analysis in the previous section supports the view that the source of this growing confidence has been the efforts of the Wi-Fi Alliance and IEEE 802.11 standards body to serve as a proxy spectrum manager to help alleviate, though not fully eliminate, the problems of the commons approach. These organizations have established successfully a *managed commons* system for Wi-Fi, where successive generations of equipment are being developed that comply and interoperate with earlier versions.

The Nobel laureate Elinor Ostrom describes a different paradigm for the successful management of pooled resources like the spectrum used in unlicensed bands.[33] Taking a subset of these principles as condensed by Milgrom, *et al*,[34] Table 3 shows that the Wi-Fi Alliance and IEEE 802.11, along with FCC, have performed key roles in support of the Ostrom principles.

Management Principle	**Wi-Fi Alliance**	**IEEE 802.11**	**FCC**

[33] See Elinor Ostrom, *Reformulating the commons*. Ambient. soc. [online]. 2002, n.10, pp. 5-25. ISSN 1809-4422.

[34] See Paul Milgrom, Jonathan Levin, and Assaf Eilat, The Case for Unlicensed Spectrum, Oct. 12, 2011, pp. 14-15, at http://www.stanford.edu/~jdlevin/Papers/UnlicensedSpectrum.pdf.

Creation of clear rules that respond to local conditions		• 802.11 Family of Wi-Fi Standards	• 2.4 & 5.8 GHz spectrum allocations • Part 15 Rules
Collective decision-making that allows participation of most community members	• Firms in Wi-Fi ecosystem	• Participation open	• FCC Rulemaking process
Effective monitoring, enforcement, and conflict-resolution mechanisms	• Certification regime	• Due process for standards development	• Rule making process to manage conflict • Part 15 equipment certification requirement
Coordination between organizations that manage commons	• 802.11 standards defines certification	• Cooperation with Wi-Fi Alliance	• No formal coordination mechanisms

Table 3: Mapping of Wi-Fi Efforts to Ostrom Principles

Just as we demonstrated earlier in mapping the efforts of the Wi-Fi ecosystem against the traditional roles of a spectrum manager, Table 3 shows how the Wi-Fi community or ecosystem has evolved to provide a successful example of a managed commons approach using the Ostrom principles as a paradigm for evaluation as well. This perhaps provides further confirmation of our conclusion in spite of using a different paradigm of evaluation.

The strategic implications for this finding are significant for the service provider. If the ecosystem is functioning as an effective spectrum manager, then the service provider investment in Public Wi-Fi networks is rational and the risk posed by saturation or overuse is reduced, in this case obviously to an acceptable level given the increase in deployment of Public Wi-Fi.

Future Direction of Wi-Fi as a Commercial Platform

Given the above conclusion regarding the strategic basis for Public Wi-Fi, we now turn to discuss the strategic implications of this finding on the future direction of platform. Given the importance of the Wi-Fi ecosystem to provide key spectrum management functions to manage the growth in popularity of the platform going forward in the future for both Public and private Wi-Fi, we organize the discussion according to the spectrum management functions introduced earlier in the paper: interference management, spectrum allocation, service flexibility, technical evolution, and platform ecosystem.

Interference Management

The problem for the Wi-Fi bands is that the continued growth in access points and end-user devices will cause higher levels of interference to the detriment of the overall performance of the system. This will be true for both Public Wi-Fi as well as residential Wi-Fi users. Service providers, however, will have more resources and motivation for managing the technical mechanisms in Wi-Fi to mitigate the impacts of interference. To do this, service providers will develop and deploy Wi-Fi network performance optimization tools, often based on powerful servers in the network cloud, to aggressively manage the interference impacting its access points. These tools will help a service provider manage its Public Wi-Fi network in the following ways:

- *Dynamic Channel Assignment.* The overall capacity of the service provider network can be substantially increased through the coordinated assignment of primary and secondary channels (e.g., spectrum location and size).
- *Dynamic Carrier Sense Threshold Adaptation*. Setting the carrier-sense threshold appropriately as a function of access point location or time of transmission can improve frequency reuse and the overall throughput of the network.
- *Multiple Input/Multiple Output (MIMO) Antenna Optimization*. Through beamforming and spatial multiplexing, data rates and link reliability can be increased and improved, respectively.
- *Load Balancing*. System throughput can be improved by load balancing across access points by forcing clients to more lightly loaded areas.
- *Transmit Power Control*. Based on radio measurements with clients, the transmit power of the access point can be adjusted to minimize interference and optimize network coverage.
- *Mesh Networking*. System reach and backhaul capacity can be managed using mesh networking technology linking access points over wireless.

Generally speaking, we were not able to identify many scenarios where the utilization of these mechanisms by service providers would improve the experience of Public Wi-Fi users at the expense of private users. Indeed, most scenarios should improve the overall noise environment for all users through more focused transmission paths at appropriate power levels. We can imagine at least two scenarios, however, where this might not be the outcome.

First, to the extent that Public Wi-Fi systems succeed, the accompanying significant growth of Public Wi-Fi access points blanketing populated areas obviously will add to the interference in the Wi-Fi bands to private users. For example, Comcast plans to provide its customers with a configured network tied only to their usage through their residential gateway, while also supporting a Public Wi-Fi option from the same device that would be accessible to any authenticated Comcast customer.[35] As a hypothetical example, if Comcast were to use beamforming for the Public Wi-Fi

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[35] Sibley, *op. cit*.

network, the level of interference for the private user within the focused antenna coverage area could be increased if overlapping channels are used. To encourage its customers to install the residential gateway routers in their homes, Comcast offers free additional capacity of 25 Mbps for the private Wi-Fi link.[36] The speed of the Public Wi-Fi link from the Comcast gateway is 25 Mbps, though it cannot be combined with the private link.

Secondly, 802.11n implemented a new quality of service feature called Enhanced Distributed Channel Access (EDCA) that prioritized some types of packet traffic (e.g. voice) over others (e.g. best effort), although it does that by changing the contention window (backoff) in the CSMA/CA protocol. If HEW extends that concept to give Public Wi-Fi traffic priority, then less favored traffic could suffer – creating a "WLAN neutrality" problem, if it were to go in this direction. WLAN treats all traffic fairly today – EDCA lets some traffic pick smaller backoff numbers – but that could change in HEW.

Spectrum Allocation

The long debate between advocates of licensed versus unlicensed spectrum allocations falls beyond the scope of this paper. Suffice it to say, however, that service providers of Public Wi-Fi will see it in their own self-interest to be strong advocates for additional spectrum allocations that are unlicensed with rules that support Wi-Fi platforms capable of transmitting more information over longer distances. In large part, this has already begun.[37] In the upcoming World Radio Conference 2015 (WRC-15) one key question to be considered is the release of 20 MHz of spectrum or more in the 700 MHz band for Wi-Fi throughout much of the world. Such "beach front" spectrum also has the attractive attribute of permitting far greater range for Wi-Fi transmissions. With the success of the Wi-Fi platform, equipment vendors and service providers become incumbents to the band, with legitimate concerns regarding the evolution and plan for spectrum allocation over time. The economic interests of these players become stronger with the growth of the platform, as will the pressure to allocate additional spectrum to support its growth.

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[36] See Shalini Ramachandran, *Comcast Beefs Up In-Home Wi-Fi*, Wall Street Journal, June 10, 2013. Comcast is providing the residential gateways to customers subscribing to broadband tiers at 25 Mbps or above.

[37] See, for example, Testimony of Thomas F. Nagel, Senior Vice President, Comcast Corporation, Before the Senate Committee on Commerce Science, and Transportation, Subcommittee on Communications, Technology, and the Internet, Hearing on State of Wireless Communications, June 4, 2013. "A core challenge is that the primary Wi-Fi spectrum band – the 2.4 GHz band – has become highly congested... Solving this problem requires a balanced approach whereby the FCC allocates additional spectrum across a number of different bands for unlicensed use and removes regulatory roadblocks that limit the efficient use of unlicensed spectrum, such as unnecessary indoor-only restrictions, power limitations, and other technical requirements and restrictions."

Service Flexibility

Service flexibility has been an extraordinary strength of the platform. The FCC's Part 15 and UNII rules allow for broad interpretation of the services permitted for use on the Wi-Fi bands. The family of 802.11 standards is now working it way through the alphabet for a second time due to the wide variation of technologies and associated services supported by the standards.

Technical Evolution

The process used by the IEEE 802.11 standards group to start new standards establishes the technical evolution for the Wi-Fi platform. The process typically begins with presentations in the Wireless Next Generation (WNG) Standing Committee, where new ideas are discussed in a fairly large audience. If 75% of the voting members of the IEEE 802.11 Working Group vote in favor of a new idea, then a Study Group is created that is tasked with drafting a Project Authorization Request (PAR). If that PAR is approved by 75% of the voters, then a Task Group is created whose mission is to write the actual standard, which must then be ratified by 75% of the 802.11 voters. This process is described in more detail in IEEE 802 LAN/MAN Standards Committee documents.[38]

The future direction of the new standards is certain to follow, at least in part, the requirements of the carriers. For example, the observation has been made that service providers have changed the focus of their Wi-Fi platform needs from data offloading to more control of the user experience and better quality of service.[39] In the long run, the important point is that service operators will be driving to implement additional mechanisms in Wi-Fi to fill in their "toolkit" to optimize and add intelligence to the Public Wi-Fi network. As we noted in our earlier discussion of the Hotspot 2.0 program in the Wi-Fi Alliance, mobile service providers will be establishing requirements to position Wi-Fi as the main access technology to support data offloading, and to support this with a connection process that is seamless and easy to use.

In addition to creating smart networks that improve quality and lower the cost of operations, service providers will also be advocates of early requirements for new services that can be supported by the mobile platform. One near-term candidate is support of seamless handoffs of connections between access points, which will move the Wi-Fi platform closer to supporting mobile services. Another possibility is support of cross-layer communications in support of video streaming or other bandwidth-intensive applications at the service layer.

Platform Ecosystem

While an in depth assessment of the Wi-Fi ecosystem falls beyond the scope of this paper, it is reasonable to assert today that the Wi-Fi ecosystem to support Public

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[38] See http://standards.ieee.org/develop/

[39] See Sue Marek, *Wi-Fi offloading morphs to integration as operators strive for more control* - FierceWireless, May 22, 2013.

Wi-Fi is robust. From a service provider perspective, the standardization achieved by 802.11 has succeeded in creating a market for widely available and competitively priced equipment. Many manufacturers now offer "carrier-class" Wi-Fi systems.

Closing the "Gaps"

In closing, we note that while the Wi-Fi Alliance and IEEE 802.11 are serving as spectrum managers for the Wi-Fi bands as described above, there are some limitations that are inherent to the unlicensed band spectrum management approach that cannot be addressed to fully eliminate the risk or uncertainty. These gaps include:

1. *Coexistence in Bands*. The efforts of the Wi-Fi Alliance and 802.11 only address the Wi-Fi platform. As an unlicensed band with broad categories of permitted services, there are other users within the band that operate outside the rules established by 802.11, though still within the bounds of Part 15. An interesting potential precedent in this regard could be the recent FCC Order regarding the request by Progeny to operate a new position location service on an unlicensed band.[40]
2. *Service Interoperability*. While the 802.11 standards and Wi-Fi Alliance certification testing establish a high degree of uniformity and interoperability in Wi-Fi equipment, the standards and testing do not address key elements of Public Wi-Fi service such as roaming across service providers. As noted earlier, service providers formed the Wireless Broadband Alliance to establish interoperability in those areas not specified by 802.11 standards. As Public Wi-Fi grows in popularity, this function will take on increasing importance to insure acceptable interconnection of services across different provider networks.
3. *Spectrum Allocation*. We have made the argument that the actions of the Wi-Fi ecosystem are sufficiently effective to stave off the "tragedy of the commons" despite the huge growth in Wi-Fi usage. What if we are wrong, however, and the main reason for the success of Wi-Fi has been that enough spectrum has been allocated in advance to adequately accommodate the growth experienced to date? In this event saturation of the Wi-Fi bands would seem inevitable in the absence of additional spectrum allocations. In effect, the only way to prevent the tragedy of the commons would be to continue a policy of "spectrum overprovisioning" to keep pace in front of the growth of the platform.

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[40] See Request by Progeny LMS, LLC for Waiver of Certain Multilateration Location and Monitoring Service Rules, *Order*, FCC 13-78 (rel. June 6, 2013)