Our Wi-Fi Future: Technology and Spectrum Enablers

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Abstract

Several technology and wireless spectrum developments are on the horizon to help MSOs, and all ISPs, meet the unique needs of wireless video and other growing network demands. This paper reviews these developments and the effect they are likely to have. In the technology space, advances in standards and network optimization techniques will advance network performance and make Wi-Fi more useful for consumers. In addition, new wireless spectrum availability will help to facilitate these advances, and will enable additional capacity and frequency diversity for expanding Wi-Fi use cases.

The goal of this paper is to provide an overview of emerging technologies and new wireless frequencies that may aid Wi-Fi video delivery, how these advances will improve the end-user experience, and what is needed to realize this future vision. We explore how a typical consumer may tangibly benefit from these advances through use cases representing a 'day in the life' progression of Wi-Fi video activity. We do not endeavor a complete technical guide to the implementation of relevant advances in light of their broad scope; rather, our intent is to provide a window into what video over Wi-Fi may look like in the near future.

INTRODUCTION

Video data traffic comprises 65% of downstream network traffic at peak times, and the share is growing[i] as total traffic volume continues to expand,[ii] making it among the most significant factors in ISP network planning. (See Figure 1.) In addition, consumers are connecting more wireless devices than ever before to consume video. Tablet sales have grown by over seven times in the last three years,[iii] are forecasted to grow another three times by 2016.[iv] 90% of tablets only use Wi-Fi, and have no mobile connectivity.[v]

While broadband consumers rely on the cost and performance advantages of the fixed network, particularly for high-bandwidth applications like video, they also value the ability to be 'untethered'. These trends pose challenges for multiple-system operators (MSOs) [vi] as they work to meet growing consumer demand for wireless video over Wi-Fi networks.

Cable operators are continuing to increase network capacity and deploy Wi-Fi access points inside and outside of homes to meet growing consumer demand. The CableWi-Fi initiative, announced last year, enables Wi-Fi access for Cable customers across over 120,000 access points [vii] (and growing) deployed by the five largest MSOs.

This effort is a significant development in Wi-Fi networking, which has historically been ad-hoc and driven by fixed broadband consumers without broader coordination. Access point deployments outside of the home in 'main street' settings, small businesses, sports venues, and other locations represent a new approach to Wi-Fi access – one that is coordinated and provides reliable capacity in most areas that consumers spend their time. The success of this effort is driven by utilizing fixed network assets to extend the value of a product with high consumer demand – high speed data.[viii]

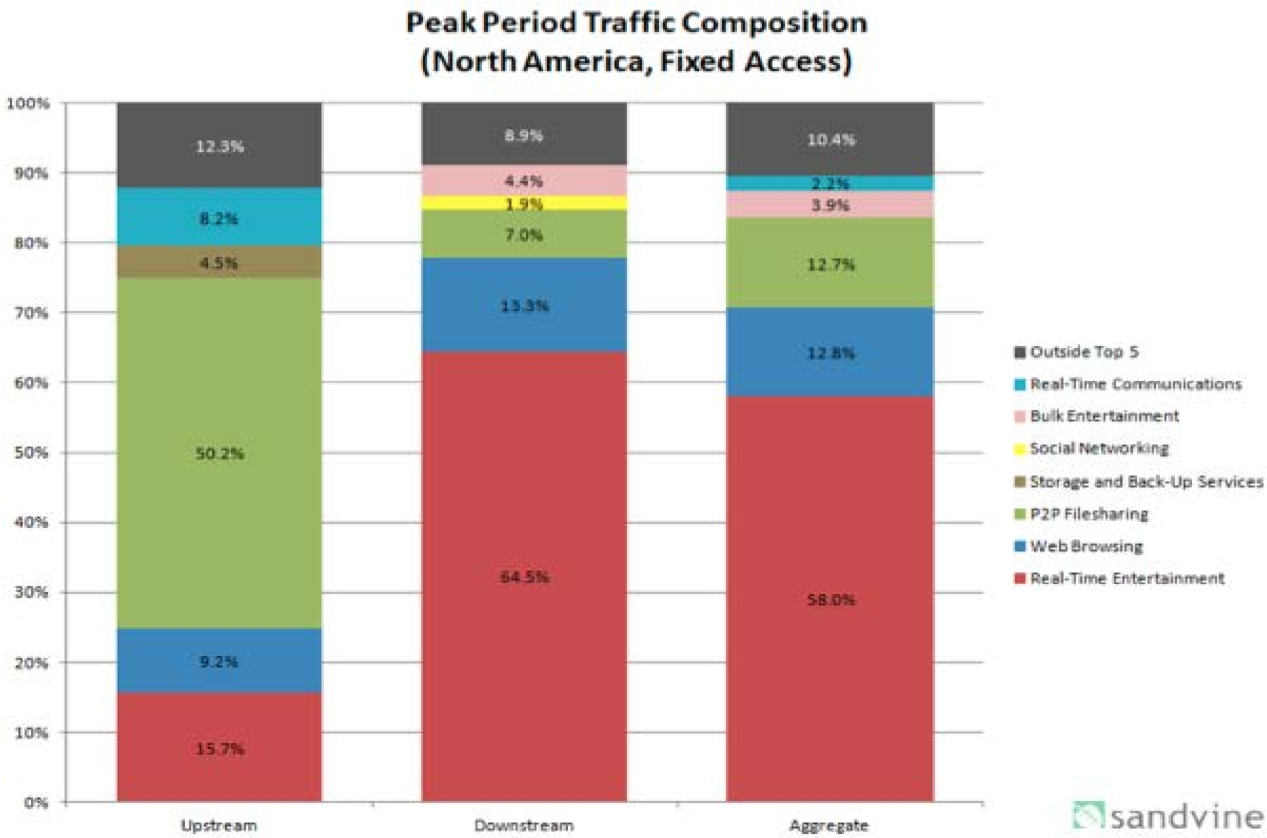

Figure 1: Sandvine Estimates of North American Peak-Period Fixed Traffic Characteristics [ix]

Coincident with this evolution in Wi-Fi networking are consumer expectations of ubiquitous wireless access. Customers expect their connected wireless devices to 'just work'. This desire for seamless connectivity and simplicity is not always today's reality in Wi-Fi world, however. Users must manually find, select, and authenticate to trusted networks, in most cases. Moreover, access point range is limited, exacerbating this complexity for Wi-Fi users on the move. Congestion is expected in crowded areas. These issues become most evident in video applications, which require significant bandwidth, and connection quality impairments are often noticeable in demanding environments.

MSO-delivered Wi-Fi is beginning to bring customer's experiences in line with their preferences. The use of the common "CableWi-Fi" SSID simplifies network selection and authentication, and dense deployment of access points help to limit congestion. While helpful, these steps are work-arounds within the current parameters of Wi-Fi.

On the horizon are several developments in Wi-Fi technology and spectrum access that can fundamentally re-shape the user experience, particularly for video services, which generally require significant and consistent throughput across diverse use environments.

New core standards and spectrum will enable throughput in excess of 1 Gbps, an improvement of nearly 3X in performance over today's Wi-Fi networks. The next-gen television experience will enable wireless content delivery, simplifying in-home networking. Outside of the home, new Wi-Fi technology will enable automatic user authentication, enhancing the utility of Wi-Fi to consumers on the go. Advances in network management will help to ensure consistent user experiences and minimize congestion. And availability of new wireless spectrum will complement these advances, enhancing capacity, reliability, and coverage.

Together, this progress will meaningfully improve the consumer's Wi-Fi experience, helping to ensure that it remains the wireless network of choice. To demonstrate what these improvements will mean in concrete terms, we will track a typical Wi-Fi use case, following a hypothetical consumer through a morning of Wi-Fi use. From when our consumer wakes up in the morning to the time he arrives at work, new developments in Wi-Fi will clearly improve his (or her) experience.

This next phase of Wi-Fi is not a given, however. Several regulatory and technology changes are needed to realize this vision. In particular, regulatory dependencies are uncertain, and will require sustained engagement on the part of the Wi-Fi community. Our hypothetical consumer – and real consumers everywhere - demand it.

TECHNOLOGY DEVELOPMENTS

Several advances in Wi-Fi technology are on the horizon and have the potential to significantly advance Wi-Fi user experiences. These advances, driven by improvements to core standards, network discovery and selection, wireless delivery to the TV, authentication protocols, and network management, including radio resource management, together can help to re-shape Wi-Fi from a manual, inconsistent user experience to one of simplicity and seamless connectivity, especially for video applications.

Core Standards

IEEE 802.11ac is a fifth-generation Wi-Fi networking technology that promises about three times the throughput capacity than the previous generation 802.11n. (See Figure 2 for the evolution of Wi-Fi standards.)

802.11ac contains several characteristics that enable throughput gains over current Wi-Fi technology. One feature is spectrum use: Whereas 802.11n uses both the 2.4 GHz and 5 GHz frequency bands, 802.11ac uses only the 5 GHz band. 5 GHz is a 'cleaner' environment than 2.4 GHz, which is populated with the majority of Wi-Fi devices in use today, along with other wireless devices and services that may cause interference. By using the 5 GHz band, 802.11ac will enable less interference to and contention among Wi-Fi users, enabling higher potential performance. However, regulatory complexity in 5 GHz terms of access may complicate implementation of 802.11ac. These issues will be explored in a later section.

Of course, a cleaner operating environment does not alone guarantee higher performance. 802.11ac also uses wider channels of 80 MHz and 160 MHz, up from the 20 MHz and 40 MHz channels of 802.11n. Expanding channel bandwidth by 4 times the current standards yields the potential to expand theoretical performance by fourfold, holding other factors constant.

In addition, 802.11ac enables greater spectral efficiency and reliability. This is achieved through a doubling of potential multiple-input, multiple-output (MIMO) spatial streams, from 4x4 in 802.11n to 8x8, as well as a more sophisticated modulation and coding scheme, up from 64 QAM to 256 QAM.

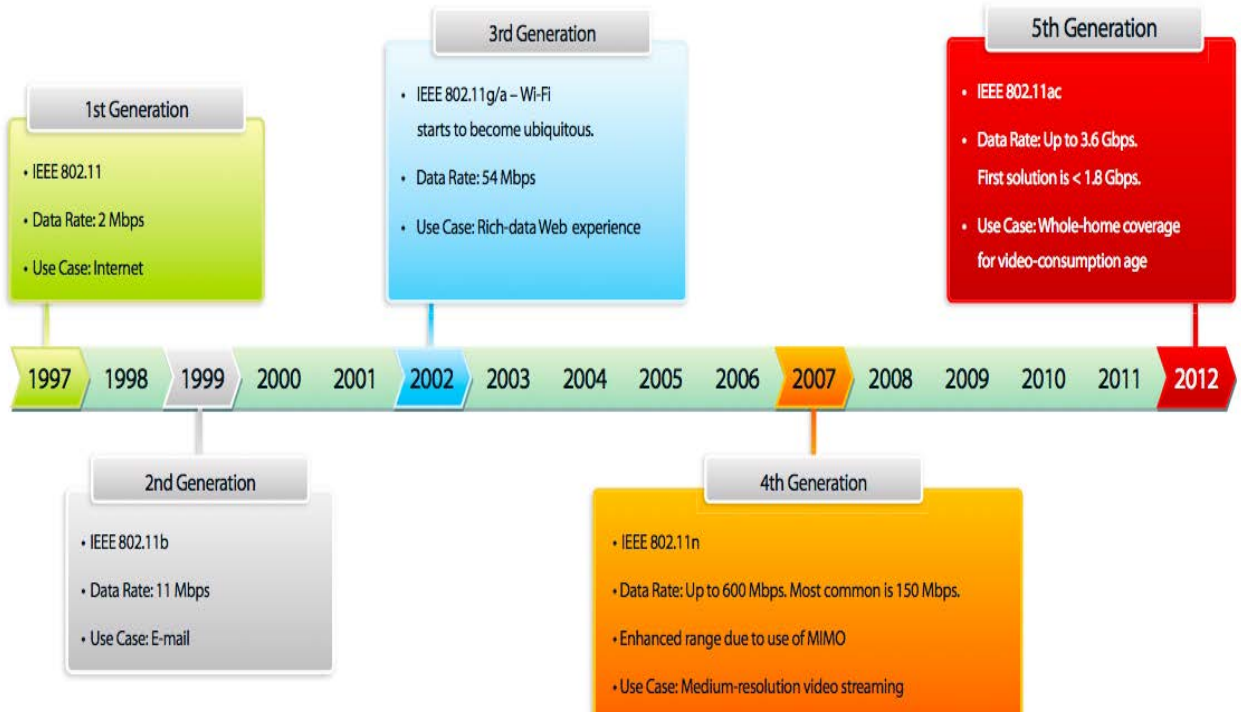

Figure 2: Wi-Fi Core Standards Evolution (Broadcom)[x]

The benefits of these improvements will be aided by standard beamforming in 802.11ac, enabling directional signaling and greater interference avoidance. Beamforming is not widely deployed in 802.11n equipment; its standard adoption will enable enhanced throughput and coverage range.

While 802.11n with MIMO supports enough raw bandwidth for wireless video streaming, these additional features in 802.11ac should make it better-suited to high-quality wireless video delivery.

<u>Wireless to the TV</u>

802.11ac and other technology developments will help enable wireless content delivery to the television. Currently, if a customer wishes to receive video content wirelessly, a common approach is to attach a Wi-Fi-capable third-party box, such as a Roku streaming player, to view IP-delivered content. If the TV has a Wi-Fi receiver, it may connect directly. However, for most consumers today, viewing linear, on-demand, or DVR video content requires a wired connection to the TV from the relevant Cable box, which also requires a connection to a coax output. Several technology advances are likely to improve wireless delivery of video content to the TV.

802.11ad, another IEEE wireless communication standard, enables a short-range direct link of up to 7 Gbps using the 60 GHz band. This standard, also known as "WiGig",[xi] is unlikely to serve as a general-purpose Wi-Fi technology due to path and propagation losses of its high-band spectrum, but may prove to be a replacement for a HDMI cable, enabling wireless delivery of a greater range of video content to the TV.

Equipment using this standard is currently under development, and the Wi-Fi Alliance is expecting to launch certification later this year.

While a robust network is a must for reliable video delivery, users also expect the system to be easy to use, with automated connection and data and video transport. DLNA, Airplay and Miracast are a few technologies that help with this.

Airplay is Apple-proprietary and allows various Apple devices on a LAN to find, connect and stream to each other. However, it is not interoperable with non-Apple products. For example, Airplay enables users to wirelessly stream video from their iPhone to an Apple TV, but an Android device could not connect to Apple TV through Airplay.

Unlike Airplay, Digital Living Network Alliance (DLNA) standards define interoperability guidelines for sharing of digital media across consumer devices of any vendor. DLNA uses Universal Plug and Play (UPnP) for media management, discovery and control. There are thousands of devices from a multitude of vendors that are "DLNA Certified". Some estimates indicate that there are hundreds of millions of DLNA enabled devices have been installed in customer homes,[xii] and many Cable operators use it as a basis for in-home video streaming. Additionally, DLNA is transport-independent and can be used with either wireless or wired network.

In addition, peer-to-peer video delivery will be enabled through a technology known as Miracast. Miracast is a Wi-Fi Alliance certification program for the Wi-Fi Display specification, and like DLNA and Airplay it defines device and service discovery, including the full application protocol stack for the delivery of multimedia. Miracast, unlike DLNA, is transport-dependent and only works with Wi-Fi Tunnel Direct Link Setup (TDLS) and Wi-Fi Direct. Standardized device-to-device video delivery will enable innovative use cases, such as viewing tablet content on the TV, without the need for a physical connection and while minimizing congestion associated with broader networking. Wide adoption of this technology, enabled through the Wi-Fi Alliance certification program, will enable content delivery across device types.

Authentication & Roaming

Currently, connecting to a new access point requires a user to manually search networks, select a trusted SSID, and authenticate. This process complicates Wi-Fi use for consumers and deters the use of Wi-Fi relative to more seamless network access and roaming on mobile networks.

The incorporation of new technologies under a Wi-Fi Alliance certification program known as Passpoint will simplify Wi-Fi network connection. Key elements of the Passpoint program include the Hotspot 2.0 and 802.11u standards, which enable network discovery and selection by communicating identifying information between the access point and client device prior to authentication. Prior to connection, supported client devices can obtain information from the access point that is necessary for network selection, such as operator policy, authentication protocol methods, and other relevant information.

In addition to automatic network discovery and selection, Passpoint also supports several authentication protocols that may ease secure network connection for users. In addition to a username/password process, which is similar to SSID authentication today, Passpoint also supports SIM-based (e.g. EAP-SIM) authentication so that operators can use the same credentials for both mobile and Wi-

Fi. In addition, a certificate-based authentication is possible using technology such as EAP-TLS, which allows operators to authenticate using device certificates.

In addition, Passpoint standardizes WPA2-Enterprise to enhance the level of security in Wi-Fi networks. Later releases of Passpoint will enable operator policy provisioning to manage business relationships, as well as online signup of new subscribers.

802.11r is also important, as it helps enable fast roaming of clients between closely located Wi-Fi Access Points. 802.11r achieves fast roaming by combining key negotiation and requests for wireless resources, targeting handoff time of less than 50 milliseconds.

Together, these advances will make the manual, SSID-based Wi-Fi connection process a thing of the past. Consumers will find it much easier to connect to new Wi-Fi Access Points through what will seem to them like an automatic process. This will enhance the utility of Wi-Fi, particularly for users that are on the move, and makes video applications more feasible when moving between Wi-Fi Access Points.

Quality of Service

Today, Wi-Fi quality of service can vary widely depending on the use environment. Within the home, service quality has historically been enabled through low contention ratios enabled by access point density relative to wireless devices, but as the number of devices in the home grows, along with wireless video traffic, this ad-hoc approach may become less effective. Outside of the home, service quality quickly suffers as access points become crowded. However, new techniques in radio resource management (RRM) and network optimization will enable a more intelligent approach to Wi-Fi service quality.

Many quality of service issues originate in today's simple Wi-Fi connection protocol – the access point with the strongest signal will serve as the default connection, and client devices may stay connected to the same access point even as the signal diminishes and others would provide a better experience. Advances in radio resource management through technologies like 802.11k will enable client devices to select the best available network based on a broader range of environmental information. For example, 802.11k may enable a client device to select an access point with a weaker signal if the access point with the strongest signal is handling a heavier amount of traffic – thus enabling higher throughput to the client device. On a network basis, this approach will ensure appropriate distribution of traffic across access points and spectrum channels, providing a more consistent experience overall.

In addition, broader Wi-Fi network optimization techniques (SON) will aid service quality. For example, throughput may be improved by dynamically managing access point transmit power when two geographically-proximate APs are operating on the same channel. Or, power may be varied depending on relative traffic loads. Latency-dependent applications like video can be provided higher priority on the network through Wi-Fi Multimedia technology. [xiii] Also, beamforming and MIMO approaches can be implemented to manage access point traffic loading. These approaches will also aid in handoff between access points and determining optimal frequency band utilization.

Together, these solutions represent a migration toward network-based Wi-Fi service quality, which will enable more consistent experiences across devices on the network. In addition, software used to implement these optimization techniques can also transmit network performance information to the operator, including maintenance needs, with the effect of minimizing costs and increasing network uptime.

Technology Roadmap

We have described a number of advances in Wi-Fi technology that will improve the user experience in wireless video and other applications. However, realizing these improvements is dependent on broad adoption. Broadly speaking, the technology described here must be adopted by the consumer electronics community, both at the access point and in consumer devices.

Controller-based access point deployments, incorporating optimization technology described here, will provide the network-level control and data needed to move from an ad-hoc Wi-Fi world to one that enables a more consistent user experience.

Equally important is adoption of enabling technology in consumer devices, such as Passpoint, that will make the use of Wi-Fi a more seamless experience for consumers.

Mobile devices are often provisioned with specifications determined by mobile carriers, particularly in markets like the United States where carriers subsidize most mobile devices. In unsubsidized devices, including tablets and many other product categories that do not rely primarily on the mobile network, consumer electronics manufacturers should find it in their interest to optimize the Wi-Fi experience for their customers. In light of the heavy reliance of mobile devices on offloading to the fixed network via Wi-Fi, ensuring the best user experience over Wi-Fi should serve the entire wireless broadband ecosystem, and adoption of enabling technology should be a priority across all Wi-Fi capable devices.

SPECTRUM DEVELOPMENTS

Wireless spectrum is also important to improving the Wi-Fi experience. The 2.4 GHz band remains the most widely-used unlicensed band today; however, heavy usage by WLAN devices as well as baby monitors, cordless phones, microwaves, and other devices has given rise to congestion. The 5 GHz band is also available for Wi-Fi and has plentiful bandwidth, but divergent terms of access complicate its use. For example, 80% of the channels are required to transmit at a lower power than the 2.4 GHz band. Further, the 5 GHz band experiences greater propagation and path loss than 2.4 GHz, which makes it useful for dense networking but more difficult and costly to deploy outside of the home. Since the technology advancements described above require spectrum as a fundamental enabler, we must also explore how spectrum access may keep pace with technology.

Several changes to Wi-Fi spectrum access are possible to enable adequate capacity, coverage, and reliability necessary for wireless video delivery. Expanded and harmonized access to 5 GHz will enable significant capacity and full functionality of 802.11ac. Expanded bandwidth will also aid reliability, and additional capacity with unique interference protections may become available in the 3.5 GHz band. Finally, Wi-Fi coverage may be enhanced through new access to low-band unlicensed spectrum as part of the FCC’s broadcast incentive auction initiative. However, various challenges exist to realizing expanded spectrum access in each of these contexts.

5 GHz

As directed by Congress, the FCC is contemplating expanding Wi-Fi access in 5 GHz where it is not currently permitted, and is studying the effects of relaxing regulatory limits to Wi-Fi access in currently-available 5 GHz spectrum.

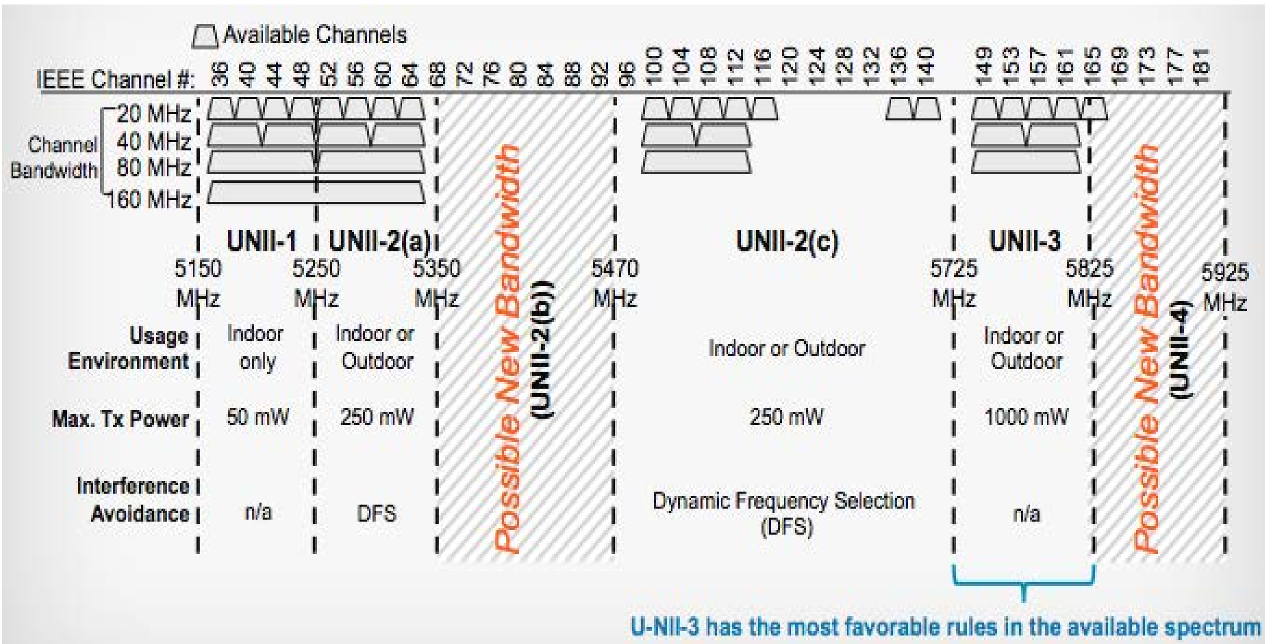

Figure 3: 5 GHz Wi-Fi Band Plan and Associated Rules

The 5 GHz U-NII band is split between an upper and lower portion, and different regulatory limits are placed on different portions of the band. In general, the lower channels are more restrictive in terms of power limits and technology, in order to avoid interference with radar and other incumbent systems that share the band. Only one portion of the band, 100 MHz known as "UNII-3", has terms of access similar to 2.4 GHz, and most utilization of the band to date has centered around that portion. Figure 3 shows specific regulatory differences across the 5 GHz band. As shown, full implementation of 802.11ac using a 160 MHz channel is not possible in the United States under the current rules without crossing sub-bands that have different rules. This limits the utility of the band and of new Wi-Fi standards.

However, expanding 5 GHz Wi-Fi bandwidth and harmonizing access rules would enable the significant technology advances explored in this paper. In particular, expanding access above 5.9 GHz has the potential to enable an additional 100 MHz of flexible Wi-Fi spectrum adjacent to the "UNII-3" band, providing 200 MHz of contiguous Wi-Fi spectrum with terms of access that are similar to 2.4 GHz.

A similar approach is also possible in amending the terms of access to "UNII-1". "UNII-2" has to date been treated differently from other Wi-Fi spectrum in its requirements for dynamic frequency selection (DFS) for interference avoidance vis-à-vis incumbent radar systems. However, DFS is not widely supported by vendors because of this unique requirement and its uncertain performance. In addition, currently-allocated Wi-Fi spectrum in "UNII-2c" has additional restrictions on use due to weather radar interference. Figure 4 below shows a possible new band plan for 5 GHz with expanded access to enable full utilization of 802.11ac and related technology.

Expanded, harmonized Wi-Fi access at 5 GHz would provide significant capacity and enable new technology. However, this outcome is only possible if appropriate, commercially-flexible coexistence protocols can be determined with incumbent spectrum users. Figure 4 below shows a possible new band plan for 5 GHz with expanded access, as well as incumbent spectrum allocations across the 5 GHz band. The number and diversity of incumbents outlines the challenge to Wi-Fi use of the 5 GHz band.

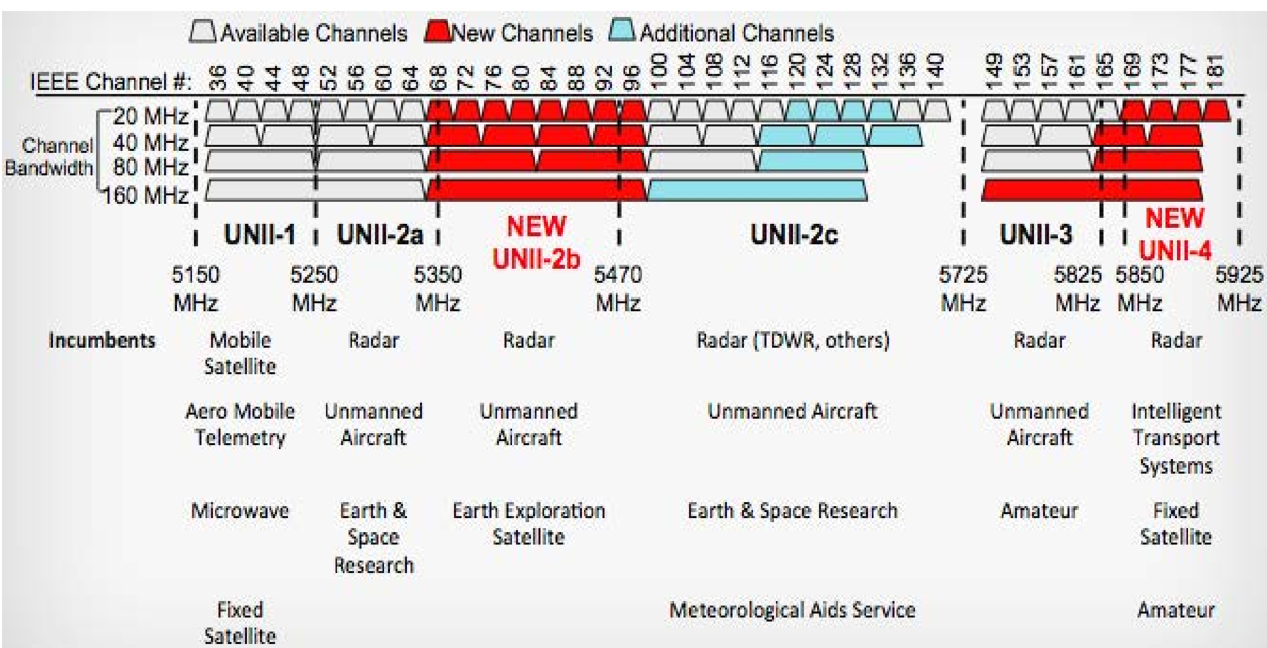

Figure 4: Possible New 5 GHz Wi-Fi Band and Non-Wi-Fi Spectrum Incumbents

3.5 GHz

In November 2010, the Department of Commerce recommended that the 3.55-3.65 GHz band be made available for new commercial use, and in December 2012, the FCC released a proposal for doing just that. Under the FCC's proposal, 100 MHz of spectrum would be made available under a 'general access' approach, akin to unlicensed, and possibly under a 'priority access' protocol with certain interference protections. This band may serve therefore to supplement Wi-Fi capacity and, if made available under priority access terms, could also provide reliability to Wi-Fi systems.

In recommending that the 3.5 GHz band be made commercially available, the Commerce Department noted that such availability would likely entail geographic restrictions to protect incumbent military radars that use the band. There are no plans to move these radars to another band due to prohibitive cost. Therefore, new commercial systems will be required to work around them, and operate at sufferance. In combination with its propagation characteristics, these circumstances limit the interest of mobile operators in utilizing the band, which provides an opportunity for economic terms of access under a "small cell" framework that may complement the Wi-Fi ecosystem.

The government proposed to manage commercial – military sharing in 3.5 GHz through broad "exclusion zones" that would preclude commercial use in the excluded area. These exclusions are shown in Figure 5 below, and are estimated to exclude approximately 60% of the US population from coverage.

These exclusion zones were developed through the government's worst-case interference analysis, assuming that new commercial services would be high-powered macro mobile networks. However, under a small cell deployment, there is reason to believe that the zones could be reduced substantially. In addition, with innovative access protocols, such as dynamic power adaptation and temporal coordination of signaling, commercial exclusion zones may be eliminated.

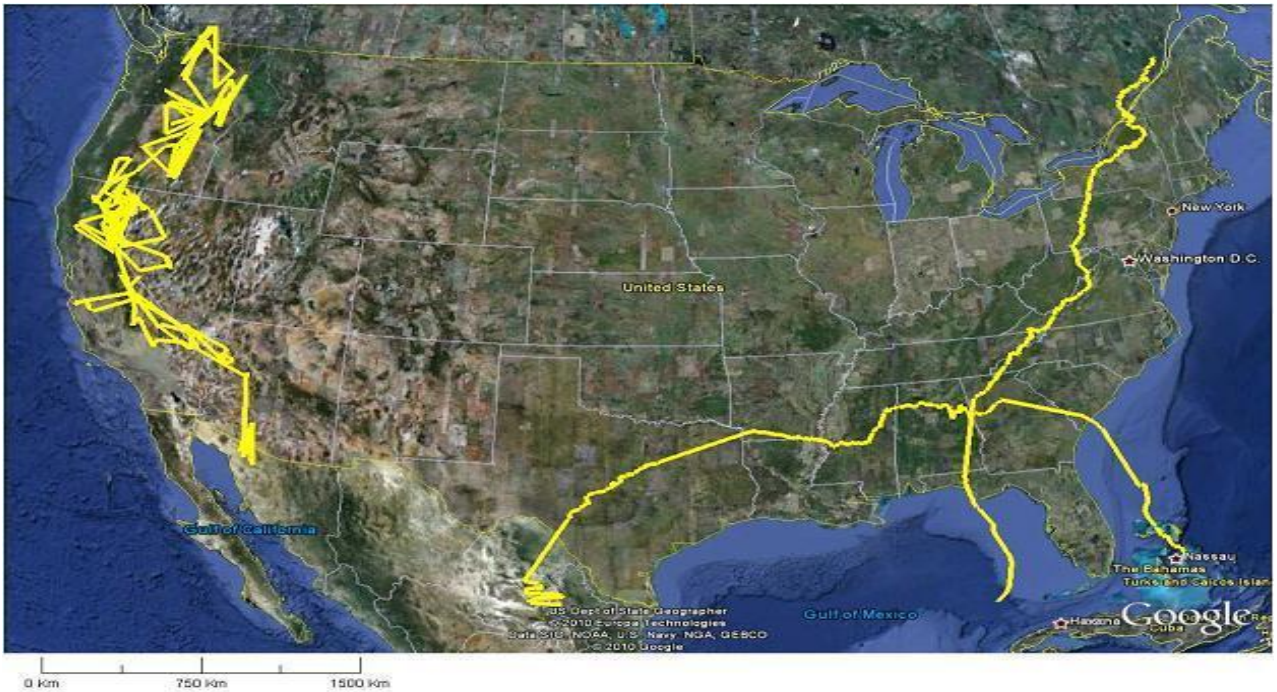

Figure 5: 3.5 GHz Commercial Exclusion from Costal Zones As Proposed by the Commerce Department [xiv]

Ongoing engagement with the Commerce Department and the FCC will be required to enhance the prospects of Wi-Fi use of the 3.5 GHz band.

600 MHz

Under Congressional direction, the FCC is preparing to reallocate up to 120 MHz of the broadcast television band for new wireless broadband use through a process known as an incentive auction. This process is, in essence, a two-sided auction in which the FCC buys spectrum back from broadcasters, repackages it for wireless use (including developing a new channelization plan for remaining broadcasters), and sells it.

In developing a new band plan for the repurposed spectrum, guard bands will be needed to protect mobile and broadcast uses. Unlicensed use is envisioned for these guard bands. If achieved, unlicensed use of 600 MHz guard bands would provide new geographic contiguity in low-band unlicensed spectrum, which is missing from the white space ecosystem today, hindering its development and utility.

Low-band unlicensed spectrum may prove to be an essential element of the Wi-Fi future. As access points are deployed outside of the home to achieve broader coverage, the favorable propagation and path characteristics of the 600 MHz band will enable a wider footprint on a more economic basis than spectrum higher in frequency. All else being equal, the 600 MHz band propagates over 60 times farther than 5 GHz, and over 14 times farther than 2.4 GHz. This property greatly reduces the number of access points needed to achieve coverage. For example, to cover an area equivalent to a 1W 600 MHz access point would require approximately 2900 2.4 GHz access points.[xv]

Such favorable propagation characteristics and related deployment economics would greatly speed Wi-Fi coverage, complementing many of the technology advances on the horizon, and enabling greater utility for a range of applications, including video. In addition, the new availability of low-band unlicensed spectrum, contiguous in frequency and geography, could enable simplification of access protocols that burden the 'White Spaces' today. The use of a 'control channel' architecture in low-band spectrum could enable network signaling to Wi-Fi devices across the full geographic footprint, both in 600 MHz and in other bands, that could greatly increase the availability and utility of unlicensed Wi-Fi spectrum.

However, the extent of unlicensed access in 600 MHz will be determined by the amount of spectrum supplied by broadcasters in the incentive auction, and the band plan the FCC chooses for the repurposed spectrum. Spectrum supply will be determined by decisions of broadcasters in the auction, but the band plan framework will be known in advance. The FCC has proposed a band plan framework that would yield very little guard band unlicensed spectrum – as little as 12 MHz, broken into two 6 MHz blocks, as seen in Figure 6 below.

Figure 6: FCC 600 MHz Band Plan Proposal[xvi]

An alternative band plan approach would be more likely to yield useful unlicensed spectrum while also better protecting mobile and TV services from interference. Such an approach would entail clearing spectrum from the top of the TV band and working down as spectrum is supplied by broadcasters, with the mobile uplink and downlink separated by an unlicensed duplex gap. This approach is depicted in Figure 7 below, which the FCC calls "Down from 51".

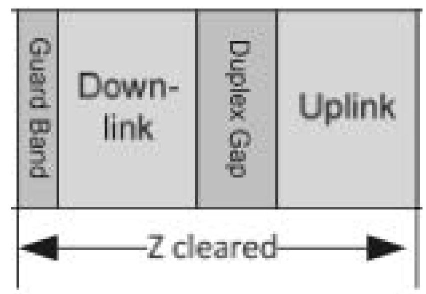

Figure 7: FCC Alternative Band Plan, "Down from 51"[xvii]

An appropriately sized duplex gap could yield 24 MHz of unlicensed spectrum, as noted by Grunwald and Baker (2013) and shown in Figure 8.[xviii]

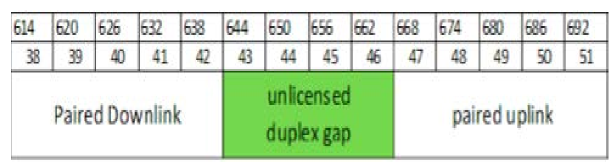

Figure 8: "Down from 51" Band Plan Yielding 24 MHz of Unlicensed Access[xix]

While there appears to be broad industry agreement on the merits of a "Down from 51" approach, the precise amount of unlicensed spectrum that would be appropriate remains under debate. The outcome of this debate will be important to realizing the benefits of low-band unlicensed spectrum and the new Wi-Fi technologies that consumers will value.

Spectrum Roadmap

The three wireless bands noted here – 600 MHz, 3.5 GHz, and 5 GHz – serve as a significant opportunity for evolving the Wi-Fi experience, and mitigating the risk of reduced performance as congestion grows in existing Wi-Fi bands.

With newfound coverage-related spectrum in 600 MHz, the ubiquity of Wi-Fi will be enhanced. With basic interference protections in the 3.5 GHz band, greater reliability may become possible for users. And with expanded and simplified access in 5 GHz, significant capacity will be achieved. These advances complement the technology developments on the Wi-Fi horizon.

Realizing Wi-Fi access to these bands presents unique challenges in each context, and will require sustained engagement with regulators and other stakeholders to achieve success.

PUTTING IT TOGETHER FOR THE CONSUMER

This paper has explored a range of next-generation Wi-Fi technologies and new spectrum access frameworks that may enable them. We have also highlighted some of the key dependencies for realizing this future vision of Wi-Fi.

To explore how these developments will be useful to consumers, we can examine how a hypothetical consumer may use video applications over Wi-Fi in the course of a day. In so doing, it becomes clear that our hypothetical user – and Wi-Fi users everywhere – will enjoy more consistent and reliable throughput and coverage, as well as more seamless network connection. These developments will lead consumers to use Wi-Fi in a wider range of contexts, helping to ensure that Wi-Fi remains the broadband access network of choice.

Our use case progression tracks our consumer through a typical morning as he uses video over Wi-Fi, from the time he wakes up to his morning meeting in the office. The stages of our use case progression are described below, along with a brief description of the operating environment and the key evolutions in Wi-Fi technology and spectrum that will improve his experience.

Figure 9: Use Case Progression: A Morning of Video Over Wi-Fi

Stage 1, "Waking up": Our user begins his day by watching the news on his iPad as he gets out of bed.		
Operating Environment: Indoor home use; access point dedicated to single household.		
Current Experience	*Future Experience*	*Enablers*
Manual setup, 'Best effort' quality	Automatic setup, Consistent high quality	802.11ac: wide channels, MIMO, SON Additional 5 GHz spectrum

Stage 2, "Eating Breakfast": Our user moves to the living room to eat in front of the TV.		
Operating Environment: Indoor home use; access point dedicated to single household.		
Current Experience	*Future Experience*	*Enablers*
Uses set-top to locate and view linear content	Mirrors iPad content on TV wirelessly	Miracast DLNA Gateway WiGig Additional 5 GHz spectrum

Stage 3, "Out the door": Our user walks to the train station, listening to the audio of video content continuing to stream on mobile device or iPad.		
Operating Environment: Outdoor neighborhood use; shared access point on the street.		
Current Experience	*Future Experience*	*Enablers*
Manual reconnection to APs, spotty coverage and throughput. Possible default to mobile.	Automatic AP connection, more consistent experience. Consistent experience enables continued Wi-Fi use.	802.11ac Passpoint / 802.11r SON / 802.11k New spectrum bands and standards (3.5 GHz for reliability, 600 MHz for coverage)

Stage 4, "On the train": Our user continues to view video content on his train ride to work.		
Operating Environment: Shared use inside train car with mobility; antenna on car connects to rail wayside access point.		
Current Experience	*Future Experience*	*Enablers*
Manual connection, irregular connectivity due to mobility, possible congestion due to	Automatic connection, consistent experience despite mobility, shared AP. Seamless experience enables	802.11ac Passpoint / 802.11r SON / 802.11k New spectrum bands and standards (3.5 GHz for reliability, 600 MHz for coverage and mobility)

shared use. Likely default to mobile use.	continued use of Wi-Fi.	

Stage 5, "Walking to work": Our user walks from train station to office, listening to the audio of video content continuing to stream on mobile device or iPad.		
Operating Environment: Outdoor downtown use; access point shared with many commuters.		
Current Experience	*Future Experience*	*Enablers*
Manual connection to SMB or public APs, low or no throughput due to congestion. Possible default to mobile.	Automatic connection to available APs, connectivity maintained despite congestion. Lower risk of default to mobile.	802.11ac Passpoint / 802.11r SON / 802.11k New spectrum bands and standards (3.5 GHz for reliability, 600 MHz for coverage)

Stage 6, "Morning meeting": Our user arrives at the office and uses Wi-Fi to facilitate a client meeting, delivering a presentation.		
Operating Environment: Indoor access point dedicated to meeting room or floor.		
Current Experience	*Future Experience*	*Enablers*
Uses Wi-Fi to pull presentation to laptop, then manually connects to projector, and emails presentation to clients later.	Uses Wi-Fi to pull presentation to laptop, WiGig to connect wirelessly to monitor, and Miracast to enable clients to view on their own screens in real time.	802.11ac Passpoint / 802.11r SON / 802.11k WiGig Miracast New spectrum bands and standards (3.5 GHz for reliability, 600 MHz for coverage)

CONCLUSION

The typical Wi-Fi user will benefit from a range of new technologies and new spectrum, enhancing capacity, reliability, and coverage, and making Wi-Fi more useful in a number of contexts. In our examination of one use case progression, these factors enable Wi-Fi to serve new purposes for consumers. Through adoption of new standards and optimization techniques, Wi-Fi can enable new home uses, and can become a more consistent and seamless experience for users outside of the home. Key to this evolution is adoption of new technologies in consumer devices and new spectrum access to enable these advances. Sustained engagement in the Wi-Fi ecosystem and spectrum policy on the part of MSOs and the broader Wi-Fi community is therefore of critical importance in realizing the future of Wi-Fi.

Endnotes

[i] Sandvine, "Global Internet Phenomena Report", 2H2012. The traffic category of "real time entertainment" comprises 65.2% of peak-period fixed access traffic in North America. Sandvine notes that this traffic category has, overall, doubled its share of total traffic over the past three years.

[ii] Cisco forecasts North American Internet traffic to grow 2.8 times between 2011 and 2016, while peak-period traffic is estimated to grow 3.1 times. Cisco Visual Networking Index, 2011-2016.

[iii] Business Insider, "How Tablet Sales Have Exploded, And Where The Next Wave of Growth Will Come From", January 8, 2013;.

[iv] Gartner Research, 2012, as reported by Matt Hambien, "Smartphones and tablets growth exploding, especially in business, Gartner says", Computerworld, November 6, 2012.

[v] Chetan Sharma Consulting, "US Wireless Market Update, Q42011 and Full Year 2011". Note that mobile-enabled tablets generally also come equipped with Wi-Fi.

[vi] The terms MSO and Cable operator are used interchangeably in this paper.

[vii] NCTA, "In America, There Are 10x More Cable Operator Provided Wi-Fi Hotspots Than There Are Starbucks", March 28, 2013.

[viii] Previous efforts at municipal Wi-Fi networks existed but largely failed due to an inability to support the investment required to build and operate the networks. For a review of municipal Wi-Fi, see Tim Wu, "Where's My Free Wi-Fi?", Slate, September 27, 2007.

[ix] Sandvine, 2012.

[x] Broadcom, "IEEE 802.11ac – Wi-Fi for the Mobile and Video Generation", January 2012.

[xi] For more information, see Wi-Fi Alliance, "Wi-Fi Alliance and Wireless Gigabit Alliance to Unify", press release, January 3, 2013

[xii] ABI Research, "Increasing DLNA Software Certification Will Propel the Adoption and Connection of Devices within the Home Network", January 24, 2011.

[xiii] Wi-Fi Multimedia is a WFA certification based on the IEEE 802.11e standard, which enables traffic prioritization by category.

[xiv] Department of Commerce, National Telecommunications and Information Administration, "An Assessment of the Near-Term Viability of Accommodating Wireless Broadband Systems in the 1675-1710 MHz, 1755-1780 MHz, 3500-3650 MHz, and 4200-4220 MHz, 4380-4400 MHz Bands", October 2010.

[xv] Dirk Grunwald and Kenneth Baker, "FCC Broadcast Incentive Auction: A Band Plan Framework for Maximizing Spectrum Utility", 2013.

[xvi] FCC 12-118, "In the Matter of Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions", Notice of Proposed Rulemaking, released October 2, 2012.

[xvii] Ibid.

[xviii] Grunwald and Baker, 2013.

[xix] In this band plan and the others shown in this document, only a portion of the band is depicted due to space limitations. In the Grunwald and Baker example, 120 megahertz

of spectrum is assumed to be repurposed through the incentive auction; additional mobile spectrum is assumed in the band plan but not shown here.