Fair Use and Innovation in Unlicensed Wireless Spectrum

LTE unlicensed and Wi-Fi in the 5 GHz unlicensed band

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EXECUTIVE SUMMARY

Wireless communication has become the bedrock of our information society, and it will continue to be as both the number of devices and the data needs of each device increases. In 2014, average smart phone usage grew 45 percent, the number of mobile devices grew 72 percent, and global mobile data traffic grew 69 percent [1]. Demand for mobile data is expected to continue to rise exponentially as data intensive technologies such as virtual or augmented reality (e.g. Google Glass), home automation, and vehicular communications hit the market. By 2020, overall mobile data traffic is expected to increase by a factor of ten, demand in certain congested urban areas is expected to increase by a factor of 1000, and the number of connected mobile devices is expected to reach 50 billion. These trends will largely be driven by the Internet of Things[1] and Machine to Machine (M2M)[2] technologies [5]. This demand increase must be met with an equal industry and government response because existing networks are not capable of providing the requisite capacity.

The necessary gains will come both from freeing up spectrum for commercial use and from using available spectrum more efficiently. The historical industry strategy to increase cellular capacity is to call for the government to make more spectrum licenses available to companies to purchase; the prudency of this approach is discussed in detail in Section 2 below. A July 2012 President's Council of Advisors on Science and Technology (PCAST) report details the need to rethink today's model of "offer[ing] only the choice between unlicensed and long term, renewable licensed spectrum" and toward thinking of the national spectrum as an infinitely renewable system with flexible licenses and cooperative access [6]. The PCAST report identifies several long-term approaches for multiple devices and different economic sectors to share

[1] The Internet of Things refers to "the pervasive presence around us of a variety of things or objects – such as Radio-Frequency IDentification (RFID) tags, sensors, actuators, mobile phones, etc. – which, … are able to interact with each other and cooperate with their neighbors to reach common goals" [2]. It means that "the Internet and networks [will] expand to places such as manufacturing floors, energy grids, healthcare facilities, and transportation" [3]. Common examples are the Nest Thermostat and wireless health monitoring bands.

[2] "Machine to machine (M2M) is a broad label that can be used to describe any technology that enables networked devices to exchange information and perform actions without the manual assistance of humans. M2M communication is often used for remote monitoring. In product restocking, for example, a vending machine can message the distributor when a particular item is running low. M2M communication is an important aspect of warehouse management, remote control, robotics, traffic control, logistic services, supply chain management, fleet management and telemedicine. It forms the basis for a concept known as the Internet of Things (IoT)" [4] Wireless smart meters, for example, often communicate as M2M devices.

spectrum efficiently and fairly. In the short term, however, it is critical that policymakers manage the current system of licensing in a manner that allows innovation in spectrum sharing and enables the most efficient and fair use of the spectrum.

Innovation and policy changes are not easy, however. Any issue concerning wireless spectrum is worth billions of dollars, with several competing stakeholders. Cellular companies covet licensed spectrum because they have complete control over transmission in a geographic area, and so their investments are less dependent on the actions of others. In the recent AWS-3 spectrum auction, cellular companies spent $44.9 billion for licenses to 65 MHz of spectrum [7]. Though unlicensed spectrum is less valuable to cellular companies due to stricter transmission rules and the inability to limit other interferers, the potential to use such bands to augment capacity in certain areas is attractive because devices can use these bands at no cost. For example, in 2014, up to 46 percent of potential cellular data was offloaded to Wi-Fi by cellular companies[3] [1]. Similarly, public and personal Wi-Fi, along with other devices that operate on unlicensed bands, are a large part of the national information infrastructure, and manufacturers have billions of dollars in device sales that depend on the unlicensed bands. Any threat to the unlicensed spectrum on which such devices operate, and their place in it, is met with fierce resistance. The essentials of wireless communication and the interplay between licensed and unlicensed bands are discussed below in Sidebar 1.1.

Against this backdrop, a new technological development promises to increase cellular data capacity by using unlicensed spectrum traditionally dominated by Wi-Fi[4]. In December, 2013, Qualcomm and Ericsson presented a method to provide efficient data transmissions on the unlicensed bands, supported by control transmissions on licensed bands [8]. Two standardization processes for this technology are underway: Licensed Assistant Access (LAA), by the cellular standards body 3GPP, and LTE-Unlicensed, by the LTE-U Forum, a collection of device manufacturers and cellular companies such as Verizon and Qualcomm. These technologies will enable cellular companies to utilize unlicensed bands seamlessly to augment their network

[3] The report states that 46 percent was offloaded to Wi-Fi and small cellular towers combined. Within this category, it is likely that large majority was offloaded to Wi-Fi, though that number is not listed.

[4] "Wi-Fi" has colloquially become a synonym for "WLAN." In reality, the IEEE 802.11 WLAN committee creates WLAN standards that anyone can implement on a device. The Wi-Fi Alliance has a certification process for devices that follow the IEEE 802.11 interoperability standards. Not all device manufacturers choose to go through the certification process, even if they follow the IEEE 802.11 standards. In this paper, "Wi-Fi" and "IEEE 802.11 WLAN" will be used interchangeably, except when the respective organizations and their positions are discussed.

capacity and improve service for their customers. Current standardization processes are focusing on parts of the 5 GHz unlicensed band [9]. Instead of relying on users to connect to Wi-Fi hotspots, companies could seamlessly send LTE signals to users through unlicensed bands. Wi-Fi companies and supporters are concerned that such additional use of the unlicensed bands will severely degrade Wi-Fi performance and that these new transmissions will not share the resource fairly with Wi-Fi due to several unique technical characteristics, which are discussed in Section 1.1. The two sides disagree on the facts of how much performance degradation LAA/LTE-U will cause to existing users of the band, as well as what coexistence mechanisms should be adopted to minimize the impacts.

These technological advancements are part of a greater conversation about the future of the unlicensed bands: whether the central tradeoff that devices can use unlicensed bands for free but in exchange must tolerate interference from others using the bands as well is broken. Increasing congestion and incentives to communicate in a way that does not allow others to use the channel threaten the future viability of the unlicensed bands. Different technologies and structural advantages may enable a given protocol, company, or economic sector to dominate the unlicensed bands, pushing out other users and hindering future innovation.

Though the discussion in this report is grounded in the technological facts of the present debate, a chief conclusion is that an overhaul in the understanding of how spectrum can be shared fairly by different parties is needed. The sharing problem is itself not new, as numerous devices on the 2.4 GHz and 5 GHz unlicensed bands already behave in a manner that is unfriendly to neighboring devices, but the problem will worsen as the number of devices continues to grow and with society's increasing reliance on mobile communication. If the Federal Communications Commission (FCC) does not want to repeat the LTE unlicensed discussion every time a new technology enters the market, it must articulate principles and enforcement mechanisms for fair use of unlicensed bands.

CURRENT STATUS

The various standards bodies (3GPP, the LTE-U Forum, and the IEEE 802.11 WLAN committee) are in the process of creating standards for LTE unlicensed, and the Federal

Sidebar 1.1: A Primer on Wireless Communications and Spectrum Policy

In wireless communications, information is carried by electromagnetic waves on different frequencies. Electromagnetic waves of different frequencies can be separated, and so different ranges of frequencies, or bandwidths, can be regarded as separate channels of communication. The amount of information that can be sent per second is a function of the bandwidth and the signal to interference plus noise ratio: higher rates are achieved through either more bandwidth or less interference from other devices.

In the United States, the Federal Communications Commission (FCC) and the National Telecommunications and Information Administration (NTIA) collectively manage the national bandwidth, or spectrum. The NTIA manages federally owned and used spectrum, while the FCC manages all other uses. They balance the needs of a whole host of stakeholders, including military, emergency responders, astronomers, cellular companies, and the general public. Broadly speaking, there are two traditional kinds of spectrum: licensed and unlicensed. License owners have the rights to the sole use of a given bandwidth in a geographic region. For example, cellular companies own the bandwidths on which they transmit and have to pay billions of dollars for such licenses. On the other hand, any device can transmit on the unlicensed bands, provided it follows certain rules designed to minimize interference to other devices using the band, such as power limits.

Wi-Fi operates on two swaths of unlicensed bandwidth, called the 2.4 GHz and 5 GHz bands. The 2.4 GHz band is the 100 MHz between 2.4 and 2.5 GHz, also called the ISM band. The 5 GHz band, called the U-NII band, runs from 5.15 to 5.825 GHz, but it is divided into several sections with different rules. Most Wi-Fi devices that are on 5 GHz band currently operate in the U-NII-3 band, from 5.725 to 5.825 GHz, which allows outdoor transmission at up to 1 Watt. The FCC in 2014 modified the rules for the U-NII-1 band (5.15 to 5.25 GHz), allowing outdoor transmission at 1 Watt, to make more room for Wi-Fi devices.

Communications Commission opened Public Docket No. 15-105, with comments due on June 11, 2015, and reply comments due on July 26, 2015[5]. The docket asked several detailed questions about technological developments and plans for the technology [10]. The docket submissions make clear that this issue is politically charged with several defined sides, and the various sides of the debate are discussed in Section 1.1.

Current regulations in the 5 GHz unlicensed bands in question do not resolve the issue; they limit transmit power and power spectral density for the parts of the band that are most

[5] The author of this report submitted a reply comment on July 25, 2015. It is available here: http://apps.fcc.gov/ecfs/comment/view?id=60001080495

relevant to this debate, but not any of the technical characteristics relevant in the current debate. If a device manufacturer were to submit a certification request to the FCC today for a LTE unlicensed device, no regulatory standard would justify a denial. These regulations are discussed in more detail in Section 1.3.

ORGANIZATION

This report is structured as follows:

In Section 1, the technology, policy, and political environment of the LTE unlicensed debate is described. First, the chief technical differentiating characteristics of LTE-U and LAA are described to help one understand the terms of the debate and the targets of any potential regulation. Then, the current FCC regulations for the 5 GHz unlicensed band are explained, with a focus on potential gaps. The 5 GHz band is discussed because all current standardization processes for LTE unlicensed are targeting that band first, before potentially moving onto to other unlicensed or shared-licensed bands [9]. Third, each of the stakeholders and potential actors – the standards bodies, companies, and the FCC – are listed to help one understand the motivations and arguments of each side, with an emphasis on disagreements on the facts.

In Section 2, the economic landscape is described to illustrate what is at stake in the current debate, for all parties and consumers. First, the present and future of Wi-Fi is discussed with focus on roles of the 2.4 GHz and 5 GHz bands and the question of whether Wi-Fi can be deemed the dominant incumbent in each band. Next, the needs and opportunities of cellular transmissions are discussed; special attention is given to the interplay between more exclusive licenses and spectrum sharing approaches, including the question of whether cellular companies should make greater use of unlicensed bands to meet demand. Finally, the specter of billions of new devices utilizing M2M technologies and unlicensed bands as part of the Internet of Things is discussed.

In Section 3, the various FCC regulatory options are analyzed. These options include both regulations recommended by various parties and new suggestions that could address some of the differences discussed in Section 1. The implications for each regulation are analyzed both within the context of the LTE unlicensed debate and beyond this debate, with respect to the implications for other devices in the unlicensed bands and future innovation and economic productivity on the band.

In Section 4, a framework to analyze these potential regulations is developed. First, it is argued that much of the current debate is a proxy for a central conflict in the stated values of the FCC on the unlicensed bands: any regulation must balance protecting the status quo economic and public benefits with supporting future wireless innovation and potential benefits. Next, a robust definition of 'fair use' of the unlicensed bands is developed, with a goal of developing a definition that can resolve future disputes.

In Section 5, the recommendations of this report are discussed. These recommendations together form a framework for unlicensed spectrum similar to the one developed by the PCAST report for federal spectrum. The central theme of these recommendations is that a structure for defining and enforcing fair use on the unlicensed spectrum must be developed and implemented. These recommendations are listed in the following section.

FINDINGS AND RECOMMENDATIONS

Table 1 contains the findings from each section of the report. These findings are the primary factual conclusions of the report. Together, they form the basis for the report's recommendations. The recommendations are listed in Table 2.

The central theme of the findings and recommendations are that the current light-touch regulatory system for the unlicensed bands are not sustainable as Internet of Things and Machine to Machine technologies continue to saturate the market. The current LTE unlicensed matter is a symptom of the maturation of the unlicensed bands and a value conflict between enabling innovation and supporting a status quo public economic good. The LTE unlicensed debate reveals the potential for a device or technology to push other devices out of the unlicensed bands if it chooses to do so. The standards bodies are the preferred avenue of resolution in this debate, and the Federal Communications Commission should pressure them to collaborate. Regardless of how the current debate is resolved, however, the standards bodies approach will not work for future conflicts.

The Federal Communications Commission should adopt a system of privileged and unprivileged devices on the unlicensed bands to maximize efficiency on the bands while simultaneously providing a framework to pursue policy goals. This report extends the framework established by the 2012 PCAST report on government-held spectrum [6]. While the PCAST report recommends spectrum sharing with privilege as an alternative to exclusive use by

government stakeholders on current government-held spectrum, this report calls for a system with privilege as an alternative to wholly shared unlicensed spectrum. A system with privilege for technologies that further various national values – such as innovation or public access – is necessary to counter the potential of a single technology preventing others from using the unlicensed bands. The coming information and communications revolution of the next five years demands such a proactive approach.

Table 1: Report Findings

	Section 1: Background
Finding 1.1	Several technical characteristics and structural advantages lead to the *potential* of dominance of one technology on the unlicensed bands at the expense of others. Whether that potential plays out in the LTE Unlicensed case depends on the standardization process.
Finding 1.2	Current unlicensed regulations for the 2.4 GHz and 5 GHz bands, predominantly limited to power constraints, are not enough to prevent a technology from pushing out other devices from the unlicensed bands if it chooses to do so.
Finding 1.3	In the LTE-U/LAA debate, both sides are well-positioned politically and have much experience with the standardization process. This level of sophistication may lead to cooperation without additional government regulation, but it is not yet guaranteed that the standards bodies will coordinate. Coordination in industry standardization is the FCC's preference.
	Section 2: Economics
Finding 2.1	Congestion on the 2.4 GHz unlicensed band makes it a poor choice for future Wi-Fi growth.
Finding 2.2	Wi-Fi cannot yet be considered the incumbent on the 5 GHz band. However, it is well poised to utilize the band in the coming years to ease congestion in 2.4 GHz, and the continued growth of Wi-Fi is tied to the 5 GHz band.
Finding 2.3	The 2.4 GHz and 5 GHz unlicensed bands are home to countless other devices besides Wi-Fi. These other unlicensed devices, often forgotten in the LTE

	unlicensed debate, must be taken into account when any new regulations are discussed. Few technology neutral mechanisms available would protect Wi-Fi from LTE unlicensed without causing collateral harm to these devices.
Finding 2.4	The current LTE unlicensed debate is part of a larger context: the trend to utilize otherwise unused parts of the spectrum to augment cellular capacity is a good one, and any regulation must not inadvertently harm such efforts. Using small cells and unlicensed spectrum in the busiest areas during peak demand is an efficient alternative to buying long-term, expensive, wide area licenses. It has helped cellular companies meet demand, easing concerns about the 'spectrum crunch.' However, this trend does not negate real concerns about whether the 5 GHz band is truly underutilized or whether LTE unlicensed is fair to other stakeholders.
Finding 2.5	The emergence of the Internet of Things (IoT) and Machine to Machine (M2M) devices threaten the status quo due to the exponentially larger amount of different technologies and devices that must coexist on the unlicensed bands. These devices increase the likelihood that some devices will act in an unfriendly manner.
	Section 3: Potential FCC Actions
Finding 3.1	The FCC cannot resolve the LTE unlicensed debate with device-level regulations without causing significant collateral damage to non-Wi-Fi devices that already operate on the unlicensed bands.
Finding 3.2	The approach to rely on standards bodies to ensure fair coexistence is flawed because of a lack of incentives to cooperate and an inability to include smaller parties in the discussions. However, it is the best path forward due to the potential for harm from FCC regulations and the difficulty of designing long-lasting regulations without loopholes.
Finding 3.3	Though a resolution at the standards body level might work in this case, but there is no guarantee of cooperation. The FCC may need to pressure the standards bodies to collaborate. Furthermore, for future debates, the standards

	bodies approach may not work at all, and the FCC should consider acting pre-emptively in future unlicensed bands.
Finding 3.4	New Listen before Talk regulations would be both difficult to design without loopholes and would significantly affect other existing unlicensed devices.
Finding 3.5	Though no framework currently exists to measure and limit the scale of installations, the discussion of sum interference in the 3.5 GHz shared spectrum band can be used to inform a system of privilege on future unlicensed bands.
	Section 4: A New Architecture for Fair Use
Finding 4.1	The stakeholders disagree significantly in the present debate about what 'fair' coexistence is. There is no generalizable understanding of what 'fair use' on the unlicensed bands entails and how the FCC should enforce such use.
Finding 4.2	The lack of an understanding of 'fair use' is due to a conflict of values for the unlicensed bands, as articulated by the FCC.
Finding 4.3	Disagreements about 'fair use' are not just philosophical – they lead to different policy decisions in the LTE unlicensed debate, as well as future debates.
Finding 4.4	No single definition of 'fair use' can be applicable for all situations. Rather, different values may be appropriate at different times and areas.
Finding 4.5	A Laissez-Faire approach to the unlicensed bands will not work for future unlicensed bands and technologies.

Table 2: Recommendations

	Recommendations
Recommendation 1	The FCC should not enact any new regulations for existing unlicensed bands, especially those are not 'technology neutral.' New regulations would be politically and economically problematic due to the wide range of devices that currently operate on the bands. Instead, the FCC should pressure the standards bodies to collaborate on a coexistence mechanism.

Recommendation 2	As future unlicensed bands (or shared bands with unlicensed access) are opened, the FCC must articulate and be willing to enforce intended uses and standards for ‘fair use’ on the band.
Recommendation 3	For future unlicensed bands, the FCC should specify an architecture in which devices back off to privileged users. The idea of a Spectrum Access System recommended by the PCAST report on government-held spectrum should be extended to privilege on unlicensed bands.
Recommendation 4	The unlicensed bands are not priced correctly. For future or currently unused unlicensed bands, the FCC, in concert with IEEE 802 and 3GPP, must find a pricing mechanism with privileged and unprivileged users. The 3.5 GHz CBRS band should be used as a testing ground for privilege.
Recommendation 5	Academic researchers should research and design real-time auctions for privileged communication in a given geographic area. These auctions could be supported by databases such as those used in TV whitespaces.

PREFACE

AUTHOR BIO

Nikhil Garg is an entering PhD student in Electrical Engineering at Stanford University, where he is supported by a National Science Foundation Graduate Research Fellowship. He received a B.S. in Electrical & Computer Engineering and a B.A. in Plan II Honors from the University of Texas at Austin with highest and special honors, both in May 2015. Nikhil is interested in wireless communications, social algorithms, and technology policy. While at UT Austin, Nikhil researched 5G cellular and heterogeneous wireless networks and built a large scale recommendation engine for books. He has interned as a Software Engineer at Microsoft and as a Space Academy Research Associate at NASA Glenn Research Center. He also was a Next Generation Scholar at the Strauss Center for International Security and Law and served as a Legislative Intern at the Office of Texas State Senator Davis. Nikhil is an Eagle Scout, a Distinguished College Scholar of Engineering and Liberal Arts, and a recipient of the Unrestricted Endowed Presidential Scholarship at UT Austin. In his spare time, Nikhil enjoys reading philosophy, working on coding projects, and being active in student societies. He can be contacted at nkgarg@stanford.edu and gargnikhil.com.

WASHINGTON INTERNSHIP FOR STUDENTS OF ENGINEERING

The Washington Internships for Students of Engineering (WISE) program was founded in 1980 through the collaborative efforts of several professional engineering societies to encourage engineering students to contribute to issues at the intersection of science, technology, and public policy. The nine-week program allows students to spend the summer in Washington, D.C. to gain exposure to the legislative and regulatory policy-making process through meetings with leaders in the Administration, federal agencies, Congress and advocacy groups. In addition, each student is responsible for proposing, researching, writing, and presenting a paper on a topical engineering-related public policy issue that is important to the sponsoring society. For more information about the WISE program, visit www.wise-intern.org.

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CONTENTS

1 BACKGROUND

	Section 1 Key Findings
Finding 1.1	Several technical characteristics and structural advantages lead to the *potential* of dominance of one technology on the unlicensed bands at the expense of others. Whether that potential plays out in the LTE Unlicensed case depends on the standardization process.
Finding 1.2	Current unlicensed regulations for the 2.4 GHz and 5 GHz bands, predominantly limited to power constraints, are not enough to prevent a technology from pushing out other devices from the unlicensed bands if it chooses to do so.
Finding 1.3	In the LTE-U/LAA debate, both sides are well-positioned politically and have much experience with the standardization process. This level of sophistication may lead to cooperation without additional government regulation, but it is not yet guaranteed that the standards bodies will coordinate. Coordination in industry standardization is the FCC's preference.

Demand for mobile data is expected to continue to rise exponentially as data intensive technologies such as virtual or augmented reality (e.g. Google Glass), home automation, and vehicular communications hit the market. By 2020, overall mobile data traffic is expected to increase by a factor of ten, demand in certain congested urban areas is expected to increase by a factor of 1000, and the number of connected mobile devices is expected to reach 50 billion. These trends will largely be driven by the Internet of Things[6] and Machine to Machine (M2M)[7]

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technologies [5]. This demand increase must be met with an equal industry and government response because existing networks are not capable of providing the requisite capacity.

Innovation and changes are not easy, however. Any issue concerning wireless spectrum is worth billions of dollars, with several competing stake holders. Cellular companies covet licensed spectrum because they have complete control over transmission in a geographic area, and so their investments are less dependent on the actions of others. In the recent AWS-3 spectrum auction, cellular companies spent $44.9 billion for licenses to 65 MHz of spectrum [7]. Though unlicensed spectrum is less valuable to cellular companies due to stricter transmission rules and the inability to limit other interferers, the potential to use such bands to augment capacity in certain areas is attractive because devices can use these bands at no cost. For example, in 2014, up to 46 percent of potential cellular data was offloaded to Wi-Fi by cellular companies[8] [1]. Similarly, public and personal Wi-Fi, along with other devices that operate on unlicensed bands, are a large part of the national information infrastructure, and manufacturers have billions of dollars in device sales that depend on the unlicensed bands. Any threat to the unlicensed spectrum on which such devices operate, and their place in it, is met with fierce resistance.

Against this backdrop, a new technological development promises to increase cellular data capacity by using unlicensed spectrum traditionally dominated by Wi-Fi[9]. Qualcomm and Ericsson, among other device makers, presented in December, 2013 a method to provide efficient data transmissions on the unlicensed bands, supported by control transmissions on licensed bands [8]. These technologies will enable cellular companies to utilize unlicensed bands seamlessly to augment their network capacity and improve service for their customers. Instead of relying on users to connect to Wi-Fi hotspots, companies could seamlessly send LTE signals to users through unlicensed bands. Wi-Fi companies and supporters are concerned that such additional use of the unlicensed bands will severely degrade Wi-Fi performance and that these

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new transmissions will not share the resource fairly with Wi-Fi due to several unique technical characteristics, which are discussed in Section 1.1. The two sides disagree on the facts of how much performance degradation LAA/LTE-U will cause to existing users of the band, as well as what coexistence mechanisms should be adopted to minimize the impacts. The FCC opened Public Docket No. 15-105 on LTE unlicensed technologies to help resolve the debate.

Any policy recommendations regarding LTE unlicensed must be made with an understanding of the technical issues, the current regulatory environment, and the stakeholders involved. Much of the debate, as carried out in the reply comments on the FCC Public Docket, concerns deeply technical characteristics of the upcoming standards. However, many of the details of the technical debate can be discussed in terms of their impacts of how various technologies use and share the unlicensed bands. Though the technical details are discussed in reference to the present debate, similar principles apply to other technologies and future innovations on the unlicensed band.

Wi-Fi stakeholders worry that existing FCC regulations are not enough to protect their use of the unlicensed bands, while the cellular proponents argue that their standards are enough to guarantee fair coexistence. With billions of dollars on the line in past investments and future profits, the various stakeholders have well defined and rigid positions. In this section, the stakeholders are listed and their chief arguments are summarized; next, the technological characteristics are first defined in enough detail to follow the debate; finally, the regulatory status quo is described.

1.1 STAKEHOLDERS

Along with the technical characteristics and the current regulatory regime, it is important to understand the positions and economic incentives of each side in the debate. In this subsection, the three main groups of entities – Wi-Fi proponents, cellular manufactures and LTE unlicensed chip manufacturers, and the regulatory regime – are discussed. Many of the positions described in the following sections are expressed in the comments and reply comments in the FCC public docket.

1.1.1 Cellular Interests

The chief motivation of the cellular companies is to use unlicensed spectrum to augment capacity in the most high-demand areas. Demand is not uniform in either geography or in time; in certain urban areas at the busiest parts of the day, networks may be overloaded. In other parts of the day, they may lie fallow. Using unlicensed spectrum as necessary thus may be a much more efficient solution than buying long-term spectrum licenses that extend throughout the country. These economic incentives are discussed in greater detail in Section 2.2.

Two main groups are in the process of developing LTE unlicensed – the LTE-U Forum, which is developing LTE-U, and 3GPP, which is standardizing LAA[10]. The former is composed of purely cellular companies and chipmakers: "the LTE-U Forum was formed in 2014 by Verizon in cooperation with Alcatel-Lucent, Ericsson, Qualcomm Technologies, Inc., a subsidiary of Qualcomm Incorporated, and Samsung" [11]. These companies, as mobile and cellular providers and chip makers (though many produce Wi-Fi chips as well), are purely pro LTE unlicensed, and the IEEE LAN-MAN Standards Committee states that "there has been no coordination between IEEE 802 and any standards body associated with LTE-U, because LTE-U was not developed by a standards body. It is the understanding of IEEE 802 that LTE-U is a proprietary solution" [12]. On the other hand, 3GPP is a true standards body with many governmental and industry partners. 3GPP is responsible for developing and maintaining LTE and 4G standards, for example, and there has been much discussion between 3GPP and Wi-Fi proponents [12].

The cellular companies and device makers, as illustrated in the Public Docket, want the FCC to maintain its technology neutral stance and to not intervene in the current debate. They maintain that coordination at the industry and standards body level is enough to resolve any technological disagreements.

1.1.2 Wi-Fi Interests

Many different companies (e.g., Cisco, Aruba Networks, Google), and the main Wi-Fi/WLAN standards and certification bodies (the IEEE 802 LAN-MAN Standards Committee, and the Wi-

[10] In this report, "LTE unlicensed" refers to both LTE-U and LAA. When these standards must be differentiated, they are identified by name.

Fi Alliance), make the pro 'Wi-Fi[11]' arguments in the Public Docket. They emphasize the importance of Wi-Fi to our national infrastructure and argue that it should be protected. For example, Cisco argues that "because Wi-Fi is such a critical ingredient in broadband delivery in so many diverse ways, it is important to carefully think through how a new unlicensed small cell technology might impact the success of a nearby Wi-Fi transmission" [12].

Wi-Fi and cellular stakeholders differ significantly on whether LTE unlicensed will degrade Wi-Fi performance. However, it may seem at first glance that, in terms of policy recommendations, the stakeholders do not disagree much on policy. Most stakeholders do not want the FCC to enact new regulations because of the potential of hindering future innovation. For example, Cisco, the world's largest provider of Wi-Fi hardware, emphasizes its support for technology neutral regulations, even as it touts the economic benefits of Wi-Fi. Cisco "supports technology neutral" because of "the company's deeply held view that vendor adherence to a particular technology can be foolhardy. Technologies evolve and new ones are introduced" [13]. Cisco's belief is so strong in the long-term benefits of technology neutral rules that the company "support[s] the Commission's view that limiting regulatory constraints on wireless technology to key radio emissions parameters, and stopping short of calling out a technology, is the best policy for innovation" [13].

However, behind the agreement on whether the FCC should enact technology specific rules, there lies serious concern about LTE unlicensed and its implications for the long term competitiveness of Wi-Fi. Stakeholders especially worry about the coexistence protocols used and are calling for coordination between the standards bodies to handle any concerns. This issue is discussed in more detail in Section 1.2.1. Though LTE unlicensed proponents praise the numerous messages exchanged between the standards bodies, Wi-Fi proponents claim that current coordination is not sufficient. For example, in its FCC filing, the IEEE LAN-MAN Standards Committee states that it "believes that 3GPP should engage with the relevant stakeholders, such as IEEE 802, in a joint forum such as a workshop, or series of workshops, to facilitate understanding of the potential spectrum sharing issues for the IEEE 802.11 family of standards and LAA, and come to agreement on appropriate sharing characteristics to ensure fair coexistence" [12]. This issue is discussed in more detail in Section 3.1. These recommendations

[11] As discussed above, 'Wi-Fi' is used as an equivalent term for any IEEE 802.11 WLAN, though the terms are distinct.

for increased collaborations suggest that the Wi-Fi stakeholders would call for FCC action if the collaboration between standards bodies does not materialize.

1.1.3 Federal Communications Commission

Though opening a docket may suggest otherwise, the FCC has indicated that it is hesitant to interfere in the issue, rather hoping that the standards bodies deal with the issue among themselves. The docket reminds filers that the "Commission has historically adopted rules that are technologically neutral and remains committed to this policy" [10]. At least one Commissioner, Commissioner O'Reilly, has indicated that he "will be vigilant in ensuring that the Commission's involvement does not result in taking sides with various stakeholders, hindering technological innovation, or having any say about what technologies should or should not be deployed" [14]. This hesitation is due to several reasons: first, the FCC has a history of acting in a "technology neutral way," as stated in the docket itself; second, it does not want to accidentally regulate away potential innovations and destroy what has historically made the unlicensed bands so successful; third, it feels that the technical detail regarding coexistence protocols and other aspects are much better left to standards bodies who may be able to move quicker as new technologies develop. These hesitations are not hypothetical: when the current rules were formulated, Wi-Fi as a technology did not exist, and over-regulation may have prevented its development and eventual dominance on the band. Several of the docket's questions also hint at the desire that the standards bodies solve the issue, e.g. "What is the status of coordination between 3GPP and the IEEE 802.11 on LTE-U and LAA" [10].

1.2 LTE Unlicensed Technical Characteristics

LTE unlicensed uncovers several characteristics that can lead to one technology pushing others out of the unlicensed bands, though it is unclear whether they will do so in this case. The current debate is largely centered on two technical issues: the coexistence protocol used by the new technologies, and the reliance on licensed spectrum to transmit overhead instructions. In addition, there are two technical characteristics have been so far under-discussed in the current debate: antenna height, and the issue of installation scale. These technical characteristics have the potential to enable one technology or device to use the bandwidth much more often and with greater efficiency at the expense of other devices trying to use the bandwidth. Thus, they make

Sidebar 2.1: Coexistence

One of the most important aspects of technologies using the unlicensed band is its coexistence mechanism – how a technology shares the spectrum in a given time and location with other technologies. If two devices transmit are sent at the same time and frequency, a receiver will not be able to understand either message. Thus, technologies that want to share the medium must either use different frequencies or send transmissions at different times.

Devices in the unlicensed bands often must take turns. Just as drivers at a stop sign take turns to cross the intersection, devices detect other users of the channel and then back off if others are using the channel. When one device has finished its current transmission, another device can begin transmitting.

Some unlicensed technologies use Dynamic Frequency Selection (DFS), in which a device decides which channel to transmit over (within a band) depending on interference. Wi-Fi uses Carrier Sense Multiple Access (CSMA) and Clear Channel Assessment – Energy Detection (CCA-ED) to coexist with other Wi-Fi and other devices, respectively.

The United States does not mandate any coexistence mechanism on the unlicensed bands, but many other countries do.

LTE unlicensed more attractive for cellular stakeholders while simultaneously worrying Wi-Fi stakeholders. Because the standardization process is not yet complete, it is unclear whether these concerns will apply to the present debate. However, these same characteristics can apply in future debates and already play out with some devices on the unlicensed bands typically used by Wi-Fi.

It is important to note in this discussion that there are three versions of the technology, in development by different bodies: LTE-Unlicensed by the LTE-U Forum, Licensed Assisted Access by 3GPP, and MuLTEfire by Qualcomm. Each of these versions has different characteristics that may strongly impact how much Wi-Fi is degraded in its presence. In this subsection, the four technical characteristics most important to this debate is discussed.

1.2.1 Coexistence Protocol

The most contentious part of the current LTE unlicensed debate is the coexistence protocols that will be used by the technologies in question. Coexistence protocols determine how a device

shares the spectrum with other devices – whether it waits for other devices to finish transmitting before it starts, how long it transmits at once, and how it decides to take turns with other devices. The Wi-Fi coexistence protocol is designed to be extremely friendly to other Wi-Fi devices, and Wi-Fi proponents worry that the LTE unlicensed coexistence protocols will significantly degrade Wi-Fi performance. Wi-Fi device vendor Aruba Networks, in its filing, articulates the main concern regarding coexistence protocols: "under the present FCC Part 15 rules, a single device in the unlicensed band can actually occupy 100 percent of the available airtime, to the practical exclusion of all other devices within radio range" [15].

The technical details are not discussed in this report; however, it is important to note that Wi-Fi proponents are worried about several aspects of the proposed coexistence protocols: the duty cycle, length of transmission, backoff mechanism, and the detection energy threshold. Sidebar 2.1 explains the purpose and basics of coexistence protocols further.

The central debate is whether LTE unlicensed will degrade Wi-Fi performance by not implementing 'Listen before Talk,' (LBT) in which a device listens on the bandwidth and refrains from communicating if it detects another ongoing transmission, and by not waiting enough time between transmissions to allow other devices to transmit[12]. LBT also distinguishes the two technologies discussed so far, LTE-U and LAA. In Europe and many countries, LBT is mandated, and LAA will implement it so it can be a global solution [16], [17]. On the other hand, LTE-U will not implement it and may only be used in the United States and other countries that do not require LBT.

Cellular proponents argue that other components of its coexistence protocol ensure that a LTE unlicensed Access Point[13] (AP) will equally split the time resources with a Wi-Fi AP, while Wi-Fi proponents argue that that the sharing will not be fair unless some form of Listen before Talk is implemented. They also argue that, without LBT, many transmissions will be interrupted and thus both quality and throughput will decrease.

The comments in the Public Docket indicate that the parties disagree about whether LTE unlicensed coexistence protocols are sufficient, and it is unlikely that this issue will be resolved

[12] This mechanism can be partially understood by an analogy to a conversation among a group of people. If someone keeps interrupting others, or instantly starts talking anytime others are silent (without waiting for others to speak), they would dominate the conversation.

[13] An Access Point is a device that allows a user device to connect to other devices or the Internet

through simulations, analysis, or small prototypical systems. Dr. Leigh Chinitz summarizes these disagreements in his reply comments, concluding that "this is an intractable problem on which proponents and opponents will never agree, and simulation conditions and parameters can be discussed forever" [18]. The political nature of the debate means that neither side will cease arguing for its positions, unless and until a large scale installation proves one side correct. This disagreement benefits the regulation status quo, as the FCC would be unwilling to act without more certainty.

It is the position of this paper that the notion of 'fair' is ill-defined, and so much of the debate about whether various coexistence protocols are 'fair' cannot be answered until 'fair' becomes well-defined. The issue is discussed in detail in Section 4.

1.2.2 License Anchoring

Another factor differentiating LTE-U and LAA from existing technologies that use the unlicensed bands is the use of licensed spectrum. This aspect is unique to LTE unlicensed and is what differentiates it from many other technologies on the band. It allows carriers to use the unlicensed bands just as they would licensed bands, and a given user can seamlessly switch between sending data on licensed and sending it on unlicensed bands.

With license anchoring, the control channel – which sets up the connection, determines user association, and manages a moving user – is on licensed spectrum owned by a carrier, while the unlicensed spectrum is used solely to augment data capacity. By sending control signals on licensed bands in which the carrier can completely manage interference, LTE-U or LAA can be much more reliable than Wi-Fi and unlicensed-only technologies as there will be fewer unanticipated interferers. The licensed bands also have lower carrier frequencies than the 5 GHz unlicensed band, and so the signals propagate further, enabling the "system to take in more mobile users and ach[ieve] greater offloading of traffic" [9]. However, anchoring to licensed spectrum does not inherently increase interference or degrade Wi-Fi performance. Rather, one could argue that it decreases interference on the unlicensed bands by increasing efficiency and by guaranteeing that cellular companies only use unlicensed spectrum when its licensed spectrum is at capacity.

On the other hand, these benefits are a direct result of cellular companies having access to licensed spectrum; they are not available to those without access to licensed spectrum, regardless

of how efficient a technology's protocols are, leading to some potentially problematic characteristics that could influence other parts of the debate.

First, the licensed anchoring creates an asymmetric effect of interference and congestion on the band. LTE unlicensed are more immune to congestion and rampant interference on unlicensed bands, as it can always retreat to the licensed bands. In the language of the Tragedy of the Commons, LTE unlicensed is much less affected if the commons is temporarily degraded, and so license anchoring may decrease the motivations of cellular companies to take care of the commons. As discussed in Section 3.1.2, FCC inaction only works if the standards bodies are incentivized to come to an agreement. Second, license anchoring allows seamless integration with a carrier's existing operations[14]. Once devices supporting LTE unlicensed are manufactured, they will be able to easily automatically switch between using licensed and unlicensed bands, without any user intervention. This capability allows cellular companies to, if they desire, install many LTE unlicensed APs alongside their existing network deployments. The issue of installation scale, discussed in Section 2.1.4 below, becomes much more apparent with such seamless installation and integration.

The question of whether to allow licensed spectrum to aid unlicensed communication, even if it does not inherently increase degradation of or interference to other receivers, is a question that will affect future development on the unlicensed bands. License assistance seems to increase unlicensed capacity and efficiency without inherent additional harm to other unlicensed users. However, the question remains whether it is desirable to establish a market structure in which the most efficient way to use unlicensed spectrum is only available to those who have the billions to spend on licensed spectrum.

It is important to note, however, that a version of LTE unlicensed that is not license assisted is in development. Alongside its initial public docket response, Qualcomm publicly announced MuLTEfire [19], which does not use the licensed band. This version could be used by anyone on the unlicensed bands, not just cellular companies with access to spectrum. If shown to be more efficient than the latest IEEE 802.11 standards, many of its featured could be integrated in the latest standardization process, or it could completely replace Wi-Fi as the network of choice for non-cellular devices. However, the two main LTE unlicensed standards bodies, the LTE-U

[14] Note that existing devices will not be able to support LTE unlicensed with just software upgrades; rather, a new generation of devices is necessary [9].

Forum and 3GPP, do not currently plan to standardize standalone LTE unlicensed technologies [17].

1.2.3 Antenna Height

One issue that has yet gone unexplored in the present debate is whether cellular companies' access to small cell towers from which to transmit LTE unlicensed will cause extra interference to neighboring devices. Unlike the coexistence protocol question, in which both sides disagree on the facts, it is a settled question that antenna height matters both for short-link and large-link signal propagation. A doubling of the transmit antenna height is equivalent to somewhere between a two to four times gain in transmit power in most signal propagation models under most standard conditions [20]. Thus, if one entity is structurally advantaged with access to higher antenna heights, its devices will cause far greater interference and will travel much farther than will devices located at lower heights.

This propagation characteristic favors the cellular companies and, by extension, LTE-U and LAA in this debate. The marginal cost to add an antenna is drastically lower for existing tower owners and leasers. Verizon has indicated that it will install LTE-U on next generation dense cellular towers, and other cellular companies are sure to follow suit [21]. Thus, under existing rules, the unlicensed bands could evolve into a two-tiered network where the distinguishing factor between technologies is their antenna height, as installations on small cell towers could over-power Wi-Fi transmitters nearer to street level[15]. Devices at higher antenna heights would be able to serve far more users than other devices and would cause much more interference than they receive from neighboring devices.

On the other hand, it is important to note that this concern is not LTE unlicensed specific. It applies to any case where one provider disproportionately has access to towers and thus higher antenna heights, even if the provider is using the same technologies as others. If a cellular

[15] It may be possible to extend some of the analysis from multi-tiered networks in which different base-stations have varying power. For example: "if offloaded users can also be served in 'normal' slots when the macros are on, then the optimal amount of blanking grows in proportion to the small cell density … for plausible small cell deployments, the optimal amount of blanking is approximately one half. This strikes many as counter-intuitive but it is true: the macrocells (the apparent network bottleneck) should be shut off about half the time, because they are also the biggest interferers" [18]. A coexistence protocol should not treat the macrocell as just another interferer vying for time blocks. Its special status as an asymmetric interferer requires a more careful protocol. The discussion gets even more complicated when users cannot switch from one tier to the other, such as when one provider operates the macro cells and others operate the small cells, as fairness issues are involved.

company wants to dominate the unlicensed band, as many opponents claim in their filings, it may be able to do so with Wi-Fi itself. All it has to do is install antennas on many of its existing towers, without the additional capacity-increasing techniques it would otherwise implement to support heterogeneous networks on its licensed bands. This concern is not new either. Comcast and other cable companies routinely hang Wi-Fi APs from their existing cable infrastructure [22]. Furthermore, the antenna height issue may not be as critical because traditional cell towers are too tall to install low power LTE unlicensed effectively, and new small cell towers are not at a much different height than Wi-Fi routers installed inside buildings. For these reasons, it is not yet apparent that cellular companies would significantly benefit from their structural advantage.

A more careful network analysis must be done on this issue to fully understand how advantageous it is to have access to small cell towers and higher antennas. How much signals from tower-mounted antennas penetrate indoors will play a large role. It remains an open question whether the FCC should regulate such advantages, but interest by cellular companies increases the urgency.

1.2.4 Installation Scale

None of the technical differences discussed above would be significant if only a few LTE-U or LAA devices ever make it to market. There are devices on the market today with unfriendly coexistence protocols; the long term advantages of license anchoring only matter if there are enough capacity to support users; and some Wi-Fi operators already own an antenna height advantage as discussed above. Though an undiscussed issue, Wi-Fi proponents are worried about LTE unlicensed because cellular companies have the resources to install a large number of access points in the most high-demand areas. The more LTE unlicensed access points there are in an area, the less time that is available to Wi-Fi routers, and so the more ‘unfriendly’ devices that there are, the more degradation observed by Wi-Fi devices. Addressing installation scale is thus one of the most important, though also the most tricky, aspect of the debate.

Furthermore, existing experiments are also inadequate in predicting how large scale installations of LTE-U will affect Wi-Fi, or how LTE-U will affect large enterprise level installations of Wi-Fi. Cisco identifies the danger in extrapolating from small experiments, asking “the simulations demonstrating fair access to spectrum in the presence of LTE-U and Wi-Fi have focused on simpler and less dynamic use cases. Do the algorithms used to derive the

sharing simulations take into account the diversity of WiFi deployment scenarios?" [13]. These questions raise the concern that the impact of LTE unlicensed on existing Wi-Fi deployments will be far greater than those predicted by experiments because the lab scale deployments do not match real life conditions.

Similar to the technical characteristics discussed above, no framework exists to limit the scale of installations by any particular entity, and this debate portends larger discussions about the use of the unlicensed spectrum: how much of an open public resource should any given entity be allowed to use? This discussion is continued in detail in Section 4, which argues for an explicit architecture for fair use on the unlicensed bands.

1.3 Regulatory Status Quo

The 5 GHz unlicensed bands are governed by rules in Part 15 of Title 47 of the Code of Federal Regulations, commonly referred to as the 'Part 15 rules.' These regulations are meant to govern low power, unlicensed devices throughout the spectrum. In general, most of the unlicensed bands

Sidebar 1.2: A closer look into 5 GHz band regulations

The 5 GHz unlicensed band is split into three sections, each with historically different rules governing devices. Figure 1 shows these different rules. Note that for the bands used by Wi-Fi (U-NII-3 and, now after a rule change, U-NII-1) only transmit power is restricted.

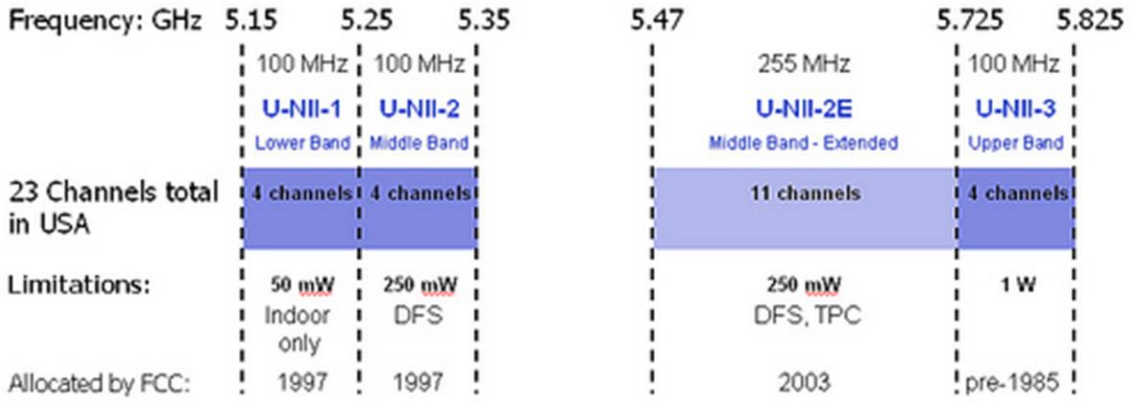

Figure 1 Different sections of the 5 GHz unlicensed band. The FCC in 2014 modified the U-NII-1 rules to allow outdoor transmission at 1 W. Image from [21].

have only power restrictions[16]. None of the technical characteristics discussed in Section 1.2 are covered by existing regulations. Potential regulations that would cover some of these characteristics are discussed in Section 3; however, it is recommended in Section 5 that the FCC not enact more regulations but instead pressure the standards bodies to act.

[16] Usually stated as either antenna output power restrictions, as electric field strength restrictions as measured at a reference distance, or as power spectral density restrictions.

2 ECONOMICS

	Section 2 Key Findings
Finding 2.1	Congestion on the 2.4 GHz unlicensed band makes it a poor choice for future Wi-Fi growth.
Finding 2.2	Wi-Fi cannot yet be considered the incumbent on the 5 GHz band. However, it is well poised to utilize the band in the coming years to ease congestion in 2.4 GHz, and the continued growth of Wi-Fi is tied to the 5 GHz band.
Finding 2.3	The 2.4 GHz and 5 GHz unlicensed bands are home to countless other devices besides Wi-Fi. These other unlicensed devices, often forgotten in the LTE unlicensed debate, must be taken into account when any new regulations are discussed. Few technology neutral mechanisms available would protect Wi-Fi from LTE unlicensed without causing collateral harm to these devices.
Finding 2.4	The current LTE unlicensed debate is part of a larger context: the trend to utilize otherwise unused parts of the spectrum to augment cellular capacity is a good one, and any regulation must not inadvertently harm such efforts. Using small cells and unlicensed spectrum in the busiest areas during peak demand is an efficient alternative to buying long-term, expensive, wide area licenses. It has helped cellular companies meet demand, easing concerns about the 'spectrum crunch.' However, this trend does not negate real concerns about whether the 5 GHz band is truly underutilized or whether LTE unlicensed is fair to other stakeholders.
Finding 2.5	The emergence of the Internet of Things (IoT) and Machine to Machine (M2M) devices threaten the status quo due to the exponentially larger amount of different technologies and devices that must coexist on the unlicensed bands. These devices increase the likelihood that some devices will act in an unfriendly manner.

In addition to the potential technological characteristics of unfair users of unlicensed bands, several economic factors related to the current debate are relevant to the policy discussion. In this question, these economic factors and future outlook for communications technologies are

discussed. The driving questions discussed in this section include: How dependent are current Wi-Fi devices on the 5 GHz band, and can they be considered the incumbent? How dependent are cellular companies on unlicensed technologies to augment network capacity? and How will the continued evolution of communications technologies affect the debate on fair use of unlicensed technologies? These questions are relevant both for the present debate and discussion about future unlicensed bands.

2.1 Wi-Fi's Present and Future

The large economic value of Wi-Fi and other unlicensed devices is well understood by a society that uses such devices every day. Every year, consumers spend $62 billion on new devices that use the unlicensed bands, and the economic value of the bands is far greater when the impact of increased internet access and wireless communications is taken into account [23]. Wi-Fi today operates largely on 2 unlicensed bands: 2.4 GHz and 5 GHz. However, the different unlicensed bands are not used equally or are as well situated for future expansion. In this subsection, the congestion on the 2.4 GHz and the relative emptiness of 5 GHz is discussed in terms of Wi-Fi usage, along with other devices that utilize the band. The main conclusion of this subsection is that 5 GHz represents the future but not the present of Wi-Fi, and other devices that operate on these unlicensed bands must also be taken into account in future regulations.

2.1.1 2.4 GHz Congestion

Most Wi-Fi devices used by consumers today use the 2.4 GHz unlicensed band, which also supports technologies such as Bluetooth. However, the 2.4 GHz Wi-Fi band is known to be congested, especially in areas such as college campuses where a large centralized network supports most users, but numerous personal networks have also been set up. Congestion of devices on the band occurs when too many devices try to use the bandwidth at once in a given location, and so each individual device gets to transmit for less time and thus must reduce its rate. Some academics argue that Wi-Fi congestion is poorly defined, and the band may not actually be congested [24]. On the other hand, most network managers observe some congestion, and many academics have sought to solve the problem. For example, according to the "assistant director of network services at Carnegie Mellon University in Pittsburgh, 'The general perception in IT, and it matches our experience, is that 2.4GHz has become somewhat of a junk

band, with all the consumer Wi-Fi routers and hotspot devices that prefer it.'" [25]. In this band, Wi-Fi is often hurt by its own success – too many routers in a location combined with the conservative protocol leads to performance degradation for all users. These congestion issues, alongside large amounts of interference by other devices on the band, have led to a shift away from the 2.4 GHz unlicensed band, and future Wi-Fi growth will largely occur outside 2.4 GHz.

2.1.2 Current 5 GHz Usage

Current plans call for LTE unlicensed to first be deployed on the 5 GHz unlicensed band, and then potentially other bands such as 3.5 GHz [9]. To fully understand the potential economic impact of Wi-Fi degradation caused by LTE unlicensed, one must first understand what technologies currently use the band and how ubiquitous they are. It is commonly stated in the industry that most Wi-Fi devices historically have operated on the 2.4 GHz unlicensed band and that 5 GHz is mostly unused. Targeted studies in the past have confirmed this assumption. In 2011, two universities reported that well more than half of their users used Wi-Fi on 2.4 GHz in spite of university investment to develop its 5 GHz capabilities [25]. In 2014, a study on airport Wi-Fi usage found that 5 GHz bands are underutilized because most devices are not capable of 5 GHz operation [26]. 5 GHz usage is also expected to increase slowly because of the large cost of additional installation where 2.4 GHz service already exist – companies first care about coverage (which the 2.4 GHz service already provides) and then about additional capacity, which the 5 GHz service would provide [27].

However, recent reports indicate that this trend is changing, partially motivated by the congestion discussed in Section 2.1.1. In 2014, over half of both new Wi-Fi device certifications and consumer shipments supported both 2.4 GHz and 5 GHz transmission as opposed to just 2.4 GHz transmission, one report indicates that the "5 GHz band no longer plays a minor role in the Wi-Fi ecosystem; it is now mainstream" [28]. By the end of 2015, 68 percent of devices are expected to use 5 GHz, and this number is expected to rise to over 90 percent by the end of 2017 [28]. At the Mobile World Congress in February 2014[17], more than half of the Wi-Fi usage was through 5 GHz [29]. Furthermore, recent developments indicate that the shift of Wi-Fi to 5 GHz will only accelerate. 802.11ac, the newest Wireless Local Area Network (WLAN) standard and

[17] An admittedly skewed sample. However, it portends the immediate future of mobile devices used by the general public.

much more advanced than previous iterations, is only compatible with 5 GHz [30]. The FCC has also recognized the increasing importance of the 5 GHz band to Wi-Fi: the 2014 rule change regarding the 5 GHz U-NII-1 sub-band was in no small part motivated by the need "to provide more flexibility for Wi-Fi and to take greater advantage of the latest Wi-Fi standard known as 802.11ac to move more data at faster speeds and support deployment of outdoor Wi-Fi hot-spots" [10]. This rule change increases the motivation for Wi-Fi devices to start using the 5 GHz bands.

From these numbers, it is clear that Wi-Fi cannot be considered the incumbent on the 5 GHz band. However, it is well poised to utilize the band in the coming years to ease congestion in 2.4 GHz, and the continued growth of Wi-Fi is tied to the 5 GHz band.

2.1.3 Other unlicensed devices

It is important to note in any discussion of potential regulations that Wi-Fi is not the only – or in some cases, even the most dominant – incumbent on the 2.4 GHz and 5 GHz unlicensed spectrum. Any regulation that aims to protect Wi-Fi from LTE unlicensed may unnecessarily hinder other devices that use the band and cause real harm to the unlicensed bands' status as the 'Innovation Bands.'

Poor performance on the 2.4 GHz band is not only due to Wi-Fi congestion; other devices often provide too much interference. One report found that Wi-Fi devices experiencing poor performance on the 2.4 GHz band "are almost certainly seeing interference from non-Wi-Fi devices such as microwave ovens, Audio Video (AV) senders, security cameras or baby monitors" [31]. These other devices often have the exact characteristics that Wi-Fi proponents dislike about LTE-U, such as unfriendly coexistence and back off mechanisms. Similarly, Bluetooth is a major player on the 2.4 GHz band, though standards have evolved to ensure an acceptable amount of coexistence for both technologies. The proliferation of these other devices on the 2.4 GHz band lead some cellular proponents to maintain that even on the 2.4 GHz band, where Wi-Fi has the strongest claim, it cannot claim to be the incumbent.

The 5 GHz band, though less congested, also is on the verge of hosting many types of devices – precisely because of the same reason that Wi-Fi is abandoning the 2.4 GHz band. One report claims that "it is generally true that fewer devices currently operating at 5 GHz are causing interference as compared to 2.4-GHz devices. But this will change over time. Just as everyone

moved from 900 MHz to 2.4 GHz to avoid interference, the 'band jumping' effect will catch up with 5 GHz. Some devices that already exist at 5 GHz include cordless phones, radar, perimeter sensors, and digital satellite" [32]. These devices also include consumer products such as baby monitors, which can already transmit on 5 GHz [33]. These devices, like those on 2.4 GHz, are often unfriendly to Wi-Fi, but they have largely coexisted with Wi-Fi because there are too few of such devices in any given area to cause significant interference.

These other unlicensed devices, often forgotten in the LTE unlicensed debate, must be taken into account when any new regulations are discussed. Few technology neutral mechanisms available would protect Wi-Fi from LTE unlicensed without causing collateral harm to these devices. These discussions are discussed in more detail in Section 3.1.1.

2.2 CELLULAR SPECTRUM CRUNCH

The issue of congestion is not limited to unlicensed bands. The "Spectrum Crunch" and how to avoid it has driven wireless policy for the last several years, with predictions that wireless demand would overrun capacity, driving up prices and stymieing the national mobile infrastructure [34]. These scares were driven in no small part by the major wireless carriers, who claimed that there simply was not enough spectrum to meet wireless needs [35].

The federal government responded to these concerns. The National Broadband Plan in 2010 called for 500 MHz of spectrum to be made "suitable for both mobile and fixed wireless broadband use" by 2020, and this priority has been reiterated by the Obama Administration several times since then [36],[37],[38]. As part of this priority, the FCC conducted the AWS-3 auction in late 2014 and early 2015, auctioning licenses for 65 MHz of spectrum to wireless carriers for a total of $44.9 billion [7]. FCC commissioner Michael O'Rielly noted that the "auction clearly demonstrates there is still a critical need for licensed spectrum in our overall spectrum framework. Although some argue that the future lies only with unlicensed or shared spectrum, this view ignores the fact that our nation's commercial wireless carriers still seek exclusive spectrum in order to be able to maintain quality of service and network control" [39].

Sidebar 2.1: Network Densification

Critics of the 'spectrum crunch', as Commissioner O'Reilly alludes to, argue that additional licensed spectrum is not the answer. Rather, they claim that additional capacity will largely be served by offloading data to Wi-Fi and by adding more, smaller cell towers closer together in high-demand areas. Though spectrum policy has been emphasized and will continue to be, additional spectrum has not been the primary driver of capacity gains; while spectrum has increased capacity 25 times since 1955, increasing density has increased communications capacity by a factor of 1600 [41].

Increasing densification and the use of multiple technologies in a network networks – such as the rise of Wi-Fi in parallel to cellular capacity – has counteracted some of the rise in mobile demand, defying expectations. In 2014, 46 percent of mobile data traffic was offloaded to WiFi or cellular small cells [1]. The FCC had predicted that this number would be consistent around 15 percent, but it has been over 40 percent since 2012 [42]. Critics point to this misprediction as evidence that the FCC has overemphasized additional exclusive spectrum licenses to cellular companies over alternative solutions, and that current policy is misguided.

However, Qualcomm notes that unlicensed will increasingly play a major role as well, stating that "For operators solving the 1000x challenge, licensed spectrum is the foundation. At the same time, unlicensed spectrum in the 5 GHz band can be used to effectively augment the capacity" [40].

Unlicensed spectrum to augment capacity is promising because mobile data demand and available infrastructure available not uniform. The busiest intersections of a large metropolitan area have far different usage characteristics than do rural areas. For example, during the London Olympics, "the situation for telecoms became so dire that in 2012, London faced the very real threat that its wireless communications network would fail under heavy load. During the 2012 Olympic Games, British communications regulator Ofcom had to borrow part of the military spectrum to ensure the audio, visual and sensor feeds didn't grind to a halt as the athletes were

sprinting across the finish line" [9], Opening up new licensed spectrum channels nationally just for a few intersections may not be a scalable solution – existing stakeholders would be moved, spectrum auctions arranged, and channel-capable devices built just for those few busy intersections.

In such an environment, with highly non-uniform usage, there are opportunities to find unused spectrum and open them up to sharing with other technologies, such as cellular. Some experts even argue that "'we don't have a spectrum crunch so much as we have a spectrum policy crunch,' says David Tennenhouse, Microsoft's vice president of technology policy and a former MIT professor and Intel executive. 'The so-called spectrum crunch really reflects artificial spectrum scarcity… The challenge now is to extend those proven successes to enable wider-area broadband access using other underutilized portions of the spectrum'" [41].

Spectrum sharing with unlicensed bands or other unused bands would scale in such an environment. Devices such as Wi-Fi and Bluetooth could use the unlicensed bands nationally. In high-demand areas, cellular traffic and unlicensed devices could share the bandwidth, provided that they learn to do so fairly. However, how such technologies share the bandwidth is the politically charged issue discussed in this paper.

This discussion places the current LTE unlicensed debate in a larger context: the trend to utilize otherwise unused parts of the spectrum to augment cellular capacity is a promising one, and any regulation must not inadvertently harm such efforts. However, this trend does not negate real concerns about whether the 5 GHz band is truly underutilized or whether LTE unlicensed is fair to other stakeholders.

2.3 THE COMING FLOOD OF IOT AND M2M DEVICES

Cellular and Wi-Fi technologies may be the dominant communication platforms today, along with Bluetooth and a host of other technologies on the unlicensed bands, but they will not remain so for long. The Internet of Things (IoT) will bring "sensors and actuators blend[ing] seamlessly with the environment around us, [with] the information shared across platforms in order to develop a common operating picture" [42]. And there will be up to 50 billion of these devices added to the network by 2020 [5]. All of these devices must connect to each other and, in many cases, to the internet. Composed of largely consumer devices, the IoT will make heavy use of unlicensed spectrum. Some of these devices may adopt various IEEE 802 standards, and so

would intrinsically coexist with other devices in a friendly manner. However, some devices or technologies may develop their own protocols. As the number of these devices increases and the unlicensed spectrum becomes more congested, there will be a greater incentive to adopt protocols that do not coexist in a friendly manner, as doing so would just decrease the given device's rate. The wireless commons has not degraded yet both because currently available unlicensed spectrum has largely provided the necessary capacity and because the majority of the transmissions – Wi-Fi in particular – follow a standard designed to coexist with itself and with other devices. That trend may not hold as the commons becomes more congested and it becomes advantageous to not coexist.

3 POTENTIAL FCC ACTIONS

	Section 3 Key Findings
Finding 3.1	The FCC cannot resolve the LTE unlicensed debate with device-level regulations without causing significant collateral damage to non-Wi-Fi devices that already operate on the unlicensed bands.
Finding 3.2	The approach to rely on standards bodies to ensure fair coexistence is flawed because of a lack of incentives to cooperate and an inability to include smaller parties in the discussions. However, it is the best path forward due to the potential for harm from FCC regulations and the difficulty of designing long-lasting regulations without loopholes.
Finding 3.3	Though a resolution at the standards body level might work in this case, but there is no guarantee of cooperation. The FCC may need to pressure the standards bodies to collaborate. Furthermore, for future debates, the standards bodies approach may not work at all, and the FCC should consider acting pre-emptively in future unlicensed bands.
Finding 3.4	New Listen before Talk regulations would be both difficult to design without loopholes and would significantly affect other existing unlicensed devices.
Finding 3.5	Though no framework currently exists to measure and limit the scale of installations, the discussion of sum interference in the 3.5 GHz shared spectrum band can be used to inform a system of privilege on future unlicensed bands.

Given the potential of various technologies, within and beyond the current debate, to affect ability of other devices to use the band, the FCC may need to consider actions to counter unfair use on the unlicensed bands. Section 1.1 discusses some of the technical characteristics of LTE unlicensed that may lead to unfair access to the unlicensed bands: the time-sharing or coexistence protocol, antenna height and other equivalents to signal power, and the issue of installation scale. The ill-defined notion of "fair" is discussed in Section 4, but regulations limiting those advantages can be discussed even with an abstract notion of the word. In this section, several potential FCC options are analyzed with respect to both the current LTE

unlicensed debate and what such decisions would mean for other devices on the band and the future of the unlicensed bands.

3.1 INACTION

The first strategy that can be pursued by the FCC is to simply do nothing, preserving the regulations that have proved wildly successful in the past and hoping that the standards bodies come to an agreement among themselves on a coexistence protocol and other areas of contention. Inaction would prevent the harms outlined in Section 3.1.1 below. The following subsections discuss this alternative to FCC action and its limits. One overall framing of the discussion is that, in many respects, use of the unlicensed commons is a repeated game: each device, technology, and company wants to maximize its instantaneous throughput, but it is also aware of how its actions affects the future actions of its competitors. Therefore, a balance between cooperation and greedy behavior must be found.

3.1.1 Constraints on New Regulation of Existing Bands

As discussed in Section 1.1.3 above, inaction seems to be the favored and most likely approach by the FCC due to its desire to maintain technological neutrality, its worry that it would accidentally regulate away potential innovations, and the recognition that the technology is too fast-moving and facts too murky to craft effective, long-lasting regulations.

Furthermore, though the wireless spectrum itself is an instantaneously renewable resource, there is a delay in the design and manufacture of new devices, and an even larger delay in the time it takes for devices built under old specifications to become antiquated and no longer used. As discussed in Section 2, there are many types of devices and applications that already make use of the 5 GHz unlicensed bands; some of these devices have the same ‘unfriendly’ characteristics that LTE unlicensed may have. Any new regulation that the FCC crafts for the 5 GHz unlicensed band would risk retroactively banning devices that have already received certification, causing real economic harm to businesses. Any new regulations must thus default to being backwards compatible, supporting legacy systems. It may be possible to grandfather in existing devices under any new rule, but such an action must take into account technology development cycles and could encourage a rush of devices designed to exploit the current rules. A new regulation may also allow a grace period in which existing devices could be upgraded or

replaced to match new regulations, but such a system would still threaten systems that cannot be replaced in time.

These restrictions make it difficult for the FCC to enact new regulations on the 5 GHz unlicensed bands in response to the potential threat of LTE unlicensed. Nevertheless, in the following sections, potential FCC responses and their specific implications are discussed.

3.1.2 The Standards Body Approach

In lieu of FCC action, the relevant standards bodies – 3GPP, the LTE-U Forum, and the IEEE 802 LAN/MAN Standards Committee – would ideally work together to create a standard suitable to all parties. Comment after comment by cellular proponents in the FCC Public Docket urges the FCC to stay out of the debate, pointing to numerous correspondences between the standards bodies as evidence of cooperation [9], [43], [17].

In addition to evidence of cooperation, there is a good argument in this debate that cellular companies, and especially chip-maker Qualcomm, care about the future of Wi-Fi as well. The companies point to the large percentage of cellular data that is offloaded to Wi-Fi, as well as their recognition that, as a public commons, all companies would be harmed if the unlicensed bands degenerated due to a lack of cooperation. For example, T-Mobile states in its response that "T-Mobile has a particularly strong incentive – because of its leadership in integrating WiFi and licensed technologies – to ensure effective co-existence. As noted above, T-Mobile has a long history of using Wi-Fi as a critical component of its network" [43]. These motivations would encourage cellular companies to act responsibly and ensure that Wi-Fi is protected.

3.1.3 Limits to the Standards Body Approach

The approach to trust the standards bodies is appealing – it leaves the decision making to those who have the most technical knowledge and the economic incentives to preserve the value of the unlicensed commons. However, the approach has its limits and may not be scalable for future discussions. There are numerous potential pitfalls of leaving the discussion to the standards bodies, both for the LTE unlicensed debate and for future concerns.

First, contrary to the claims of LTE unlicensed proponents, there are reasons to doubt that the economic incentive to preserve Wi-Fi in the 5 GHz band is as strong as the incentive to maximize the potential of using LTE unlicensed. As argued in Section 2, 5 GHz is more the future of Wi-Fi than its present. Companies such as T-Mobile and AT&T have invested in dual-

band Wi-Fi hotspots and Wi-Fi calling, but 2.4 GHz service is far more common and reliable [44], [45]. Similarly, as discussed in Section 1.2.2, license anchoring makes LTE unlicensed more robust under bad interference conditions than Wi-Fi, and this asymmetric impact reduces the cooperation motivation.

Second, without a legal mandate to follow a standard, companies can deploy pre-standard devices that do not employ the same cooperation characteristics that a later standard may endorse. This concern is real for the LTE unlicensed debate and is recognized by the FCC. It asked in the docket, "What plans do carriers and manufacturers have for pre-standard deployment of LTE-U and LAA equipment including possible upgrades to 3GPP-based LTE-U or LAA and how would the above questions (particularly with respect to coexistence issues) be addressed relative to pre-standard versions of LTE-U and LAA?" [10]. In its filing, wireless network systems provider ViaSat announced its concern "about the stated plans of vendors such as T-Mobile to release pre-standard LTE-U systems. T-Mobile announced that it will deploy LTE-U networking abilities in 2016 and has stated that it can acquire LTE-U-capable handsets by the end of 2015" [46]. T-Mobile in its filing acknowledged pre-standard deployments, stating that "commercial deployment of LTE-U is anticipated in 2016, with the implementation of LAA following the completion of discussions on and standardizations for LAA" [43]. A pre-standard deployment does not inherently mean that Wi-Fi performance will be degraded or that unfriendly coexistence protocols will be implemented; however, it does not guarantee that the technology will coexist fairly or that concerns of Wi-Fi stakeholders will be addressed.

Third, even if all companies wait for standards before deploying devices, there is no guarantee that the standardization process will consider the positions of all stakeholders or that the standard will lead to a fair sharing of the spectrum. This concern is present in the current debate. Although, as discussed above, there has been correspondence between IEEE 802 and 3GPP, "it is the understanding of IEEE 802 that 3GPP member companies will agree on sharing mechanisms and a definition of 'fairness' without requiring agreement from stakeholders outside of 3GPP membership" [12]. The Wi-Fi Alliance, in its reply comments, continued: "3GPP has not committed to use the information from [a workshop between 3GPP and Wi-Fi stakeholders] to develop appropriate sharing characteristics to ensure coexistence with the Wi-Fi family of standards. To the contrary, it now appears that 3GPP intends to make those determinations without coordinating with IEEE802 or others. 3GPP's workshop does not constitute the

‘coordination’ about which the Commission inquires” [47]. Without FCC regulation or public announcement regarding a joint standardization process, there is no incentive for LTE unlicensed proponents to engage meaningfully with Wi-Fi stakeholders, and so any negotiation would be asymmetric.

Fourth, even if the above doubts are misplaced and coordination between 3GPP, the LTE-U forum, and IEEE 802 is productive, the standards bodies approach does not take into account the concerns of other, smaller other users of the band. One possible result of coordination is an agreement on a coexistence mechanism that allows Wi-Fi and LTE unlicensed to recognize each others’ overhead packets and share the spectrum appropriately, like Wi-Fi does with itself. Another result may be, as some have suggested, that in some cases Wi-Fi cede control to a centralized controller that efficiently and fairly allocates time blocks to various devices, such as in LTE. Both these approaches could leave out other unlicensed devices, who could lose access to the spectrum. The standardization approach could work for the large device manufacturers and interests, but not the small players on the band. In many areas, it is a government’s purpose to protect the concerns of the small players over the power and control of larger players, and the unlicensed bands may be no different.

Finally, the standards bodies approach may not be scalable with the coming flood of new devices and applications, any more than technology-specific regulations are. One argument for the FCC to maintain its ‘technology neutral’ stance is that a technology specific approach is not scalable with numerous new devices; however, the standards bodies approach is itself a technology specific approach, albeit one out of the hands of the government. Past worries about degradation of the commons have proven unfounded, but those concerns were with a few dominant players. As the number of types of devices and applications increases, as discussed in Section 2.3, it may be more advantageous for any individual company to design devices that do not coexist well with others. Relying on agreements between companies (or standards bodies) is not sustainable as the number of devices increases, especially if there is no economic incentive or government pressure to cooperate.

Together, these concerns suggest that though a resolution at the standards body level might work in this case, there is no guarantee of cooperation. The FCC may need to pressure the standards bodies to collaborate. Furthermore, for future debates, the standards bodies approach

may not work at all, and the FCC should consider acting pre-emptively in future unlicensed bands.

3.2 Listen Before Talk

One of the most common recommendations made in the current LTE unlicensed debate is that the FCC mandate that devices in the unlicensed bands implement Listen before Talk (LBT). In this section, potential Listen before Talk regulations are discussed along with their implications. LBT, as discussed in Section 1.2.1, is the main factor in the 'friendliness' of one Wi-Fi device to another. Mandating LBT is tempting for several reasons: it is a 'technology neutral' solution, it addresses the most controversial component of LTE unlicensed, and it is similar to rules on other unlicensed bands and so would be both easy to implement and not unprecedented. Furthermore, other regulatory bodies – most notably the European Telecommunications Standards Institute (ETSI), the standards body for the European Union – already require a form of LBT on the 5 GHz unlicensed band [48]. LBT regulations thus seems to be a feasible option for the FCC in resolving the current debate and similar future ones.

However, there are several caveats that render the solution infeasible for the 5 GHz band in the United States. First, the backwards compatibility argument discussed in Section 3.1.1 is especially strong, as many existing devices either do not implement LBT or may not implement it in exactly the same way that a regulation may require. Second, any LBT regulation may lock in certain technical details that may quickly become antiquated as Wi-Fi and other technologies develop, and it may not be possible for the regulations to keep up. There are many different parameters and specifications from which to choose, and it may be difficult to choose between them – and each choice has real economic implications. Third, at least one article suggests that a LBT regulation similar to the one by ETSI may not resolve the current debate anyway [47]. This point suggests a larger danger with mandating a specific LBT protocol: it may be that most regulations can be exploited for unfair transmission, and too stifling of a regulation may hinder future innovation excessively. Finally, Listen before Talk mandates may not be necessary for the present debate on 5 GHz. As discussed in Section 1.2.1, 3GPP's standardization process for LAA will most likely integrate LBT into the standard so that it can be used internationally. T-Mobile and Nokia, for example, suggest that LBT will be in the standard in their public docket responses [49], [50]. On the other hand, the LTE-U Forum did not include what is commonly referred to as

LBT in its protocol, though it did include other coexistence techniques that are not acceptable to Wi-Fi proponents.

3.3 SUM INTERFERENCE REGULATIONS: ADDRESSING THE ISSUE OF SCALE

As indicated in Section 1.2.4 above, a single 'unfair' device is often not problematic because it cannot cause significant degradation. However, multiple such devices in a small and congested area may cause unacceptable degradation to another device. The issue of scale is central: imagine a perfect coexistence protocol using which two devices of different technologies and applications share the medium equally. Now, consider what would if one of the device owners decides to install eight more of its devices to improve its service, in the same area. The coexistence protocol would now give 90 percent of the time blocks to one service, and 10 percent to another. It is not clear what a 'fair' coexistence protocol would do in such a situation, and this problem is discussed below in Section 4. In this subsection, possible FCC approaches to address the issue of scale are discussed, though the central concern of enforcement may prove insurmountable.

At least one component of the issue of scale – the issue of too many of one technology interfering with another stakeholder – is relevant to and is being addressed in another FCC proceeding. In a notice on June 15, 2015, the FCC sought comment regarding issues related to the establishment of a new Citizens Broadband Radio Service (CBRS) in the 3550–3700 MHz (3.5 GHz) band [51]. This notice tackles the problem of sum interference: when any individual device does not interfere too much with a privileged user, but many devices together do. A key difference between the bands may render it difficult to translate any solutions: the 3.5 GHz band in question has existing, privileged users which are protected – other users of the band must not interfere with these privileged users. However, the notion of sum interference to privileged users yields a question that may be relevant to the 5 GHz unlicensed debate: when many devices or technologies are causing prohibitive interference, which ones should be turned off? Any mechanism found in that docket may prove invaluable in this discussion.

Several criticisms of this approach suggest that regulating aggregate interference would not work. First, and most importantly, the measurement and enforcement challenges may be too great. It is unclear how the contributions of different devices to the aggregate interference can be measured when one does not know how many devices there are, where they are, or how they are transmitting. Similarly, it is unclear how a given device can be instructed to turn off even if a

determination can be made regarding which device should be turned off. Second, there is currently no concept of a privileged user on the unlicensed bands, and so measuring interference at any given location or receiver does not make sense. Any single interferer close enough to another receiver would measure as being above the aggregate interference threshold. Similarly, it is unclear which devices would deserve protection and which would not. However, one of the recommendations in this report, as discussed in Section 5, is to establish a notion of privilege in future unlicensed bands. The 3.5 GHz band can be instructive in designing such a system. If these challenges can be surmounted, a system of privilege on the unlicensed bands can be set up.

The FCC is right to seek comments on how to avoid direct regulation of such interference in the CBRS notice. Depending on how that filing progresses, proposed solutions may be able to be modified for the case where there is no privileged user, and a solution to address implementation scale may be found.

4 A New Architecture for Fair Use

	Section 4 Key Findings
Finding 4.1	There is vast disagreement in the present debate about what 'fair' coexistence is. There is no generalizable understanding of what 'fair use' on the unlicensed bands entails and how the FCC should enforce such use.
Finding 4.2	The lack of an understanding of 'fair use' is due to a conflict of values for the unlicensed bands, as articulated by the FCC.
Finding 4.3	Disagreements about 'fair use' are not just philosophical – they lead to different policy decisions in the LTE unlicensed debate, as well as future debates.
Finding 4.4	No single definition of 'fair use' can be applicable for all situations. Rather, different values may be appropriate at different times and areas.
Finding 4.5	A Laissez-Faire approach to the unlicensed bands will not work for future unlicensed bands and technologies.

The discussion in the sections above illustrates both the harm that a technology can do if it does not communicate in a friendly manner and the difficulty in enacting regulations to stop devices from doing so. The promise of the unlicensed bands lies in any device being allowed to communicate on the band with minimal regulations. Any new regulations, especially those that are not 'technology neutral,' hinder that promise. However, so does any single device or technology that uses the bandwidth in such a way as to prevent others from using it as well. As discussed in Section 3.1.1, any new regulation is difficult to retroactively apply to existing unlicensed bands.

In future, new unlicensed bands, that logic no longer holds true. Especially as billions of new devices enter the unlicensed bands, many of them eschewing standards, as discussed in Section 2.3, regulations to prevent outright deterioration of the unlicensed bands must be implemented. However, to design regulations to ensure fair usage of the band, one must first know what fair means. The current LTE unlicensed debate can prove instructive on the term. In this section, a framework for defining fair use on the band is constructed to guide future regulations on the unlicensed bands.

4.1 LESSONS FROM THE LTE UNLICENSED DEBATE

The present debate illustrates the real implications of an ill-defined fair use. The Public Docket comments, coexistence mechanisms, activity by standards bodies, and potential rules all hinge on the definition of 'fair.' Whether the standards bodies act or the FCC does, fairness must first be defined and agreed upon. This fact is recognized by multiple filers. The IEEE 802 LAN-MAN Standards Committee filing argues that "an agreement between 3GPP and IEEE 802 is needed on what fairness means in a range of realistic usage scenarios" and that this issue is important enough that all stakeholders need to be involved [12]. As currently constructed, the Part 15 rules neither provide guidance on what fairness means nor require that users (or any future technology) consult with other stakeholders.

4.1.1 Problems in Proposed Definitions

A large number of filings in the initial period discuss 'fair share,' 'fair and reasonable manner,' 'fair coexistence,' and other similar terms. However, few filers even attempt to define the term, and the definitions that are offered are problematic.

The chipset manufacturer Huawei included a definition that is echoed by many proponents of LAA: "LAA is being designed to enable fair coexistence with existing Wi-Fi networks; that is, to have no impact on Wi-Fi services with respect to throughput and latency[18] any more than would an additional Wi-Fi network on the same carrier" [52]. The same sentiment – to define a 'good neighbor' as one that affects Wi-Fi the same way it affects itself – appears in other comments as well. This definition is problematic for several reasons. First, the definition is not quantifiable or generalizable. The impact by a Wi-Fi network on itself depends on the location, network(s) size, version of Wi-Fi, terrain, and the base station locations, to name a few variables, and so it is almost impossible to generally characterize the impact on throughput or latency. Second, it is not clear that a technology's coexistence with itself is a good metric. For example, as future Wi-Fi standards are developed, past standards may be deemed a bad neighbor. The definition also pre-supposes that there is a dominant status quo stakeholder in the frequency band in question and that this stakeholder deserves some special consideration. Even if the definition is sufficient for the 5 GHz or 2.4 GHz unlicensed bands, it provides no guidance for

[18] Latency is how long it takes to go from one endpoint of the system to another

fair use on future, new unlicensed bands. If the FCC does not want to have this debate every time a new technology or band comes up, this definition is not sufficient.

Wireless semiconductor manufacturer Broadcom, on the other hand, takes the opposite approach as Huawei's by defining an exact standard that would, in its view, ensure coexistence. "Broadcom suggests standardization of at least a three-pronged approach to healthy and fair coexistence among broadband unlicensed technologies, but others may be required as well. First, such technologies should have an initial wait or defer time (we suggest ~43 microseconds) to allow for unaffiliated data transmissions to complete prior to arbitration and transmission. Second, the technologies should incorporate a coexistence mechanism that backs-off rapidly when significant interference with other users is detected (exponential back-off). Third, the technologies should incorporate LBT prior to each data transmission. LBT should be capable of detecting lower levels of energy, preamble, or carrier sense (e.g., energy detection at -82 dBm to -92 dBm) than the existing LBT requirements in some countries (i.e., -62dBm)" [53]. Similarly, the LTE-U Forum seems to have a quantifiable metric that they claim ensures fair coexistence. In Cablevision's filing, they report what the LTE-U Forum has stipulated: "the proponents of LTE-U and LAA consider sharing 'fair' so long as Wi-Fi can deliver 4 Mb/s – a fraction of what consumers are enjoying today" [54]. Both these definitions are quantifiable and verifiable. However, they have their own pitfalls. The Broadcom definition presents a mechanism to achieve "healthy and fair coexistence," but it does not define the term itself. As a result, this definition cannot move the debate toward a consensus: it may be a mechanism to achieve 'fairness,' but it is prone to the criticism that other mechanisms (such as those without LBT) are sufficient. On the other side, avoiding the question of whether Cablevision is correct in its claim of what the LTE-U forum believes, it would be a mistake to specify any number as a minimum rate. Such a specification would require the FCC to come up with a new reasonable rate every few years as technology develops. It also pins the definition to Wi-Fi, while a professed reason of the unlicensed bands is to support new technologies that do not exist today.

These definitions indicate that there is no generalizable understanding of what 'fair use' on the unlicensed bands entails and how the FCC should enforce such use.

4.1.2 Values Conflict on the 5 GHz Band

The lack of good, generalizable, quantifiable definitions of 'fair' is not a failure on the parts of the filers. Rather, this case is one where the stated values of the FCC, including the stated goals of the unlicensed bands, contradict:

a. The unlicensed bands are the 'Innovation Bands.' They are specifically meant to allow the development of the next great technology, one that is unknown today and for which specific regulations cannot possibly exist. The FCC has a mandate to protect these bands while not accidentally regulating potential innovation away.
b. Today, after billions of dollars of investment, Wi-Fi has matured to become a critical component of our national infrastructure. Even though Wi-Fi has not yet matured in the 5 GHz band, it is well poised to, as discussed in Section 2.1. The FCC has an economic mandate to protect that investment and its benefits. More generally, the FCC has an economic interest in how spectrum is used.

These mandates lead to two questions regarding choices:

a. Should the status quo (and its past investments) on an unlicensed band be protected to the potential detriment of more innovative technologies?
b. Should potential future innovation be protected to the detriment of technologies in use today?

These questions are not just philosophical – they would lead to different policy decisions in the LTE unlicensed debate, if the FCC decides to act. Suppose non-LBT protocols are found to both significantly degrade Wi-Fi performance but overall increase capacity for the public[19]. Whether to mandate LBT hinges on the first question. Now suppose that there is a technology that could dramatically increase spectral efficiency on unlicensed bands, but it would significantly hinder future innovation and would push out other users. Whether to regulate coexistence to the detriment of the current technology hinges on the second question. The parties disagree on the facts, and so it is unclear whether these cases apply to the LTE unlicensed discussion. However, even if the technological facts were settled, as currently constructed no framework exists through which a 'fair coexistence mechanism' can be found.

[19] There will probably not be a consensus on these questions without large installations, as is discussed above.

4.2 STANDARDS FOR FAIR USE

Such value conflicts will continue to occur on congested or degraded unlicensed bands, especially as IoT and M2M devices continue penetrating the market. These value conflicts are necessarily to resolve for each unlicensed band to answer the questions of what it means to be a 'good neighbor' on the unlicensed bands and what 'fair use' on these bands looks like. The FCC has not historically sought to answer these questions of values on the unlicensed bands. However, the FCC has certain policy goals, and if it does not act to further those goals, the market that develops on these will resolve the questions as it please. For example, the FCC is chartered to further wireless capacity, but also fairness, competition, price and availability for low income and rural areas, and the general economic welfare of the country. Without more active management, some of these goals may be forgotten in service of others by industry.

In this subsection, different value conflicts are discussed. The central argument is that many of these value conflicts do not, and cannot, be answered in a singular manner. In practicality, the FCC cares about both innovation and economic infrastructure, and it should pursue policies that can maximize both goals. Thus, no single definition of 'fair use' can be applicable for all situations. Rather, different values may be appropriate at different times and areas. Furthermore, the FCC can no longer rely on a Laissez-Faire approach to the unlicensed bands – such a policy will not work with a flood of devices all trying to use the unlicensed bands in increasingly congested areas.

4.2.1 Other Value Conflict for Unlicensed Bands

Several questions illustrate the potential of value conflicts beyond those present in the LTE unlicensed debate and the need for more active management:

1) Should commercial vs. public interest matter? Industry has been enormously successful in providing communications capacity in metropolitan and affluent areas. However, it has not been as successful in providing basic internet access to rural or low-income areas. As devices can be designed to potentially push others out of the bandwidth, a system may evolve where only those with access to licenses (and thus more robust under unlicensed degradation, as discussed in Section 1.2.2) and expensive service can access the unlicensed bands efficiently. The FCC may need to act to preserve 'public interest' and access to unlicensed bands.

2) Should installation scale matter, i.e. should the number of access points per area (or devices per area for a M2M technology) be restricted to allow for other technologies? The issue of installation scale and sum interference is discussed in Sections 1.2.4 and 3.3. A larger question is whether such issues even matter from a regulatory perspective: if an entity procures the land rights to install antennas in an area, or if there are many users of a particular service in an area, why should its use be restricted?
3) How do property rights and the will of the land/property owner factor into these policy goals? Much of the discussion so far has implicitly been about public areas. However, these discussions cannot be divorced from discussions of the desires of property owners, who often have much practical control due to their power over approving antenna leases. This issue is discussed as a potential mitigating factor in the need for more regulation in Section 4.2.2 below. However, a value conflict may still emerge where certain property owners have commercial interests that conflict with the public interest. For example, in a cellular example, one hotel was found to illegally block users' Wi-Fi hotspots (most likely connected to the internet through a cellular connection) in order to charge higher rates for its own service [55].

These questions cannot be answered in a single manner – competition is useful and often an ideal mechanism to ensure fairness among entities. Thus, an ideal system for the unlicensed bands would be flexible and able to pursue various, potentially conflicting, policy goals simultaneously.

4.2.2 A Laissez-Faire Approach Will Not Work Anymore

The question remains whether a heavier regulatory regime would be the best mechanism to pursue these policy goals, or whether the costs of such a regime would be too high. Technological neutrality has long been successful for the unlicensed bands, and most entities would like to see the FCC maintain this successful policy. In Recommendation 3 below, a technology neutral mechanism to pursue certain policy goals – an unlicensed Spectrum Access System with privilege for devices – is discussed. Many of the technology and economic drivers for regulation have been discussed in Sections 1 and 2. However, it may be that market based solutions will be most effective due to the nature of future unlicensed bands.

New unlicensed bands are going to be high frequency bands (such as the 60 GHz unlicensed band), and the densification trend for base stations will provide much of the necessary capacity increases, as discussed in Sidebar 2.1; with higher frequencies and denser networks, any particular device interferes with far fewer other devices. Base stations must be installed much closer together – on buildings, street lights, and short poles next to roads, for example. As a result, according to this argument, market based solutions such as antenna lease agreements with building owners would resolve many of this value conflicts with local decision making. Similarly, with base stations far closer together, there may be so much capacity that devices act fairly on the band. However, several aspects of the IoT and M2M communications temper this argument. Just as the standards body avenue would not take into account smaller device manufacturers as discussed in Section 3.1.3, the market based solution to rely on antenna lease agreements does not affect the potential of devices that communicate directly with each other, rather than through a larger network, to interfere with other devices. Such M2M devices may also desire to communicate at larger distances and so are potentially unaffected by the densification trend. Furthermore, as discussed in Section 3.1.3, devices may continue to seek ways to maximize their throughput regardless of their impact on other devices.

Most fundamentally, as discussed in the last point of the previous subsection, market-based solutions may not resolve these value conflicts in the same way that the FCC or the public as a whole would. This section identified a value conflict that is at the heart of the current LTE unlicensed debate, as well as the real implications of such a values conflict. This case illustrates that the market cannot solve value conflicts in a flexible manner, and the FCC at the least needs to articulate a vision for the unlicensed bands to help answer the question, “What is the future that we want on the unlicensed bands?”

5 RECOMMENDATIONS

	Recommendations
Recommendation 1	The FCC should not enact any new regulations for existing unlicensed bands, especially those are not 'technology neutral.' New regulations would be politically and economically problematic due to the wide range of devices that currently operate on the bands. Instead, the FCC should pressure the standards bodies to collaborate on a coexistence mechanism.
Recommendation 2	As future unlicensed bands (or shared bands with unlicensed access) are opened, the FCC must articulate and be willing to enforce intended uses and standards for 'fair use' on the band.
Recommendation 3	For future unlicensed bands, the FCC should specify an architecture in which devices back off to privileged users. The idea of a Federal Spectrum Access System recommended by the PCAST report on government-held spectrum should be extended to privilege on unlicensed bands.
Recommendation 4	The unlicensed bands are not priced correctly. For future or currently unused unlicensed bands, the FCC, in concert with IEEE 802 and 3GPP, must find a pricing mechanism with privileged and unprivileged users. The 3.5 GHz CBRS band should be used as a testing ground for privilege.
Recommendation 5	Academic researchers should research and design real-time auctions for privileged communication in a given geographic area. These auctions could be supported by databases such as those used in TV whitespaces.

5.1 RECOMMENDATION 1: INACTION IN THE LTE UNLICENSED DEBATE

The FCC should not enact any new regulations for existing unlicensed bands, especially those are not 'technology neutral.' New regulations would be politically and economically

problematic due to the wide range of devices that currently operate on the bands. Instead, the FCC should pressure the standards bodies to collaborate on a coexistence mechanism.

The LTE unlicensed case study is a useful one that illustrates the holes in current regulations. However, new regulations to respond to new technological developments by the FCC are not recommended. First, there are too many other devices already in use on the 5 GHz band that would be harmed by new regulations, and grandfathering in new technologies may be difficult, especially in a technology neutral manner. This concern is discussed in detail in Section 3.1.1. Second, the trend toward more spectrum flexibility, especially to augment capacity in the busiest areas, is a trend to be encouraged, not discouraged. It is important to ensure that actors use bandwidth fairly, but FCC action in this case could freeze future developments in spectrum sharing. This trend is discussed in more detail in Section 2.2. Third, Wi-Fi is not yet the incumbent on the 5 GHz band, and so it is not apparent that it deserves the protections of an incumbent. This reason is discussed in detail in Section 2.1. Finally, the standards bodies approach to regulation, though severely flawed, is more likely to yield a technically sound and robust solution to the problem.

The FCC's current actions of opening the Public Docket and following the debate is part of an effective strategy of pressuring the standards bodies to act. As discussed in Sections 3.1.2 and 3.1.3, the standards bodies approach is flawed due to a lack of incentive to collaborate and an inability to integrate the concerns of smaller stakeholders. If the FCC continues its oversight of the issue and can successfully pressure the standards bodies – 3GPP and IEEE in particular – to collaborate, a fair solution can be found. This pressure can come in the form of stating criteria under which it would act, such as whether the FCC would seek to block a pre-standard installation or one that is found to excessively interfere with neighboring technologies once installed. Using these tactics, the FCC can avoid both the costs of new regulations and the potential harm of unfriendly coexistence.

5.2 Recommendation 2: Fair Use Enforcement on Future Bands

As future unlicensed bands (or shared bands with unlicensed access) are opened, the FCC must articulate and be willing to enforce intended uses and standards for 'fair use' on the band.

The standards bodies approach is the most likely to be successful in the present debate; however, in future unlicensed bands in which the same legacy system constraints do not apply and many devices do not follow a standard, the FCC must articulate intended uses for the band. As discussed in Section 4.1, much of the present debate is based on a conflict in the stated values of the unlicensed band: to enable innovation, and to provide economic benefit (and thus defend incumbent investments). The FCC cannot act in the debate without choosing one of those benefits over another. Furthermore, as discussed in Section 4.2, many other potential value conflicts may also arise in future discussion. The strategy of articulating at the outset the stated goals of the band make it more amendable to adopt solutions such as those discussed in Section 3 and several of the recommendations below.

It is important to note that this strategy belies the current approach, and there is danger that such an articulation could hinder future innovation too much; however, if implemented correctly, the strategy of articulating and then enforcing priorities on the bands would aid in protecting innovation. For example, one sub-band of a new unlicensed band could have prioritization for 'innovative devices,' and so classes of devices that meet set criteria would have priority over other devices – such as enterprise Wi-Fi or LTE unlicensed. The current system does not provide a stable environment for innovation because an area may be too congested with mature devices to provide a reliable connection. If the band priorities are chosen carefully, a system in which intended uses are articulated and then prioritized would allow the FCC to better pursue national priorities.

5.3 Recommendation 3: Framework for Privileged Users

For future unlicensed bands, the FCC should specify an architecture in which devices back off to privileged users. The idea of a Federal Spectrum Access System recommended by the PCAST report on government-held spectrum should be extended to privilege on unlicensed bands.

The PCAST report on government held spectrum recommended "that the Federal Government, using industry partners, establish a new Federal Spectrum Access System (SAS) that will serve as an information and control clearinghouse for band-by-band spectrum registrations and

conditions of use and allow non-Federal users to access underutilized spectrum in Federal bands" [6]. This report recommends that this idea be extended to support a framework of privileged users on unlicensed bands as well. Non-privileged devices would either listen for other transmissions or look at a database to determine if the band is clear for transmission. Different measurement and look-up techniques could be specified for different time scales (e.g. a database could be updated on the order of minutes, while spectrum sensing could inform devices on the order of milliseconds or seconds). Privileged devices could also transmit special header packets that indicate information similar to what Wi-Fi devices transmit, such as when the current transmission will end.

Recommendation 2 would not be practical without a mechanism to enforce priority, and it would be inefficient to simply ban all devices that do not meet the intended use for a given band. As discussed in Section 2.2, much of perceived 'Spectrum Crunch' is actually rooted in inefficient spectrum policy: while parts of the spectrum are congested in some areas, other parts of the spectrum are underutilized. Creating a system of privileged users – and then allowing any other device to communicate when those privileged users are not communicating – would solve both of those problems.

The FCC can establish such a system in each new unlicensed band by specifying mechanisms through which devices would identify privileged users. All users that transmit on the band would use these mechanisms. Next, the FCC would identify which users would be privileged on the band, in accordance with the values it wants to further on the band. Privileged users do not necessarily have to be identified directly, but rather determine that all users who meet certain criteria can identify themselves as 'privileged' and transmit as such. For example, the FCC may determine that municipal Wi-Fi is a priority to connect all Americans and that numerous IoT devices would otherwise create too much congestion on a band. Thus, it could specify that on the band in question, municipal Wi-Fi should be given privilege.

This mechanism has several advantages. First, when privileged users are not transmitting, the band becomes an unlicensed band like any unlicensed band available today. Second, the mechanism is flexible because as priorities change, the devices that are allowed to transmit using the priority headers can be changed. Third, the mechanism would be technology neutral – within the privilege framework, it does not specify any coexistence mechanism or other aspect. As discussed in Sections 3 and 4.2.2, many of the proposed regulations have potential loopholes

and, as the number of devices increases, devices will more incentivized to take advantage of those loopholes. A privileged framework would not have such loopholes. Non-compliance can come in two forms: a non-privileged device transmits as it is privileged, or a non-privileged device ignores the privileged headers and transmits anyway. Both these actions can be easily detected, and the rules can be enforced. The first form of non-compliance can also be tested during the certification process. These characteristics would allow seamless integration of privilege into the existing regulatory environment.

5.4 RECOMMENDATION 4: A PRICING MECHANISM

The unlicensed bands are not priced correctly. For future or currently unused unlicensed bands, the FCC, in concert with IEEE 802 and 3GPP, must find a pricing mechanism with privileged and unprivileged users. The 3.5 GHz CBRS band should be used as a testing ground for privilege.

A system with privileged users would solve some of the pitfalls of the current laissez-faire regulatory system. However, it would not solve all the concerns, and would create a new one: users with privilege would not be incentivized to use the band efficiently. A fundamental cause of these debates is that the unlicensed bands are unpriced, and so there is zero marginal cost to each individual to use more of the bandwidth than it needs. Similarly, no mechanism exists with which to compare the needs of two separate devices or technologies.

Many of the implementation details of privileged users can be tested in the 3.5 GHz unlicensed band. In a notice on June 15, 2015, the FCC sought comment regarding issues related to the establishment of a new Citizens Broadband Radio Service in the 3550–3700 MHz band (3.5 GHz Band). Targeted toward protecting privileged communication on the band, this notice seeks comments on how to regulate aggregate interference in a fair and non-discriminatory manner. It also seeks answers for the question of how to incentivize privileged users to allow others to use the band as well. These discussions can prove valuable for future discussions of privilege in unlicensed bands. There are significant enforcement challenges in attempting to regulate aggregate interference. These challenges may prove economically and technologically unsurmountable, and regulating sum interference may be impossible. However, the FCC is right to seek comments on how to avoid direct regulation of such interference in the CBRS notice.

This discussion is part of a decades-long transformation of spectrum policy to one with increased flexibility in usage called for by the PCAST report.

5.5 Recommendation 5: Real-Time Auctions

Academic researchers should research and design real-time auctions for privileged communication in a given geographic area. These auctions could be supported by databases such as those used in TV whitespaces.

One possible way to price the unlicensed bands is to set up an auction system in which devices must 'bid for' spectrum usage. Real-time auctions have revolutionized online advertising, and they could prove to be a natural extension to the large auctions conducted by the FCC for spectrum licenses. These auctions could occur in real-time on the order of minutes to determine which users would be able to transmit on the band.

Large logistical and economic challenges are associated with an auction pricing mechanism, and the area is fertile ground for further academic research. First, each device's transmission cause interference to devices around it, but those devices may not interfere with each other. Designing an auction with this property is in general computationally intractable.[20] Second, an auction system would break the democratic nature of the unlicensed bands, resulting in a paradigm shift from a system in which any device or user can communicate on the unlicensed bands to one in which only those who can bid the most would have access in situations where many users would like access. Third, logistical details of payment (who would pay and to who the payments would go) must be worked out. As with the challenges of a privilege system, these obstacles may be too large to overcome. However, they form a useful area of research.

[20] It is NP-hard

6 CONCLUSION

This report analyzes the future of the unlicensed bands through the lens of the current debate on LTE unlicensed technologies. The central theme of the findings and recommendations are that the current light-touch regulatory system for the unlicensed bands are not sustainable as Internet of Things and Machine to Machine technologies continue to saturate the market. The current LTE unlicensed matter is a symptom of the maturation of the unlicensed bands and a value conflict between enabling innovation and supporting a status quo public economic good. The LTE unlicensed debate reveals the potential for a device or technology to push other devices out of the unlicensed bands if it chooses to do so. The standards bodies are the preferred avenue of resolution in this debate, and the Federal Communications Commission should pressure them to collaborate. Regardless of how the current debate is resolved, however, the standards bodies approach will not work for future conflicts.

The Federal Communications Commission should adopt a system of privileged and unprivileged devices on the unlicensed bands to maximize efficiency on the bands while simultaneously providing a framework to pursue policy goals. This report extends the framework established by the 2012 PCAST report on government-held spectrum [6]. While the PCAST report recommends spectrum sharing with privilege as an alternative to exclusive use by government stakeholders on current government-held spectrum, this report calls for a system with privilege as an alternative to wholly shared unlicensed spectrum. A system with privilege for technologies that further various national values – such as innovation or public access – is necessary to counter the potential of a single technology preventing others from using the unlicensed bands. The coming information and communications revolution of the next five years demands such a proactive approach.

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APPENDIX 1: FCC PUBLIC DOCKET 15-105 REPLY COMMENT

The FCC opened a public docket regarding the LTE unlicensed. After going through the numerous comments from the initial period, I decided to submit a reply comment on June 25, 2015. My comment can be found on the FCC ECFS website here: http://apps.fcc.gov/ecfs/comment/confirm?confirmation=2015625169624, and it is reproduced in the following pages. Parts of my response were also used above.

It highlights what I think is the main barrier toward coming up with a coherent agreement for 'fair' coexistence mechanisms -- we don't know what fair is because the FCC's values/mandates for the unlicensed bands conflict in this case. I also discuss what I think are overlooked issues in the debate: the impact of the scale of implementations (e.g. no one complains about things like baby monitors that also have unfriendly coexistence mechanisms) and structural advantages by cellular companies such as access to cell towers and thus high antenna heights.

Before the

FEDERAL COMMUNICATIONS COMMISSION

Washington, D.C. 20554

In the matter of	)	
Office of Engineering and Technology and	)	
Wireless Telecommunications Bureau	)	ET Docket No. 15-105
Seek Information on Current Trends in	)	
LTE-U and LAA Technology	)	

REPLY TO COMMENTS

Table of Contents

Overview

The first round of filings on LTE-U and LAA illustrate that there is a language ambiguity behind which stakeholders are hiding. A majority of the filings include the term 'fair use' or an equivalent as an explicit goal of any regulation or standard concerning use of unlicensed bands. However, few of the filers even attempt to define the term, and none provide definitions specific enough to guide regulations or standards. The parties are using the term to mean very different things, and a conflict between the FCC's stated values for the unlicensed bands is the culprit. Each party assumes a definition of 'fair' that is based on the value that most suits their self-interest. A framework is necessary for standards bodies (or the FCC) to resolve these conflicts.

Once such a framework is established, and the value conflict resolved, the FCC must recognize that current constraints on the unlicensed bands are insufficient. Regulations allow structurally advantaged users (such as those that have access to towers and thus high antenna-heights) to asymmetrically interfere with other users without breaking power constraints. It will prove difficult to prevent large scale, unfriendly coexistence mechanisms without causing real harm to other users of the band (besides Wi-Fi and Bluetooth) that so far have not caused significant degradation to other users, even without friendly coexistence mechanisms. The Commission should potentially distinguish between large and small scale installations of a given technology. For the unlicensed bands, the FCC should also look into adopting approaches similar to the ones it is considering for other bands with privileged users, among other regulations concerning coexistence protocols and tower access.

1. **The FCC needs a doctrine of 'Fair Use' on unlicensed bands that incorporates its values.**

The comments, coexistence mechanisms, activity by standards bodies, and potential rules all hinge on the definition of 'fair.' Whether the standards bodies act or the FCC does, fairness must first be defined and agreed upon. This fact is recognized by multiple filers. In the IEEE 802 LAN-MAN Standards Committee filing, it was argued that "an agreement between 3GPP and IEEE 802 is needed on what fairness means in a range of realistic usage scenarios[21]" and that this issue is important enough that all stakeholders need to be involved. As currently constructed, the

[21] Comments of IEEE 802 LAN-MAN Standards Committee on Docket No. 15-105, submitted 6/08/2015, page 2

Part 15 rules neither provide guidance on what fairness means nor require that users (or any future technology) consult with other stakeholders.

Existing understandings/definitions of 'Fair Use' are either underdeveloped or too specific. A large number of filings in the initial period discuss 'fair share,' 'fair and reasonable manner,' 'fair coexistence,' and other similar terms. However, few even attempt to define the term, and the definitions that are offered are problematic:

a. Huawei – "LAA is being designed to enable fair coexistence with existing Wi-Fi networks; that is, to have no impact on Wi-Fi services with respect to throughput and latency any more than would an additional Wi-Fi network on the same carrier.[22]"

The same sentiment – to define a 'good neighbor' as one that affects Wi-Fi the same way it affects itself – appears in other comments as well. This definition is problematic for several reasons. First, the definition is not quantifiable or generalizable. The impact by a Wi-Fi network on itself depends on the location, network(s) size, version of 802.11, terrain, and geometry of network nodes, to name a few variables, and so it is near impossible to generally characterize the impact on throughput or latency. Second, it is not clear that a technology's coexistence with itself is a good metric. For example, as future 802.11 standards are developed, past standards may be deemed a bad neighbor. The definition also pre-supposes that there is a dominant status-quo stakeholder in the band in question and that this stake-holder deserves some special consideration. Even if the definition is sufficient for the 5 GHz or 2.4 GHz unlicensed bands, it provides no guidance for fair use on future, new unlicensed bands. If the FCC does not want to have this debate every time a new technology or band comes up, this definition is not sufficient.

b. Broadcom – "Broadcom suggests standardization of at least a three-pronged approach to healthy and fair coexistence among broadband unlicensed technologies, but others may be required as well. First, such technologies should have an initial wait or defer time (we suggest ~43 microseconds) to allow for unaffiliated data transmissions to complete prior

[22] Comments of Huawei Technologies on Docket No. 15-105, submitted 6/11/2015, page 6

to arbitration and transmission. Second, the technologies should incorporate a coexistence mechanism that backs-off rapidly when significant interference with other users is detected (exponential back-off). Third, the technologies should incorporate LBT prior to each data transmission. LBT should be capable of detecting lower levels of energy, preamble, or carrier sense (e.g., energy detection at -82 dBm to -92 dBm) than the existing LBT requirements in some countries (i.e., -62dBm).[23]"

And

Cablevision, on what the LTE-U Forum has stipulated – "the proponents of LTE-U and LAA consider sharing 'fair' so long as Wi-Fi can deliver 4 Mb/s – a fraction of what consumers are enjoying today[24]."

Both these definitions are quantifiable and verifiable. However, they have their own pitfalls. The Broadcom definition presents a *mechanism* to achieve "healthy and fair coexistence," but it does not define the term itself. As a result, this definition cannot move the debate toward a consensus: it may be *a* mechanism to achieve 'fairness,' but it is prone to the criticism that other mechanisms (such as those without LBT) are sufficient.

On the other side, avoiding the question of whether Cablevision is correct in its claim of what the LTE-U forum believes, it would be a mistake to specify any number as a minimum rate. Such a specification would require the FCC to come up with a reasonable rate every few years. It also pins the definition to Wi-Fi, while a professed reason of the unlicensed bands is to support new technologies not available today.

The FCC needs to define its values on the unlicensed bands and resolve contradictions in the values. Until then, 'fair' cannot be defined. The dearth of good, generalizable, quantifiable definitions of 'fair' is not a failure on the parts of the filers. Rather, this case is one where the stated values of the FCC, including the stated goals of the unlicensed bands, contradict:

c. The unlicensed bands are the 'Innovation Bands.' They are specifically meant to allow the development of the next great technology, one that is unknown today and

[23] Comments of Broadcom Corporation on Docket No. 15-105, submitted 6/11/2015, page 3.
[24] Comments by Cablevision on Docket No. 15-105, submitted 6/11/2015, page 16.

for which specific regulations cannot possibly exist. The FCC has a mandate to protect these bands while not accidentally regulating potential innovation away.

d. Today, after billions of dollars of investment, Wi-Fi has matured to become a critical component of our national infrastructure[25]. The FCC has an economic mandate to protect that investment and its benefits. More generally, the FCC has an economic interest in how spectrum is used.

These mandates lead to two questions regarding choices:

c. Should the status quo (and its past investments) on an unlicensed band be protected to the potential detriment of more innovative technologies?
d. Should future potential innovation be protected to the detriment of techniques that may increase capacity today?

These questions are not just philosophical – they lead to different policy decisions in the LTE-U/LAA debate. The question of whether to mandate LBT hinges on these questions. Suppose non-LBT protocols are found to both significantly degrade Wi-Fi performance but overall increase capacity[26]. Whether to mandate LBT hinges on the first question. Now suppose that there is a technology that could dramatically increase spectral efficiency on unlicensed bands, but it would significantly hinder future innovation and would push out other users. Whether to regulate coexistence to the detriment of the current technology hinges on the second question. The parties disagree on the facts, and so it is unclear whether these cases apply to the LTE-U/LAA discussion. However, even if the technological facts were settled, as currently constructed there is no framework through which a 'fair coexistence mechanism' can be found.

Other values also affect any definition of 'fair.'

a. Should commercial vs. public interest matter?
b. How much does diversity of technologies and applications matter, and how much does general data capacity?
c. Does a user's access to other spectrum, or its ability to bid on licensed spectrum, matter?

[25] This fact is well document. For example, refer to [1]
[26] There will probably not ever be a consensus on these questions without large installations, as is discussed below.

d. Adding a new network node or technology, almost by definition, will affect performance of other nodes. How do we say how much is too much?

These issues must be clarified by the FCC.

'Technological Neutrality' is a method, not a goal. In his reply comments, Leigh Chinitz summarizes the 'Technological Neutrality' stance and explores the history of Part 15 regulations[27]. He argues that "the Commission has considered what the specific characteristics of the band would have to be in order to make it a successful commons, and they have done their best (and have made changes over time) to put rules into place that would support those characteristics[28]". However, the question no longer is just what 'characteristics' the band should embody, but rather what the Commission has decided is the standard for 'success.' Different values lead to different standards lead to different characteristics lead to different rules.

Being 'technology neutral' is a method to achieve a goal, not a goal unto itself. One may argue that 'technology neutral' helps support future innovation or is an important component of a regulation that can stand the test of time. It may also be true that 'technology neutral' is necessary for competitive fairness between various parties. On the other hand, it may be true that 'technology neutral' hinders the Commission's ability to protect its economic incentives. The Commission must first decide its preeminent values and then attempt to answer the 'technology neutral' question. Otherwise, just as in defining 'fair,' it cannot come up with a coherent decision.

2. Transmit Power and Power Spectral Density constraints are not enough anymore.

Regardless of what the FCC decides are its most important values for the unlicensed bands, it is clear that existing constraints are not enough. The LTE-U/LAA debate has raised issues on unlicensed use that must be addressed before large installations and investment make it too late to address. However, any potential regulations must keep in mind numerous other devices (besides Wi-Fi and Bluetooth) that also use the band.

[27] Reply Comments of Leigh M. Chinitz Docket No. 15-105, submitted 6/22/2015, page 16-17
[28] Ibid.

Coexistence Protocols. The comments in the initial filing indicate that there is a clear disagreement about whether LTE-U/LAA coexistence protocols are sufficient, and it is unlikely that this issue will be resolved through simulations, analysis, or small prototypical systems. Leigh Chinitz summarizes these disagreements in his reply comments, concluding that "this is an intractable problem on which proponents and opponents will never agree, and simulation conditions and parameters can be discussed forever[29]." Worse, even if it is established that a technology is not a good neighbor, current regulations are insufficient to block such a device. Standards bodies may enforce their definitions of 'friendly coexistence,' but there is no guarantee of compliance or friendliness without FCC rulemaking.

Antenna Height[30]. Numerous comments discussed the importance of coexistence protocols, and disagreed on its facts. One issue that was forgotten is that signal propagation is a function of much more than transmit power. Unlike the coexistence issue, it is a settled question that antenna height matters both for short-link and large-link signal propagation. Most path loss models "use the distance, carrier frequency, and transmitter and receiver heights as input[31]." A doubling of the transmit antenna height is equivalent to somewhere between a 2x to 4x gain in transmit power in most models under most standard conditions.

This propagation characteristic undoubtedly and systemically favors the cellular companies and, by extension, LTE-U and LAA in this debate. The marginal cost to add an antenna is drastically lower for existing tower owners and leasers. Thus, under existing rules, the unlicensed bands could evolve into a heterogeneous network where the distinguishing factor between base stations is their antenna height, not their transmit power. The tower-installed antennas would serve as the 'macrocells,' while all others would be 'small cells.' Each installation would interfere with far more antennas than from which it receives interference. The large existing academic literature on heterogeneous networks can be applied here. If the goal is to maximize capacity in the band (ignoring fairness issues):

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[29] Reply Comment of Leigh M. Chinitz Docket No. 15-105, submitted 6/22/2015, page 6
[30] This issue was brought to my attention by Dr. Michael Marcus.
[31] [20]

"If offloaded users can also be served in 'normal' slots when the macros are on, then the optimal amount of blanking grows in proportion to the small cell density … for plausible small cell deployments, the optimal amount of blanking is approximately one half. This strikes many as counter-intuitive but it is true: the macrocells (the apparent network bottleneck) should be shut off about half the time, because they are also the biggest interferers." [32]

A coexistence protocol should not just treat the macrocell as just another interferer vying for time blocks. Its special status as an asymmetric interferer requires a more careful protocol. The discussion gets even more complicated when users cannot switch from one tier to the other, such as when one provider operates the macro cells and others operate the small cells, as fairness issues are involved.

It is important to note that this concern is not LTE-U/LAA specific. It applies to any case where one provider disproportionately has access to towers and thus higher antenna heights, even if the provider is using the same technologies as others. If a cellular company wants to dominate the unlicensed band, as many opponents claim in their filings, it may be able to do so even with Listen Before Talk (LBT) or Wi-Fi itself. All it has to do is install antennas on many of its existing towers, without the additional capacity-increasing techniques it would otherwise implement to support heterogeneous networks on its licensed bands. Note that this concern is not new. Comcast and other cable companies routinely hang Wi-Fi Access Points from their existing cable infrastructure[33].

A more careful network analysis must be done on this issue to fully understand how densely these high-height antennas can be installed before it pushes out other users. How much indoor penetration there is from tower-mounted antennas also will play a large role. It may be that the antenna height is not high enough, or the installations dense enough, to significantly degrade capacity on other nodes. It remains an open question whether the FCC should regulate such advantages, but interest by cellular companies increases the urgency.

Any potential regulation must be carefully designed to prevent collateral harm. Installing antennas on towers improves signal propagation and thus capacity in the absence of cells that are degraded, but competitive fairness and the potential for future innovation is harmed if certain advantaged companies can take over the band.

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[32] [56]
[33] Paul Kapustka, "How cable companies have quietly dominated public Wi-Fi," on Oct. 11, 2013, http://www.techhive.com/article/2053943/how-cable-companies-have-quietly-dominated-public-wi-fi.html

On the other hand, the long history of pole attachment regulations makes it clear that the FCC has the authority and a historical precedent to deal with such issues. It has recognized in the past that structural economic advantages such as access to towers should not insurmountably advantage one user or technology over another.

Values trade-off from one another, and different values may be more important in different cases[34]. Numerous devices, not just Wi-Fi or Bluetooth, operate on the unlicensed bands in question, including wireless backhaul and baby monitors. Many of these devices do not have coexistence mechanisms such as LBT or exponential back-off. For these devices, the existing regulations are sufficient because the gain in the 'innovation' and 'diversity' values outweighs the economic issues regarding degradation of Wi-Fi – there simply are not enough of these devices in a given area to degrade co-located Wi-Fi significantly. The FCC must consider these devices in any rule-making: ensuring friendly coexistence from LTE-U/LAA should not come at the expense of other devices that on sum do not cause prohibitive interference. The risk of over-regulation is real. It will be difficult to design device-level regulation that would prevent a potential takeover from a large scale implementation of LTE-U/LAA without unnecessarily harming these numerous other devices.

The FCC can take a similar view as it has of protecting privileged communication. In a notice on June 15, 2015, the FCC sought comment regarding issues related to the establishment of a new Citizens Broadband Radio Service in the 3550–3700 MHz band (3.5 GHz Band)[35]. Though targeted toward protecting privileged communication on the band, this notice seeks comments on how to regulate aggregate interference in a fair and non-discriminatory manner. This discussion can prove valuable for the unlicensed bands in question for LTE-U/LAA. As indicated above, a single 'unfair' device is often not problematic because it does not cause significant degradation. However, many of such devices in a small and congested area may cause unacceptable degradation. Scale is the true reason for concern with LTE-U/LAA: the potential for large deployments that may not coexist in a friendly enough manner.

[34] This section was prepared with advice from Dr. Charles Jackson.
[35] Federal Register, Vol. 80, No. 114 on June 15, 2015. http://www.gpo.gov/fdsys/pkg/FR-2015-06-15/pdf/2015-14495.pdf

There are significant enforcement challenges in attempting to regulate aggregate interference. Worse, there is no concept of a privileged user on the unlicensed bands, and so measuring interference at any given location/receiver does not make sense (any single interferer close enough to another receiver would measure as being above the aggregate interference threshold). These challenges may prove economically and technologically unsurmountable, and regulating sum interference may be impossible. However, the FCC is right to seek comments on how to avoid direct regulation of such interference in the CBRS notice. Depending on how that filing progresses, proposed solutions may be able to be modified for the case where there is no privileged user. Regardless, the FCC needs to directly tackle this issue of scale of deployments on the unlicensed bands.

Summary and Recommendations

Value judgements are nuanced, and it is not necessarily harmful for the FCC to have values that sometimes conflict. However, when they do, as in this case, the FCC must provide guidance. Standards bodies may be the best avenue for regulation, but the FCC needs to first decide what it is willing to protect.

Antenna height differences and coexistence protocols illustrate the gap in current regulations. These concerns are not new, but the potential for LTE-U and LAA adds new urgency to the problem. The advantages or protocols themselves are not problematic, as demonstrated by existing devices with similar characteristics; the scale of potential new installations, however, is troublesome. It may not be possible to regulate out such concerns without opening up a regulatory can of worms, but the FCC must at the least articulate its goals for the unlicensed bands. It should also consider seeking comment on how to factor in the dimension of installation scale on the unlicensed bands.

Respectfully Submitted,

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